



**SCHOOL OF GRADUATE STUDIES**

**GROWTH AND YIELD RESPONSE OF TEF (*Eragrostis tef* (Zuc) Trotter)  
VARIETIES TO DIFFERENT WEED MANAGEMENT PRACTICES IN  
ABESHGE DISTRICT, CENTRAL ETHIOPIA**

**MSc THESIS**

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**Growth and Yield Response of Tef (*Eragrostis tef* (Zuc) Trotter) Varieties to  
Different Weed Management Practices in Abeshge District, Central  
Ethiopia**

**A Thesis Submitted to School of Graduate Studies in Partial Fulfillment of  
the Requirements for the Degree of Master of Science in Agronomy**

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# APPROVAL SHEET

## WOLKITE UNIVERSITY

### SCHOOL OF GRADUATE STUDIES

We hereby certify that we have read and evaluated this thesis titled “**Growth and Yield Response of Tef (*Eragrostis tef* (Zuc) Trotter) Varieties to Different Weed Management Practices in Abeshge Woreda, Central Ethiopia**” prepared under our Guidance by Sisay Woldemariam Bereka. We recommended that the Thesis shall be submitted as fulfilling the requirements for the award of MSc degree in Agronomy.

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## **BIOGRAPHICAL SKETCH**

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## ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ATA	Agriculture Transformation Agency
B:C	Benefit Cost ratio
BC	Before Christ
CSA	Central Statistical Agency
CV	Coefficient of Variation
DAE	Days After crop Emergence
DH	Days to Heading
FAO	Food and Agricultural Organization
GW	Grain Weight
HEI	Herbicide Efficiency Index
HI	Harvest Index
LSD	Least Significant Difference
MoARD	Ministry of Agriculture and Rural Development
MSAV	Mean Square Analysis of Variance
OD	Oil Dispersion
PM	Physiological Maturity
RCBD	Randomized Complete Block Design
WCE	Weed Control Efficiency
WD	Weed Density
WDW	Weed Dry Weight
WI	Weed Index
WM	Weed Management

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## ABSTRACT

*Tef is a staple food crop for many people in Ethiopia; however, weed competition poses a significant threat, leading to substantial yield reduction. Hence, this study was conducted to investigate growth and yield response of tef varieties to different weed management practices during the main crop production season of 2022/2023 in Abeshge district. The experimental treatment comprised three tef varieties (Kora, Dagim, and Quncho) and six weeding methods (W1 = Pallas 45 OD 0.4 l ha<sup>-1</sup> at 31 days after crop emergence (DAE); W2 = Pallas 45 OD 0.3 l ha<sup>-1</sup> at 31 DAE, supplemented with one hand weeding at 41 DAE; W3 = one hand weeding at 31 DAE; W4 = two hand weeding at 31 and 41 DAE; W5 = weed free; and W6 = weedy check. The experiment was laid out in randomized complete block design in a factorial arrangement and three replications. The results indicated that Poaceae (11 species) were more prevalent weed families competing with tef, followed by Composite families. The highest weed control efficiency was observed in weed-free treatments. Furthermore, the interaction between Kora variety and Pallas 45 OD at 0.3 l ha<sup>-1</sup> supplemented with one hand weeding resulted in (88.9) % weed control efficiency. The highest grain yield (2.72 ton ha<sup>-1</sup>) was obtained from the combination of weed free conditions and the Kora variety, while the lowest grain yield (0.46 ton ha<sup>-1</sup>) in weedy check with the Quncho variety. The economic analysis demonstrated that the combination of the Kora variety and Pallas 45 OD at 0.3 l ha<sup>-1</sup> with one hand weeding resulted in the marginal revenue (97,312 birr) and benefit-cost ratio (3.2). In conclusion, the study finding indicate that the Kora variety, in combination with Pallas 45 OD 0.3 l ha<sup>-1</sup> with one hand weeding resulted in the highest crop growth and grain yield.*

**Key words:** Benefit-cost ratio, Effective weeding management, Pallas, Tef, Weeds,

# 1. INTRODUCTION

Tef (*Eragrostis tef* (Zuc) Trotter) is one of the most important small grain crops grown as staple and co-staple food supports more than (60-72%) of Ethiopia's population (Birhanu Gizaw *et al.*, 2018). The cultivation of tef by Ethiopian farmers has been going on for a long time in the history of the farmers and it is more important in terms of planted area and production value compared to other cereals and it is an important crop to generate income for the local farmers (Esubalew Tadele and Tewabe Hibistu, 2021). In Ethiopia Annually, 3 million hectares of land (32% of the total farmland) is covered by tef, and 5.2 million tons of grain (21% of the production volume) is produced in Ethiopia (Ademe Mihretu *et al.*, 2022). In Gurage zone, more than twenty four thousands hectares of land is covered with tef and its productivity is 1.88 tons ha<sup>-1</sup> (CSA, 2021/22); making it the most extensively cultivated cereal crop in terms of area coverage.

These main relative advantages include: First, tef grain has high water holding capacity, long shelf life, unique taste, and it provides *Injera* (Ethiopian traditional bread pancake) preferred by consumers. Second, the grain yields a high flour yield when 99 percent is milled, compared to 60-80 percent of wheat (Kibebew Assefa and Solomon Chanyalew, 2018). Third, tef has minimal post-harvest losses even under traditional storage conditions. Fourth, the straw is important mainly as fodder for cattle and as a binder of mud used for plastering walls of local houses. Fifth, tef offers cash crop value for farmers owing to the high market prices of both the grains and the straw. Despite its numerous beneficial characteristics, its productivity remains relatively low compared to other cereals (Ademe Mihretu *et al.*, 2022).

Inappropriate weed management practices have been identified as one of the major limiting factors for tef productivity in Ethiopia (Zewditu Dawit *et al.*, 2020). Effective weed management is crucial to minimize yield losses and reduce the costs associated with weed control. The decision may vary with the weed, level of infestation, environmental conditions, and management practices. Chemical, physical (manual and mechanical) and integrated weed management methods are among the weed management practices used in many cropping systems in Ethiopia. The use of herbicides is the most important method of weed management (Getachew Mekonnen, 2022). Hand weeding is the most commonly used method for weed management in tef fields; however, it requires significant labor and time investment, posing

challenges for farmers, particularly during the main cropping season when labor resources are limited (Negassaa Dechassa, 2023).

Weed competition poses a significant threat to teff production, resulting in yield reductions ranging from 35% to 65% depending on the intensity of infestation (Habtamu Gebrehiwot *et al.*, 2020). Weeds not only compete for nutrients, water, and sunlight but also act as hosts for disease-causing pathogens and insect pests, further impeding crop growth and development (Hundesaa Niguse *et al.*, 2023). The use of herbicides, either alone or in combination with hand weeding, has shown promising results in weed control and can contribute to higher crop yields with reduced effort and cost (Afroz *et al.*, 2019; Subramanian *et al.*, 2005). Additionally, selecting appropriate tef varieties with competitive traits can help mitigate the negative effects of weed competition (Habtamu Gebrehiwot, 2019).

Despite the increasing threat of weeds to tef production in Ethiopia, limited studies have investigated the effect of weeding methods and varietal selection on tef productivity in the study area. Therefore, research on the effects of these factors is crucial for developing effective and sustainable weed management strategies. This study aims to fill the knowledge gap by investigating growth and yield response of tef varieties to different weed management practices in the study area. The findings will provide valuable insights into selecting the most suitable weeding methods and tef variety for achieving high yields and economic returns.

**General Objective:**

- ✓ To investigate appropriate weed management practices help to improve tef performance and sustainable production in study area.

**Specific Objectives:**

- ✓ To evaluate the effect of weeding management practices and varieties on growth and yield response of tef.
- ✓ To select the best weed management and variety, with the best economic return.

## **2. LITERATURE REVIEW**

### **2.1. Tef (*Eragrostis tef* (Zucc) Trotter)**

#### **2.1.1. Origin, Distribution and Cultivation of Tef**

Tef is the most important cereal crop and Ethiopia is the center of origin and diversity (Tsion Fikre *et al.*, 2018). Tef is endemic to Ethiopia and its major diversity is found only in this country. It is believed to have originated in Ethiopia between 4000 BC and 1000 BC (Ponti, 1978). However, there is no doubt that it is a very ancient crop in Ethiopia, where domestication took place before the birth of Christ (Seyfu Ketema, 1997).

It was probably cultivated in Ethiopia even before the ancient introduction of wheat and barley (Shaw, 1976). Tef cultivation has been successfully adapted to other parts of the world such as the USA, India, and Australia (Ozkose *et al.*, 2022). It is entirely cultivated in Ethiopia and Eritrea as a food crop and distributed to several other countries and a certain amount is grown for cattle fodder in Australia, India, Kenya and South Africa (Susie Teshome, 2020). Cultivation of tef in Ethiopia has in part been motivated by its relative advantages over other cereals in the use of both the grain and straw (Dinka Zewudie *et al.*, 2021). In Ethiopia, tef is mostly produced during the main rain season, between July and November. It is known as an "emergency crop" because it is planted late in the season; most other crops have already been planted.

#### **2.1.2. Climatic and Soil Requirements of Tef**

Tef is adapted to a large diversity of climatic conditions, soil types, and is widely cultivated both in high potential production areas receiving adequate rain sufficient for growth and marginal production areas receiving inadequate rain difficult to complete life cycle of most other staple crops (Tafes Desta *et al.*, 2022). It is adaptable and it can grow in various environments, at altitudes ranging from sea level to 3,200 meters. However, it does not tolerate frost. Highest yields are obtained when tef is grown between 1,800 to 2,100 m. This grass is best adapted to areas where the annual rainfall is approximately 600 mm per annum for optimal production, but can be cultivated in areas with an annual rainfall as low as 400 mm per annum (Ozkose *et al.*, 2022), and daily temperatures range from 15 to 27 °C yields

decrease when annual rainfall falls below 250 mm and when the average temperature during pollination exceeds 22 °C. Despite its surface root system, tef is quite drought-resistant thanks to its ability to regenerate rapidly after a moderate water stress and to produce fruits in a short time span. It is daylight sensitive and flowers best with 12 hours of daylight (Cheng, 2017). Physiologically, tef is an herbaceous annual plant requiring 60–140 days to attain physiological maturity and a C4 plant and it requires high optimum temperature for photosynthesis (Kibebew Assefa *et al.* 2017).

Tef is predominantly cultivated on sandy-loam to black clay soils (Tamirat Wato and Tilahun Negash, 2020). Moreover, tef withstands low moisture conditions and often considered as a rescue crop that survives and grows well on residual soil moisture in the season when early planted crops (e.g. maize) fail due to low moisture Anonymous, (2022).

### **2.1.3. Varietal Differences of Tef in their Response to Biotic and Abiotic Stress**

Tef has shown tolerance to several biotic and abiotic stresses and is highly resistant to growth and yield stress caused by environmental factors such as drought, waterlogging, soil acidity and salinity (Cannarozzi and Zerihun Tadele, 2022). The main biotic stresses on tef productivity are caused by weeds, diseases, insects and pests, especially birds, some of which have economic impact, especially in certain growth and production years or in certain environmental regions (Alemayehu Abdeta and Batie Dube, 2023).

#### **2.1.3.1. Biotic stresses**

Compared to other cereal crops grown in Ethiopia, tef has shown relative tolerance or resistance to biotic stress caused by pests, insects and weeds (Tefera and Belay, 2006).

Previous studies in Ethiopia identified 22 fungal species and 3 pathogenic nematodes associated with tef. Among the fungi and pests that cause disease and affect tef productivity in humid regions of Ethiopia, leaf rust (*Uromyces Eragrostidis*), head rot (*Helminthosporium Miyakei*) and damp smut (*Drechslera* spp. and *Epicoccum Nigrum*) are the main ones (Tefara and Belay, 2006). The use of fungicides have been shown to be effective in limiting fungal diseases under experimental conditions, however, few have been used in field applications (Tefara and Belay, 2006). Pests or insect species known to attack tef in the field include: Wollo-bush cricket (*Decticoides Brevipennis*) acting on seeds and seedlings, red tef worm

(*Mentax Ignicollis*), tef *Epilachna*, and tef black beetle (*Erlangerius Niger*) affecting inflorescence structures (Stallknecht *et al.*, 1993; Tefara and Belay, 2006). Although biotic stresses are known to cause grain loss and are of concern to farmers and breeders, the loss of tef grain due to abiotic stress is for more reasons

#### 2.1.3.2. Abiotic stresses

The main abiotic stress factors affecting the growth and yield are drought, soil salinity and acidity (Numan *et al.*, 2021), while Some studies have shown that different types of tef show a relative tolerance to the addition of salinity (Kinfemichael Geresu Asfaw and Fisseha Dano, 2011) and soil acidity (Ermias Abate *et al.*, 2013), most studies have reported on the drought tolerance of tef (Balcha and Mohammed, 2012).

#### 2.1.3.3. Salt stress

The tef crop has been subjected in Ethiopia in the lowland and rift valley areas, especially in the Awash Valley and the lower plains; the salinity has increased (Kinfemichael Geresu Asfaw and Fisseha Dano, 2011). Kinfemichael Geresu Asfaw and Fisseha Dano (2011), the effects of increasing salinity on tef production and tef components were investigated by screening 15 lowland tef species at different salinity levels. They found grain yield per main panicle to be the most affected by increased salinity and, although there were differences in genetic variation among tef varieties and accessions, salt tolerance was observed in accession (237186) and variety DZ-Cr 37 (Tsedey) genotypes. Because increased soil salinity affecting grain production during harvest is a growing concern in Ethiopia in general, especially in the Awash Valley, the authors encourage further investigations to address the problem (Kinfemichael Geresu Asfaw and Fisseha Dano, 2011).

#### 2.1.3.4. Soil acidity

In Ethiopia, less than half of the total land area (41%) contains acidic soil, and a third (33%) has high aluminum content (Ermias Abate *et al.*, 2013). A recent study involving observations of different species of tef in strongly acidic soil (pH 3.94 and acid saturation 78%) was conducted to evaluate the response of tef to root length, seedling length, root dry weight and shoot dry weight (Ermias Abate *et al.*, 2013). By using the aluminum tolerant, weeping love

grass (*Eragrostis Curvula*) variety, Ermelo, as a control, the authors were able to evaluate the response of tef to highly acidic and aluminum-toxic conditions. In general, all tested tef cultivars were negatively affected by high acid and aluminum exposure, showing stunted shoot growth and root cutting compared to the control Ermelo cultivar (Ermias Abate et al., 2013). However, among the tef cultivars tested (Dima, Emerson and Brown to name a few), the brown seeded cultivar Dima showed the highest tolerance to all growth parameters tested under high salinity and aluminum soil conditions (Ermias Abate et al., 2013).

#### 2.1.3.5. Drought stress

Drought stress tolerance can be characterized by seasonal, local, and simulated drought conditions with limited water availability for plant growth, development, and adequate yield (Sallam et al., 2019). In most parts of Ethiopia, tef is grown under non-irrigated field conditions during the seasons June to September and February to May (Abuhay Takele, 1997). As a result, tef crops are regularly subjected to dry-spells where rainfall is limited and yield productivity is affected (Abuhay Takele, 1997). Although tef is suitable for growth and development in semi-arid areas, it is often susceptible to drought (Cannarozzi et al., 2022); Water scarcity stress or local drought is one of the major factors limiting tef productivity (Degu and Fujimura, 2010).

Previous studies on the effects of drought on tef leaves have shown morphological changes in leaf structure; this causes leaf tissue to shrink in size and shape rather than showing leaf loss or dieback (Abuhay Takele, 1997). Leaf rolling or the curling inwards of leaves to avoid excessive moisture loss was hypothesized to be an inherent adaptive characteristic of tef to drought conditions (Dejene Mengistu, 2009). In a study examining the physiological response of tef to drought stress at different growth stages, leaf rolling was associated with reduced net carbohydrate uptake and reduced photosynthetic and respiratory rates that varied with tef plant growth stage (Mengistu, 2009).

Balsamo *et al.* (2006) investigated leaf tensile properties (leaf behavior during mechanical stress caused by water loss) of three *Eragrostis* grass species, the drought-sensitive *E. capensis*, the moderately drought tolerant *E. tef* and the drought tolerant *E. Curvula*, during dehydration stress. They found a positive correlation of leaf strength with drought stress (Balsamo *et al.*, 2006). Leaf tensile strength values were the highest for the drought-tolerant *E.*

curvula, followed by the moderately drought tolerant *E. tef* and lastly *E. capensis*, whose leaf tensile strength values were the lowest (Balsamo *et al.*, 2006). Increased leaf tensile strength was positively correlated with changes in leaf architecture and mechanical properties of cell wall chemistry, and ultrastructural studies showed increased cell membrane elasticity for both *E. tef* and *E. Curvula* (Balsamo *et al.*, 2006). Changes in leaf architecture in *Eragrostis* species, *E. tef* and *E. curvula* were proposed to play a dynamic role in stabilizing the lamellae during drought stress (Balsamo *et al.*, 2006).

Additional physiological investigations by Ginbot and Farrant (2011), where white- and brown-seeded *tef* varieties were compared to the resurrection grass species, *Eragrostis Nindensis*, during a dehydration/rehydration cycle were performed. The study was conducted to observe a crop variety that performs better in water-limited conditions (Ginbot and Farrant, 2011). A decrease in respiration rate, photosynthetic potential and an increase in electrolyte leakage rate were observed in *tef* brown and white seed cultivars as relative water contents (RWCs) decreased to 43 and 39% RWC, respectively (Ginbot and Farrant, 2011). Further ultra-structural studies showed damage of membranes and cellular organelles at the water contents, 43 and 39% RWC, for brown- and white-seeded *tef* varieties, respectively (Ginbot and Farrant, 2011). However, dehydration-induced damage was reversed in the *tef* brown-seeded variety upon re-watering while the *tef* white-seeded variety was unable to recover (Ginbot and Farrant, 2011). Below 30% RWC, however, irreparable damage occurred to the entire subcellular organization causing loss of plant cell viability (Ginbot and Farrant, 2011). This indicates that brown-seeded *teff* can survive water content above 30% RWC and is more tolerant to internal water loss compared to white-seeded *tef* (Ginbot and Farrant, 2011).

Among the *tef* components that have been investigated for drought tolerance, *tef* root tissues have been reported to adapt to changes in soil moisture due to drought conditions (Degu and Fujimura, 2010). A deep, penetrating and well-established root system has been suggested to be beneficial for improved drought tolerance, by increasing the ability of plants to mine deeply stored soil water (Degu and Fujimura, 2010). The effect of increasing root lengths during water-limiting conditions has been observed in a few cereal crops such as rice, soybean and sorghum. However, root elongation patterns such as root length under moisture-limiting conditions vary among *tef* seeds (Mulu Ayele *et al.*, 2001); Major Root tissues of *tef* cultivars

K. Murii and Ada were shown to be elongated by 34.6 and 35%, respectively, when exposed to drought conditions compared to the humidified controls. Regulation of root elongation has been reported to be an important adaptive mechanism to cope with drought stress in tef (Degu and Fujimura, 2010).

## 2.2. Common Weeds of Tef

The term “weed” can be defined, from an agronomic point of view, as any plant not on purposely sown or propagated by the farmer that requires management to avoid any interference with crop or livestock production. Indeed, “volunteer crops”, such as buckwheat, rye, Japanese millet, corn or soybean, can become weeds when they self-seed and emerge in another part of the crop rotation when they are no longer wanted. By growing simultaneously with crops, weeds decrease productivity and even the quality of the harvested product, whether due to competition for water, sunlight, nutrients and space; allelopathy or parasitism (Monteiro et al., 2022). The major weed species identified in tef fields: broad leaved weeds *Amaranthus* spp, *Argemone Mexicana*, *Bidens Pilosa*, *Commelina* Spp, *Convolvulus* Spp, *Galinsoga Parviflora*, *Guizotia Scabra*, *Plantago Lanceolata*, *Oxalis Corniculata*, *Parthenium Hysterophorus*, *Polygonum Nepalense*, *Datura Stramonium*, *Nicandra Physalodes*, *Chenopodium Album* (Birhanu et al., 2018). Grasses weeds are *Digitaria* spp, *Phalaris* spp, *Setaria* spp, *Echinochloa* spp, *Cynodon Dactylon*, *Snowdenia Polystachya*, *Dinebra Retroflexa*, *Brachiaria Erueiformis* (Kassahun and Tebkew, 2013). Sedges are *Cyperus* spp (Ermias Abate, 1985).

Among the major yield limiting biotic factors in tef production, annual and perennial grass and broad leaved weeds are labor-intensive and time-consuming operations in tef cultivation. They also listed other problematic weeds in tef including the parasitic witch-weed (*Striga Hermonthica*), the introduced alien invasive weed commonly known as congress-weed (*Parthenium Hysterophorus*), field bindweed (*Convolvulus Arvensis*), and other noxious weeds. Because of morphological features, especially its short and thin stem, small leaves and shallow fibrous root system, and low seedling stand establishment, tef has a limited ability to compete with weeds (Gebrekidan Feleke et al., 2022). Most broad leaved weeds (Dicots) were sensitive to tillage when established as seedlings can be eliminated by first hand weeding. However most of the grass weeds (Monocots) especially those with actively regenerative parts

upon cutting by plough (e.g. *Cynodon Dactylon*) are more tolerant tillage (Habtamu Gebrehiwot, 2020), and were the most diverse and important weeds in the tef growing areas.

Most of the weed species were annuals; therefore their infestation can be minimized easily by crop management practices. If there is continuous rainfall during the production season their competitive ability towards tef can be higher. The internodes and rhizomes of some creeping species of permanent plants can aggravate their invasion of the tef field. This is because during hand weeding perennial monocot weeds is small and may not be uprooted completely this guards the spread of fast regenerative rhizomes and internodes. These type of weeds are commonly part of the two most diverse families i.e. *Poaceae* and *Asteraceae*. Most weed species were obtained at mid altitude (1500-2500 m a. l.) where tef production is more frequent and intensive cropping system management practices are the most important factors contributing to the variability of weed species richness and composition in the crop field (Fried *et al.*, 2008).

### **2.3. Critical Period of Crop Weed Competition**

The critical period of competition is the period during which the crop must be maintained weed-free to avoid irreversible damage through competition (Van Acker *et al.*, 1993). It is the shortest time span of crop when weeding results in highest economic returns. The critical period of weed competition for tef is three to four and six to seven weeks after crop emergence (Kassahun & Tebkew, 2013). Generally, an increase in one kilogram of weed growth will decrease one kilogram of crop growth (Bogale Ayana *et al.*, 2020).

Factors influencing the timing of weed-crop interference or crop weed competition are:

### **2.3.1. Weed Growth Period**

Weeds interfere with the crop whenever they are present in the crop. Thus, weeds that germinate along with crops are more competitive. Sugarcane takes about a month to complete the germination stage, while weeds require much less time to complete germination. By that time crop plants are usually smothered by the weeds completely. In general, the first 20-30 days of weed-free time is very important for most annual crops (Bewket Getachew, 2022).

### **2.3.2. Weed Crop Density**

Increase in weed intensity reduces crop yield. The relationship between yield and weed competition is sigmoid. Increasing the number of plants reduces weed growth and reduces competition for soil moisture and other nutrients until they compete with each other. For example, row spacing was reduced from 20 to 15 cm in wheat and dry matter production of *Lolium* and *Phalaris* sp. decreased by 11.8% and 18.3% respectively (Bewket Getachew, 2022).

### **2.3.3. Result of Plant Species**

**Weed species:** Weeds vary in their ability to compete with crops at the same density level. This is due to the difference in their growth and to some extent due to the allelopathic effect. **Crop species and varieties effects:** They differ in their competing ability with weeds. Among winter grains the decreasing order of weed competing ability is barley > rye > wheat > oat fast canopy forming and tall crops are more competitive than slow growing short stature crops (sorghum, maize, soybean and cowpea) because of their slow initial growth. Late-sown dwarf wheat is affected by late-emerging weeds such as Canada thistle and wild grass.

### **2.3.4. Soil Condition**

**Soil fertility:** For balanced nutrient conditions, there is competition between crops and weeds. Soil type, soil fertility, soil moisture, and soil response influence crop weed competition. Higher soil fertility encourages more weeds than crops, thereby reducing crop yields. The method and timing of the application of the fertilizer to the crop will determine whether the added fertilizer will limit or encourage weed growth in the field. Applying fertilizer during

early crop growth was more beneficial when weed growth was negligible. Applying band fertilizer to the crop makes it less accessible to invasive weeds.

**Soil moisture status:** Weeds differ in their response to soil moisture. Russian thorn salsa showed similar growth in both dry soil and wet soil. Large crabgrass, however, *Digitaria Sanguinalis* grows more on wet soil. When fields are irrigated immediately after planting, then weeds will be more competitive than crops. If the weeds were already present at the time of irrigation, they would grow luxuriantly until they completely covered the crop. In waterlogged soil, weeds are more competitive than crops. In the conditions of water in the rice, it will cause damage to the weeds. But if there is a break in the water, the weeds can grow and grow more than the crops, even if the fields are submerged later.

**Soil reaction:** Abnormal soil responses (too high or too low pH) often exacerbate weed competition. Weeds provide more competition for crops on abnormal pH soils than on normal pH soils. *Rumex Acetosella* and *Pteridium spp* in acid soil, *Taraxacum Stricta*, *Agropyron Repens* in saline alkaline soil are the main weeds (Bewket Getachew, 2022).

### **2.3.5. Climate influences**

Adverse weather conditions such as drought, floods and high temperatures make most of our crop species very vulnerable to such climatic effects, while weeds are resistant to the stress and strengthen weed-crop interference.

### **2.3.6. Cropping Practices**

**Time of planting crops:** If the planting time of a crop coincides with the arrival of the first weeds, it will lead to high weed-crop interference. Usually, the longer interval between crops and weeds was less weed-crop interference.

**Method of planting:** Weed seeds germinate most readily from top 1.25 cm of soil, though it is considered up to 2.5 cm depth. Avena, barnyard grass, Xanthium and Vicia spp may germinate even from 15 cm depth. Therefore, a planting method that quickly dries the top 3-5 cm of soil to prevent weed seeds from germinating, and up to the first irrigation, Pon weeds emerge.

**Crop density and squareness:** It determines the quantity and quality of crop area available for weed growth. Wide row spacing with a high number of in-row plants at the same time can

create dense weed growth. But the square planting method is suitable to reduce intra-row competition (Bewket Getachew, 2022).

## **2.4. Types of Competition**

Above-ground (Aerial) competition which takes place in the leaves and the growth factors involved are light and carbon dioxide. Below ground (Subterranean) competition which takes place mainly in the roots while the growth factors involve water, nutrients and oxygen. Competition between crop plants and weeds is most severe when they have similar vegetative habits and common demand for available growth factors. The perceived consequence of competition with crops is reduction in the economic yield of affected crop plants.

### **2.4.1. Competition for Light (Solar Energy)**

Plant height and vertical leaf area distribution are the important elements of crop weed competition. When moisture and nutrients in soil are plentiful, weeds have an edge over crop plants and grow taller. Competition for light occurs during early crop growth season if a dense weed growth smothers the crop seedlings. David *et al.*, (1990) reported that crop plants suffer badly due to the shading effect of weeds during the seedling stage. Unlike competition for nutrients and moisture once weeds shade a crop plant, increased light intensity cannot benefit it. From 19 to 25 percent yield loss was observed due to 44-56 percent of the crop being infested by the weed.

### **2.4.2. Competition for Nutrient**

It is an important aspect of crop weed competition. Weeds usually absorb mineral nutrients faster than crop plants (Korav *et al.*, 2018). Usually weeds accumulate relatively larger amounts of nutrients than crop plants and nutrient removal by weeds leads to huge loss of nutrients in each crop season, which is often twice that of crop plants. The uptake of N, P and K by parthenium increased with increase in its competition period. This might be due to higher accumulation of dry biomass per unit area. Nitrogen, phosphorus and potassium uptake by parthenium was in the range of 2.7-18.4, 0.2-2.4 and 2.3-17.7 N, P and K kg ha<sup>-1</sup>, respectively, at its different competition periods (Safdar *et al.*, 2016).

### **2.4.3. Competition for Moisture**

Water competition takes place underground; it mainly depends on the roots structure and size. For producing an equal amount of dry matter the weeds absorb more moisture from soil than the crop. Therefore, the actual evapotranspiration from the weedy crop fields is much more than the evapotranspiration from a weed free crop field. For example, consumptive use of *Chenopodium album* is 550mm as against 479mm for wheat crop (Korav *et al.*, 2018). Further it was noted that weeds remove moisture evenly from up to 90 cm soil depth. While major uptake of moisture by wheat was limited to top 15 cm of soil depth. In the pearl millet field the *Cynodon Dactylon* has twice the water transpiration than pearl millet because its roots are deeper in soil. In a weedy field the moisture is more extracted by weeds and crops are at plants reaching active vegetation to reproduction stage. From a water use efficiency point of view, most weed species are C4 type having higher water use efficiency as compared to the C3 type of crop species (Silva *et al.*, 2007).

### **2.4.4. Competition for Space**

Crop-weed competition for space is the requirement for CO<sub>2</sub> and the competition may occur under extremely crowded plant community conditions. A more efficient utilization of CO<sub>2</sub> by C4 type weeds may contribute to their rapid growth over C3 type of crops (Korav *et al.*, 2018).

## **2.5. Economic Importance of Tef Production**

Tef is one of the most important and dominant staple cereal crops in Ethiopia. In Ethiopia Annually, 3 million hectares of land (32% of the total farmland) is covered by tef, and 5.2 million tons of grain (21% of the production volume) is produced in Ethiopia (Ademe Mihretu, 2022).

### **2.5.1. The Role of Tef in Ethiopian Agriculture**

The cost of tef per kilogram is significantly higher than other cereal crops. For instance; In 2003/2014, tef production was 2.52 US dollars compared to other grains (Ibrahim Worku *et al.*, 2018). The role of tef in agricultural production varies greatly in different regions. This

significant difference can be driven by climate change and other factors. Oromia region is the leading teff producer in the country; and its share in the total national product is estimated to reach 48 percent. The second highest region is Amhara region with 39 percent. The rest of the regions are comparatively less important (Ibrahim Worku *et al.*, 2018).

Other than general cropping area classification; 73% of the teff cultivated area was in the hands of farmers with less than 2 hectares, and the remaining 27% of the teff cultivated area was owned by farmers with more than 2 hectares (Ibrahim Worku *et al.*, 2018). This indicates that teff producing farmers are small in size; it means that the teff production system is not marketed in the country; it remains fragmented and may have a negative impact on the role of teff in the Ethiopian economy. Another role of teff in agriculture is to serve as animal feed. Fodder sources in Ethiopia are pastures (61.48%); crop straw (27.71%); hay (6.35%); by-products (0.82%); improved fodder (0.8%) and others (3.47%). This indicates that crop straw is the most important animal feed in Ethiopia. Tef straw accounts for 6.93 percent of the total grain crop straw produced in the country Fikadu Asmiro (2019)

Moreover; In the 2004/2005 crop year, 36.3% of the cultivated land was allocated to teff and 6.47 tons of crop straw was produced. At the family level; teff straw (33%), maize (31.6%) and wheat straw (6.97%) contributed to the total household annual crop straw production Tesfaye (2006). Another study showed that out of the total teff straw (9.54 million tons); nationally, only 6.68 million tons of teff straw was supplied for animal feed. The reason may be due to the distance between the crop field and the houses and the lack of transportation, although teff straw has less waste than other crop straw Aredo Tesfaye (2006). However, straw production has an important role in the agricultural sector in Ethiopia. That means; there is room to improve animal production and productivity by cultivating teff straw and increasing its fodder value, because the lack of adequate or sufficient fodder supply is a problem for animal husbandry in Ethiopia, especially during the winter months.

### **2.5.2. The role of Tef on food economy in Ethiopia**

The highest consumption of teff is seen in the major cities of Ethiopia; with Addis Ababa (101 kg per capita); Next are Harar (40 kg) and Dredawa (38 kg). The main production zones of the country also show relatively high per capita consumption levels; 36 kg in Amhara; 35 kg in

Oromia; and 38 kg in Tigray. Consumption levels are relatively low in the southern (a region known for consumption of root crops) and western parts of the country (a region where maize is commonly consumed) that is; 19 kilograms in SNNP; 17 kilograms in Gambella; and 3 kilograms in Somali. Injera is consumed more in urban areas both in relative and absolute terms. Except for Addis Ababa; the Amhara region is the only region where white tef consumption exceeds 10 kilograms per capita per year (Ibrahim Worku *et al.*, 2018).

### **2.5.3. The Role of Tef on Ethiopian Business Sector**

#### **2.5.3.1. Tef exports**

Tef is mostly grown for the market due to its high cost and lack of alternative cash crops (Demeke and Marcantonio (2013). Tef is the second most important cash crop after coffee and generates an annual income of US\$ 500 million for local farmers (Minten *et al* (2013). Export volumes fluctuate and relatively high volumes were exported in 2001 and 2005, but exports declined from January 2006 onwards. This is mainly due to domestic inflation and an ineffective ban on government exports. The main reason was to bring domestic inflation price into consumers' affordable level and meet local food security demand before export. However; the imposed ban averts the Ethiopia government particularly farmers from engaging and benefiting in the rising world trade; which could increase GDP and change the livelihood of producers. Even if; some reports suggest that interest in America is very high; the largest number of Ethiopian refugees in the Middle East and Europe live there.

#### **2.5.3.2. Value-added products of tef**

Tef is the most value-added crop compared to other cereal crops. Following the ban on the export of raw teff grains; Production of teff products has started to increase nationally and internationally and has benefited many stakeholders in the process. Currently; Ethiopian Pancake (Injera) is sold in local and foreign markets. It will contribute to creating job opportunities for many people in the country.

### **2.5.4. The Nutritional Value of Tef and its Contribution to Human Health**

A few years ago; Knowledge of the composition of tef was limited. Because of this; it was difficult to develop teff-based food products for international consumers. Consequently; the

human consumption of tef at globally was too low. However, studies stated that the nutritional consumption of tef and its processing quality and new tef-based products have grown. Tef provides two-thirds of the basic nutrition for the population. As multi-studies; tef is very rich in: minerals; protein; Carbohydrates (newly discovered teff dietary fiber for blood sugar management, weight control and gut health) and also; Sodium is low; bad fat and cholesterol. The main point of interest is that teff is a gluten-free grain and helps celiac to fight obesity and diabetes. In the year 2010, approximately 285 million people worldwide had diabetes Solomon Bizuayehu (2014). But; about 20-30% reduces the risk of developing type -2 diabetic by consuming teff Secorun (2016). Tef is a good solution to prevent and control iron deficiency and diabetes. This suggests that teff has the potential to be a future global functional food for health promotion and disease prevention.

## **2.6. Yield Losses due to Weeds**

The tef crop is not only suitable for different agro-climatic conditions but also has wide genetic diversity for different agronomic traits. Such wide adaptation to different agro-ecosystems exposes it to different weed species as described by Qasem et al., (2011). The negative effect of weeds in addition to crop yield reduction because of competitions, weed can serve as a host to disease causing pathogens and insect pests, hinder growth and development of crop plants by emitting toxic substances (allelochemicals), reducing crop seed quality by contaminating the product, late emerging weeds can obstruct harvesting and limit choice of crop rotation sequences and cultural practices (Habtmu Gebrehiwot, 2020). Grain yield of tef can be reduced up to 42.4% due to weed infestation in all weeds (Gebrekidan Feleke et al., 2022). Similarly, weed competition has been reported to cause a yield loss of 48 to 49% (Bashar et al., 2023). Likewise, (Seyfu Ketema (1997) reported a 52% yield reduction without weed control. Weeds are the major problem in tef, causing 35-65% reduction in yield depending on the intensity of infestation (Habtmu Gebrehiwot et al., 2020). The main reasons for the reduction of crop production are identified as weed-crop occurrence, competition time, weed life cycle and growth habit, weed and crop plants, crop species and cultivars. According to Qasem et al., (2011) a significant reduction in overall crop yield is caused by increasing the number of weeds occupying a given crop field. Weeds grow faster and taller than crop plants and form a foliar layer that shades the crop plants. The weed is developing extensive root

extension and branching, which is said to take up more nutrients and water from the soil at the expense of the crop. Some weed species increase competitiveness by producing phytotoxicity substances that have a negative effect on the growth and development of crop plants. These chemicals are released into the soil as root exudation or as liquid from living or dead plants.

Other studies also suggest that weeds are one of the main limiting factors for achieving high tef production (Zewditu Dawit *et al.*, 2020). In addition to eliminating crop loss, weeding requires farmers and their families to spend a lot of time on weeding, and more than 50% of the labor is done for weeding, mainly by women and children in the farming family. Tef is vulnerable to weeds due to its shallow root system and slender stems with thin leaves. This makes weed control one of the key management components of tef production.

## **2.7. Weed Management Practices in Tef**

Managing weeds has always been placed at the center of agricultural activity by farmers since ancient times (Scavo, 2020). The control of weeds is a big challenge in agriculture and in many cases a complex, controversial and also expensive problem to solve. In fact, weed management accounts for nearly one third of the total cost of the production of field crops (Monteiro and Santos, 2022). This agronomic practice goes beyond the control of existing weed problems and places greater emphasis on preventing weed reproduction, reducing weed emergence after crop planting and minimizing weed competition with the crop. Currently, weed management in agricultural systems branches out into two distinct directions corresponding to different approaches. On the one hand is the widespread use of synthetic herbicides, while on the other, weed control is widely based on mechanical, and cultural methods (Monteiro and Santos, 2022).

### **2.7.1. Mechanical Methods**

Mechanical or physical techniques either destroy weeds or make the environment less favorable for seed germination and weed survival. These techniques include hand-pulling, hoeing, mowing, plowing, disking, cultivating, and digging. Mulching (straw, wood chips, gravel, plastic, etc.) can also be considered a mechanical control since it uses a physical barrier to block light and inhibit weed growth. Mechanical weed control by soil tillage is probably the most common control method of weeds because tillage and cultivation directly affect

weeds by burying shoots, by cutting up plants and by uprooting plants so that they desiccate. Most organic growers cultivate a conventionally tilled seedbed before planting the crop (Goldammer, 2017). Higher plant height, biomass yield and grain yield was obtained in conventional tillage most likely because of less weed infestation compared to less tillage frequency. Tillage intensity can, however, also influence soil physical, chemical and biological properties and hence, can affect plant height, biomass yield and grain yield. A lower yield in zero and reduced tillage compared to traditional tillage has been reported in other studies conducted on teff and other cereal crops in Ethiopia (Haftamu Gebretsadik, 2019).

Although the tillage operation can often have other purposes than weed control, it affects the weed flora in some way. Generally, as explained by (Håkansson et al., 1998) weed seedlings are more sensitive to soil tillage compared to established perennial weed species, and young plants of annual species can be killed largely even by relatively light soil cultivation. Repeated soil cultivation can also decrease weed seed bank inside the soil, but it is then important that weeds through the crop season be prevented from flowering and seed setting. Compared to seedlings, established plants of perennial weeds will in most cases require deep tillage for destruction and/or to remove the reproductive parts such as rhizomes and bulbs, as a strategy for starving out the weeds. Many studies have shown that moldboard plowing gives a significant control of perennial weeds. Deepening moldboard plowing increases effectiveness furthermore, the effect of mechanical weed control will differ for different perennial weeds species because of their specific biology (Brandsaeter *et al.* 2017).

### **2.7.2. Chemical Methods**

Herbicides can be defined as crop protection chemicals used to kill weedy plants or interrupt normal plant growth. Herbicides provide a convenient, economical, and effective way to help manage weeds. They allow fields to be planted with less tillage, allow earlier planting dates, and provide additional time to perform the other tasks that farm or personal life require. It is important to understand both the benefits and disadvantages associated with chemical weed control before selecting the appropriate control. As a chemical method of control, the use of post emergence selective herbicide is one component during intensive and conventional crop production practices. Teff weeding is a laborious task that is critical for productivity. Hand weeding is the most widely used practice to control weeds in teff production. Controlling

annual and perennial grass and broadleaf weeds from tef fields is of prime importance. Recently one promising wide spectrum herbicide (Pyroxsulam) had been already investigated for the control of both grass and broadleaf weeds problematic weeds in tef and wheat (Shugute Addisu, 2016). Pyroxsulam was found effective in controlling *Guizotia Scabra*, *Galium Spurium*, *Galinsoga Parviflora*, and *Amaranthus Spp*, *Chenopodium spp*, *Bromus Pectinatus* and *Avena spp* with efficacy of 100, 97, 97, 95, 82, 96 and 98%, respectively. However, observation on nation-wide demonstration of Pyroxsulam showed that this herbicide is not effective against certain grass and broadleaved weed species such as *Sorghum Arundinaceum*, *Phalaris Paradoxa*, *Convolvulus Arvensis* and *Cichorium Intybus*, and *Commelina Benghalensis* (Shugute Addisu, 2016).

Herbicides should be used in combination with good preventative, physical and cultural practices. A wide variety of herbicides are available for both annual grassy and broadleaf weed control in tef. The effectiveness of the herbicide will depend upon a number of application and environmental factors. Most herbicides are recommended at a range of rates either to facilitate control of weeds in a window of growth stages or under differing densities. Weed control is always easier and less disruptive to the crop when done at an early growth stage on the weeds. However, the use of herbicides in conjunction with cultural and mechanical control methods usually results in the most effective management of weeds (Egan *et al.*, 1993).

Ayana, (2019) described that herbicide application decreased dry weight of weeds significantly compared to dry weight in non-treated plots. Chemical weed control in crops was best in producing higher grain yield than hand weeding. Moreover, the highest weed suppression was from the combination of Pallas 45 OD with 2, 4-D and twice hand weeding (Zahara and Shigute, 2017). The results of the present investigations: annual weed species like *Amaranthus Hybridus L.*, *Argemon Mexicana L.*, *Bindens Pilosa L.*, *Commelina Benghalensis L.*, *Datura Stramonium L.*, *Guizotia Parviflora*, *Guizotia Scabra*, *Plantago Lanceolata* and *Xanthium Strumarium L.* were highly managed by these herbicides application. Megersa Kebede *et al.* (2017) observed various weed species such as *Guizotia Scabra*, *Polygonum Nepalense*, *Convolvulus Arvensis*, *R. Raphanistrum*, *Achyranthes Aspera*, *Avena Fatua* and *Setaria Pumila* were effectively controlled by the application of Pyroxsulam. This chemical

was more effective on controlling broadleaved weeds which reduced the weed population as compared to 2: 4-D and also it can control serious grassy weeds on wheat (Bekele Belete *et al.*, 2018). The grain yield of the Pyroxsulam treatment was higher than the hand weeding treatment which could be due to the effectiveness of the herbicide in reducing weed competition at all stages of the crop.

### **2.7.3. Integrated Weed Management**

Integrated Weed Management (IWM) is defined as a weed management system that can keep the weed infestation level below economic threshold by combining different weed control methods (Habtamu Gebrehiwot *et al.*, 2020). To ensure effective weed control, the following principles are most relevant. 1) Before any curative control takes place, possible preventive methods of cultural control need to be considered; 2) Know the weed pressure through monitoring; 3) Monitor weed pressure for a decision about the necessity of control; 4) Decide when proper non-chemical measures should be preferred, also in conventional farming; 5) Restrict application of herbicide ingredients, with least side-effects, to those species requiring control; 6) Make case-specific reductions of herbicides dose and application frequency in combination with the use of site-specific weed management; 7) Establish anti-resistance strategies to maintain effect of the products. 8) Check the effect of applied weed control measures (Dwight, 2017).

It is developed in response to the need for effective weed control methods that can enhance crop yield with minimum effect on the agro ecosystem. In conventional agriculture frequent tillage and applying herbicides negatively affect soil properties and the biological diversity of the agro ecosystem. This calls for the development of sustainable, environmentally friendly and well-integrated weed management strategies to reduce the weed infestation below the levels that do not cause significant crop yield loss while avoiding devastating effects on the environment and biological diversity of the agro-ecosystem. The risk of the intensive use of herbicides on human health and the environment, challenges associated with adequate weed control, the emergence of herbicide resistant weed species and the need for sustainably higher crop yield to feed the ever increasing human population are the main drivers for the development and adoption of Integrated Weed Management. According to Rana and Rana (2016), IWM includes two basic decision making processes: The appropriate time to apply the

control method(s) that can reduce weed infestation levels far below the economic threshold, and the best combination of the control methods that can provide high advantage to the crop over weeds, resulting in higher crop yield and maximum profit.

## **2.8. Effect of Varieties on Tef Yield**

Tef is a staple and well adapted crop in Ethiopia. Weed competition and control have major effects on yields and economic returns of the crop in the country. Among the weed management methods, development and use of weed competitive tef varieties remain the cheapest and most sustainable weed management option (Andrew *et al.*, 2015). Plants exhibit multiple interactions when growing among each other and such interactions include competition for resources of factors such as water, nutrients, solar radiation and space. This competition includes interference through chemical exudates emitted from plants to the soil. Inhibition of root growth of weeds and other plant species is among the indicators of the allelopathic effects of crop plants (Walker *et al.*, 2003). At this time, we believe there are no research reports on the allelopathic effect of tef on different weed species. Most reports have focused on the allelopathic effect of certain plant species on tef (Tefera, 2002). For example, leaf extracts from different eucalyptus species and *Parthenium Hysterophorus* had an effect on the germination and early growth of tef. In the experiment, where that did not potentially allow competition for resources between tef and model weeds, showed that the different tef varieties caused differential root growth of ryegrass and radish (Habtamu Gebrehiwot *et al.*, 2020).

A large number of studies have been conducted showing differences in competitive ability between species of different cereal crops such as wheat, oat, and barley (Andrew *et al.*, 2015). They give many examples of traits, e.g., canopy height, early vigor, and release of different allelochemicals that contribute to increased suppressive ability against weeds. Planting design, which includes planting density, row spacing, and orientation, can also be used as a method of weed management because it can enhance the crop's competitive advantage over weeds (Vander and Chawhan, 2017). Habtamu Gebrehiwot *et al.*, 2020) studied the competitive ability of tef varieties as well as their traits, e.g., canopy heights and tillering potential of different tef varieties. In most species, there were between production potential and weed competitiveness, especially for 'Kora' and 'DZ-Cr-387' (Quncho) as they lost less of their

yields while significantly reducing weed infestation. In addition to the allelopathic effect, emergence and crop biomass yield were the most important agronomic traits contributing to the ability of tef to suppress weeds and inhibit their growth, although the contribution of plant height and tillering potential was also important. There were low initial weed counts in well-established treatments, particularly tef, correlated with (Brown, 2017) who found that tef was able to suppress weed emergence even when the weed seed bank levels were considered high. Habtamu Gebrehiwot *et al.*, 2020 had similar findings on the importance of having well-established tef management, concluding that a tef cover crop with suitable plant establishment had 41% less overall weed cover compared with those that failed to successfully establish.

### 3. MATERIALS AND METHODS

#### 3.1. Description of the Study Area

The study was conducted at Abeshge Woreda, in the Wolkite Agricultural Research Center site. It is located at 8°17'21.34" N latitude and 37°50'54" E longitudes at an altitude of 1878 m a.s.l. The site is located 7 km east from Abeshge district (Wolkite town). The district is bordered on the south by the Wabe River which separates it from Cheha district, on the west and north by the Oromia Region, and on the east by Kebena district. The district has generally a midland climate with an altitudinal range of 1100-2300 m a.s.l although there are some lowland areas (1100-1500 m a.s.l). It covers an area of 61,016 ha of which the midlands and lowlands constitute roughly 85 and 15 %, respectively. The main rainy season ‘*kiremt*’ extends from June to September with the peak rainfall occurring during July and August. The short rainy season called ‘*Belg*’ stretches from March to May (Mekdes Dessie *et al.*, 2017).

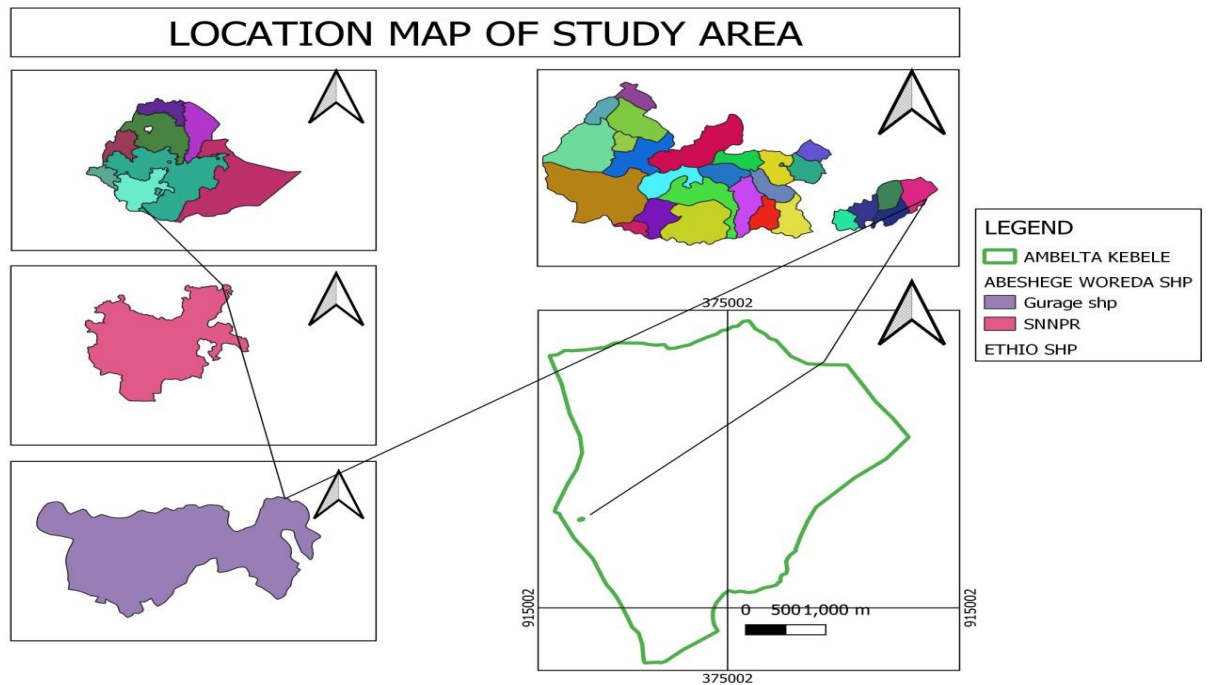


Figure 1. Map of the study area

### 3.2. Experimental design and Treatments

The experiment comprised two factors namely, variety (V1-V2) and weed management practices (W1-W6)

- ✓ **W1:** Chemical Pallas 45 OD 0.4 l ha<sup>-1</sup>. Regarding the post-emergence herbicide treatment, Pallas 45 OD 0.4 l ha<sup>-1</sup> (optimum recommendation) was applied as a hand spray on the field at 31 days after crop emergence (DAE) and weed management was not done until harvest.
- ✓ **W2:** Chemical Pallas 45 OD 0.3 l ha<sup>-1</sup>. In Pallas 45 OD 0.3 l ha<sup>-1</sup> (lower dose) applied at 31 DAE and supplemented by one hand weeding at 41 days after crop emergence.
- ✓ **W3:** One hand weeding. In one hand weeding was allowed to grow up to 31 DAE and then hand weeding was done and then no weeding was done until harvest.
- ✓ **W4:** Two hand weeding. Two-handed weed control; Weeds were allowed to germinate with the first 31 DAE. A manual weeding was done in 31 days after crop emergence. Weeds were allowed to grow with the crop up to 41 DAE, then another hand weeding was done and then no weeding was done until harvest.
- ✓ **W5:** Completely weed free. Weeds in weed-free plots are frequently removed by hand (when weeds have emerged) to keep the plots weed-free.
- ✓ **W6:** weedy-check. Weeds are allowed to grow until harvest.

While three tef varieties were included (V1) denotes *Quncho*, (V2) *Kora*, and (V3) *Dagim*. The experiment was arranged factorial in randomized complete block design with three replications. There were 54 plots in all with the size of 2m × 3 m each (Appendix table - 1).

### 3.3. Experimental Materials

Improved tef varieties from the Wolkite Agricultural Research Center (WKARC) were used as experimental inputs. The varieties were released from Debre Zeit Agricultural Research Center (DZARC) in areas with sufficient rainfall.

Table 1. Description of tef varieties used in the study area

Variety name	Kora [DZ- Cr - 438 (RIL No 133B)	Quncho (DZ- Cr- 387)	Dagim DZ-Cr-438 (RIL No. 91A)
Altitude (a.s.l)	1700 – 2400	1500 – 2500	1700 - 2400
Rainfall (mm)	720 – 1200	300 – 700	500 - 1000
Year of release	2014	2006	2015
Panicle length (cm)	37.3	39.8	35.5
Days to maturity	113	116.5	114
Height cm <sup>-1</sup>	102.5	102	95.6
Seed color	Very white	Very white	Very white
Grain yield on station ton ha <sup>-1</sup>	2.5-3.2	2.46	2.63
Grain yield on farm ton ha <sup>-1</sup>	2-2.8	1.27	1.36
Developed by	DZARC	DZARC	DZARC
Released year	2014	2006	2015

**Sources:** MoA, 2014; MoARD, 2008 and MoA, 2015

Table 2. Description of the herbicide, which was used for the experiment

Trade name	Chemical name	Water	Rate	Application time
Pallas 45 OD	Pyroxulam:N-(5,7-dimethoxy[1,2,4] triazolo[1,5-a]pyrimidin-2-yl)-2-methoxy4-(trifluoromethyl)-3-pyridine sulfonamide	200 l ha <sup>-1</sup>	0.4 lha <sup>-1</sup>	30-35 days after crop emergence

**Source:** Devendar, 2019; Berhan *et al.*, 2021

### 3.4. Experimental Procedures and Management

The experimental field was prepared for good cultivation in June (2022) using an oxen plough. The experiment comprises gross size 11 m x 44.5 m (489.5 m<sup>2</sup>) with 15 rows for 20 cm inter row spacing and the path between experimental units and replications are separated by 0.5 m and 1.0 m, respectively. Each treatment combination was assigned to experimental units within a block by a random lottery method. The net plot area was 2.6 m x 1 m (2.6 m<sup>2</sup>) leaving one outer row on both sides of each plot and 0.5 m row length at both ends of the rows to avoid possible border effects (Bell *et al.*, 1994). The plots were adjusted as per the layout.

The tef seed rate of 10 kg ha<sup>-1</sup> of each variety was drilled in a wide 20 cm between rows (Niguse Hundessa *et al.*, 2023). NPSB and Urea fertilizers were applied at rates of 100 kg ha<sup>-1</sup>

(N-18.9 P-37.7 S- 6.95 B- 0.1) and 100 kg ha<sup>-1</sup> Urea (46-0-0), respectively. NPSB was applied at sowing time, whereas Urea was applied in two split half amounts at sowing time and the remaining amount at the tiller stage of the crop (Niguse Hundessa *et al.*, 2023) (Appendix table - 7). The herbicide amount required for the treatment was calculated and measured using a cylinder and applied at three weeks after crop emergence. Hand weeding as per the treatment was done in the assigned plots. Moreover, all experimental plots and other agricultural activities were done at an equal level. Weed assessment had been beginning after crop emergence until final harvest and in the year the harvest took place on December 20, 2022 and 7 days left on the field to sun dry before threshed.

### **3.5. Data Collected**

#### **3.5.1. Weed Parameters**

##### 3.5.1.1. Weed community

The main purpose of identifying weed species was to determine the weed species composition, which might have aggressive competition with tef. In order to identify the weed species present in the experiment, and at 45 DAE, at 55 DAE and at 15 days before harvest, based on visual observation from each plot.

##### 3.5.1.2. Weed density and biomass

Weed plant density were assessed three times before harvest from each plots two throws in probability random sampling method an iron rod quadrat 0.25 m length with 0.25 m width was used for weed count in each plot at 45 days after crop emergence (DAE), at 55 DAE (stem elongation and/ or flowering stage) and about 15 days before the expected harvest time. A mean of weed plant density count in each plot was recorded, expressed in per m<sup>2</sup> and weeds were identified as broad leaved weeds, grasses and sedges.

At the same time, the density assessment of aboveground weed biomass was collected from each quarter at 45 DAE, 55 DAE and 15 days before the expected harvest. The harvested weeds were washed the basal parts to remove soil, separated and identified weed species before drying, in each plots broad leaved, grasses and sedge weeds and placed into paper bags separately treatment and sun dried for 4 days before drying in oven at a 65<sup>0</sup>C temperature till

constant weight for 48 h and subsequently the dry weight was measured and the dry biomass was expressed in g m<sup>-2</sup>.

### 3.5.1.3. Data analysis for weed management parameters

Weed control efficiency (WCE): is described as the effectiveness of weed control. Calculated taking into consideration the reduction in weed dry matter in treated plots over weed dry matter in weedy-check (Boutagayout *et al.*, 2023).

$$WCE = \left( \frac{WDC - WDT}{WDC} \right) * 100$$

Where:

WDC = weed dry matter production (g/m<sup>2</sup>) in weedy-check

WDT = weed dry matter production (g/m<sup>2</sup>) in weed control treatment

Herbicide efficiency index (HEI): is the potential of a particular herbicide for controlling the weeds along with their phytotoxicity effect on the crop and it was calculated based on formula described by Khaliq *et al.*, (2014).

$$HEI = \left( \frac{YT - YC}{YC} \right) * 100 / \left( \frac{WDT}{WDC} \right) * 100$$

Where:

YT= crop yield from treatment plot

YC= crop yield from weedy-check

WDT= weed dry matter biomass in treated plot and WDC= weed dry matter biomass in weedy-check plot

Weed index (WI): it is the magnitude of yield reduction due to the presence of weeds in comparison with weed-free check and is calculated as

$$\text{Weed Index} = \left( \frac{X - Y}{X} \right) * 100$$

Where:

X= Yield in weed free

Y= Yield in a particular treated plots

### **3.5.2. Data Analysis Related to Crop Parameters**

#### **3.5.2.1. Crop growth parameter**

Plant height (cm): This was calculated as the average of ten plants that were randomly selected from the middle rows of a net plot area and measured using a meter from the base of the main stem junction between shoot and root to the tip of the plant.

Number of total tillers: This is to count the tillers except the main stem, at the point of physiological maturity, by counting all the tillers from ten randomly selected plants in the middle rows of the net plot area and the average is taken into account.

Above ground biomass (ton ha<sup>-1</sup>): Biomass yield was recorded by weighing the whole plant parts from the net plot area harvested and measured after 7 days sun drying and then threshing, winnowing subsequently.

#### **3.5.2.2. Yield and yield components**

Panicle length (cm): This was measured for ten randomly selected plant samples with the net plot area in the middle row, the plant was from the node (where the initial panicle branches emerged) to the tip of the panicle and the average was taken into consideration.

Thousands grain weight (g): The seeds were taken from each plot at harvest and 1000 seeds counted by hand and then weighed a sensitive balance.

Grain yield (ton ha<sup>-1</sup>): Grains were cleaned following harvesting and threshing, weighed using sensitive balance, and oven dry method (Lee, 2016) was used to record the moisture percentage of the grain was determined by drying samples in an air circulating oven set at 105 °C for 24 h and was found to be 11% wet basis (Zewdu and Solomon, 2007). The moisture

content at harvest was adjusted to 11% since actual moisture content may increase or reduce grain yield and to get actual grain yield by using the following formula.

$$\text{Grain yield} = \left( \frac{100 - \text{MC}}{100 - 11} \right) * 100 \quad (\text{Ngoune } et al., 2019)$$

Straw yield (ton ha<sup>-1</sup>): Was obtained by subtracting the grain yield from the total above ground biomass yield

Harvest index (HI): Was obtained by dividing grain yield to the total above ground biomass yield.

$$\text{HI} = \left( \frac{\text{Grain yield}}{\text{Above ground biomass}} \right)$$

### 3.5.2.3. Crop phenology

Days to 50% heading: This was recorded as the number of days from the date of sowing up to the date when 50% tips of the panicles first emerged from the main shoot of the plant per plot.

Days to physiological maturity: This is recorded in the number of days from the date of sowing until 50% of the crop - stems, leaves and flower buds - have turned light yellow, in the visual observation. The data measured was indicated by the senescence of the leaves as well as the free threshing of grain from the glumes when pressed between the forefinger and thumb.

## 3.6. Data Analysis

All the data was subjected to analysis of variance (ANOVA) using computer software R version 4.2.2 packages (R Core Team, 2022).

All factors from both data groups were considered to be fixed. Weed assessment was performed three times (at 45 DAE, 55 DAE, and 15 days before harvest). A repeated-measurement mixed model was used during weed data analysis to account for a correlation among the assessments from the same plot recorded in different times. Model assumptions for the factorial analysis were that the data were normally distributed and that the errors were independent with homogeneous variances. When ANOVA showed significant differences, the

mean separation test was carried out using the Least Significant Difference test at a 5% level of significance (Steel *et al.*, 1997; Gomez and Gomez, 1984).

### **3.7. Cost Benefit Analysis**

A cost-benefit analysis for proposed management practices that included both herbicide and cultural (hand weeding) strategies was determined using the (Program *et al.*, 1988) process. During cost benefit analysis, total production input cost, gross revenue; marginal revenue and benefit ratio are considered. Total input cost (additional costs for weeding and experimental management) was calculated by adding all costs (variable + fixed input costs) incurred during the study. Plowing and fertilizer costs, as well as planting and harvesting wages, were considered fixed production costs. For knapsack spraying and manual weeding, herbicides and labor are considered as variable production costs.

The total income is determined by multiplying the market supported price and grain production (Daramola *et al.*, 2019). Marginal revenue is calculated by subtracting total variable costs from total revenue. In addition to; the benefit cost ratio is calculated as the ratio of marginal revenue (numerical) to total variable cost (denominator) (Daramola *et al.*, 2019).

## 4. RESULT AND DISCUSSION

### 4.1. Weed Parameters

#### 4.1.1. Weed Community

The field experiment conducted in this study identified a total of 29 weed species that strongly compete with tef (*Eragrostis tef*). These weed species belong to 13 different families, with *Poaceae* (grass family) being the most abundant, represented by 11 species. The next most abundant families were *Compositae* (5 species), *Commelinaceae* (3 species), *Cyperaceae* (3 species), *Leguminosae* (2 species), *Polygonaceae* (2 species), and *Solanaceae* (2 species). Other families, including *Convolvulaceae*, *Papaveraceae*, *Chenopodiaceae*, *Amaranthaceae*, *Plantaginaceae*, and *Araliaceae*, one species each

Table 3. Weeds species in research site

weed species	Local Name	Common Name	Family	life form	m <sup>-2</sup>
<i>Bromus Pectinatus</i>	Gicha	Brome grass	<i>Poaceae</i>	Annual	2
<i>Avena fatua</i>	Sinar	Wild oat	<i>Poaceae</i>	Annual	2
<i>Snowdonia Polystachya</i>	Muja	Tufted grass	<i>Poaceae</i>	Annual	1
<i>Cynodon dactylon</i>	Sardo	Bermuda grass	<i>Poaceae</i>	Perennial	5
<i>Digitaria Abyssinica</i>	Warat	Blue couch grass	<i>Poaceae</i>	Annual	4
<i>Echinochloa spp</i>	Daho	Barnyard grass	<i>Poaceae</i>	Annual	41
<i>Eleusine indica</i>	Akirma	Finger millet	<i>Poaceae</i>	Annual	5
<i>Paspalum dilatatum</i>	-	Dallisgrass	<i>Poaceae</i>	Perennial	10
<i>Phalaris paradoxa</i>	Asendabo	Canary grass	<i>Poaceae</i>	Annual	12
<i>Setaria pumila</i>	Y. sindedo	Foxtail grass	<i>Poaceae</i>	Annual	14
<i>Commelina benghalensis</i>	Wuhaankur	Spiderwort	<i>Commelinaceae</i>	Annual	39
<i>Launaea cornuta</i>	Watate	Wild lettuce	<i>Compositae</i>	Perennial	5
<i>Xanthium Strumarium</i>	Yemognfikir	Cocklebur	<i>Compositae</i>	Perennial	6
<i>Galinsoga Parviflora</i>	Abadabo	Quick weed	<i>Compositae</i>	Annual	4
<i>Chenopodium spp</i>	Amedmado	Goosefoot	<i>Chenopodiaceae</i>	Annual	2
<i>Bidens Pilosa</i>	Chegogit	Spanish needle	<i>Compositae</i>	Annual	22
<i>Cyperus species</i>	Engicha	Nut grass	<i>Cyperaceae</i>	Perennial	45
<i>Hydrocotyle Leucocephala</i>	-	Pennywort	<i>Araliaceae</i>	Perennial	10
<i>Polygonum Nepalense</i>	Yetija siga	Nepalese smart	<i>Polygonaceae</i>	Annual	8
<i>Rumex Abyssinicus</i>	Meq Meqo	Dock	<i>Polygonaceae</i>	Perennial	4

<i>Amaranthus Spinosus</i>	Aluma	Spiny pigweed	<i>Amaranthaceae</i>	Annual	6
<i>Plantago Lanceolata</i>	Kortobi	Leaf plantain	<i>Plantaginaceae</i>	Perennial	5
<i>Trifolium medium</i>	Sidissa	Clover	<i>Leguminosae</i>	Annual	8
<i>Guizotia Scarba</i>	Mech	Sun flecks	<i>Compositae</i>	Annual	9
<i>Penisetum Clandestinm</i>	Kukuye	Creeping grass	<i>Poaceae</i>	Perennial	8
<i>Convolvulus arvensis</i>	Timilmil	Field bindweed	<i>Convolvulaceae</i>	Perennial	6
<i>Argemone mexicana</i>	Nechlebash	Mexican poppy	<i>Papaveraceae</i>	Annual	5
<i>Datura stramonium</i>	Atsefaris	Jimson weed	<i>Solanaceae</i>	Perennial	2
<i>Solanum nigrum</i>	Tikur Awitt	Nightshade	<i>Solanaceae</i>	Annual	5

Note: Broad leaved weeds (52.2%), grasses (32.5%), and sedges (15.3%)

Among the weed species, those belonging to the Poaceae family, such as *Echinochloa* spp (41 individuals), and *Commelina Benghalensis* (39 individuals) from the Commelinaceae family, were the most prevalent. *Biden Pilosa* (22 individuals) from the Composite family and *Cyperus* spp (45 individuals) from the Cyperaceae family were also present in relatively high numbers. Additionally, *hydrocotyle Leucocephala* (10 individuals) from the Araliaceae family had a noticeable presence.

When classified according to their life cycle, the identified tef field weeds comprised 18 annual species and 11 perennial species. Broadleaved weed species were the dominant group, accounting for 52.2% of the total weed population in the experimental field, followed by grass weed species at 32.5%, and other weed species at 15.3% (Table-2).

The occurrence of a greater number of weed species in the experimental field can be attributed to factors such as poor weed control practices and favorable environmental conditions. These conditions include the nature of the crop, cultural practices, cropping system, soil type, moisture availability, and the history of previous crop growth at the site. Negassa Dechassa *et al.*, (2022) have previously reported that the occurrence of weed species in a cropped field is influenced by its history and agronomic practices, which are likely contributing factors to the variation in weed population observed in this study.

#### 4.1.2. Effect of weed management and varieties of tef on WD

Average weed density varied from 7.65 to 46.9 per square meter (Table 4) depending on weed management practices and varieties used in all field experiments. Weed density had a significant effect on weed management practices and variety.

##### 4.1.2.1. Effect of weed management on weed density

At 45 DAE, weed density significantly higher ( $64.16 \text{ m}^{-2}$ ) for broad leaved weeds, ( $137.55 \text{ m}^{-2}$ ) for grass weeds, and ( $37.61 \text{ m}^{-2}$ ) for sedge weeds recorded at weedy check plots and lower weed density ( $0.0 \text{ m}^{-2}$ ) from weed free plots. Similar results were observed by Thapa and Jha (2002) he reported that the highest weed density and dry weight of weed was recorded in weedy plots. Chemical weeding was added  $0.3 \text{ l ha}^{-1}$  at 31 DAE by one hand weeding at 41 DAE. Minimum weed density was one hand weeding ( $14.44 \text{ m}^{-2}$ ) for grasses and ( $7.18 \text{ m}^{-2}$ ) for sedge weeds; Chemical weeding ( $26.88 \text{ m}^{-2}$ ) for large leaf weeds.

At 55 DAE, the highest weed density was recorded in the weed check treatment ( $69.44 \text{ m}^{-2}$ ) for broadleaf weeds, ( $142.32 \text{ m}^{-2}$ ) for grass weeds, and ( $27.37 \text{ m}^{-2}$ ) for the lowest weeds. Weed free treatments were added with chemical weeding  $0.3 \text{ l ha}^{-1}$  at 31 DAE and one hand weeding at 41 DAE. While minimum weed density one hand weeding ( $23.78 \text{ m}^{-2}$ ) for grass, and ( $15.07 \text{ m}^{-2}$ ) chemical weeding at 31 DAE ( $6.73 \text{ m}^{-2}$ ) for weed and ( $13.88 \text{ m}^{-2}$ ) for broadleaf weed. The weedy check plot harvested ( $74.4 \text{ m}^{-2}$ ) for broad leaved weeds, ( $18.54 \text{ m}^{-2}$ ) for grass weeds, and ( $27.12 \text{ m}^{-2}$ ) for sedge weeds recorded the highest weed density and the lowest weed density was recorded at weed free plots ( $0.0 \text{ m}^{-2}$ ) followed by chemical weeding  $0.3 \text{ l ha}^{-1}$  at 31 DAE supplemented by one hand weeding at 41 DAE produced less weed density one hand weeding ( $4.74 \text{ m}^{-2}$ ) for broad leaved weeds and ( $15.07 \text{ m}^{-2}$ ) and ( $2.54 \text{ m}^{-2}$ ) for sedges and chemical weeding at 31 DAE ( $18.54 \text{ m}^{-2}$ ) for grass weeds.

Post-emergence herbicide has been found to be very effective in reducing the density of weed groups and suppressing them until harvest. Hand weeding and post emergence herbicide had the highest weed control in the field experiment. Low weed density resulted with hand weeding and post emergence herbicide weeding in higher crop number, straw biomass, panicle count, tiller number and grain yield and crop competition reduced for space, light, moisture and nutrients, resulting in stronger plant growth and production (Kolleh, 2016)

#### 4.1.2.2. Effect of variety on weed density

The density of weed was significantly influenced by varieties from 45 DAE to harvest stages of the crop. The Quncho variety recorded the highest weed density ( $34.88 \text{ m}^{-2}$ ) for broad leaved weeds; the variety Dagim ( $60.27 \text{ m}^{-2}$ ) for grass weeds and Quncho variety ( $19.46 \text{ m}^{-2}$ ). Therefore, according to the results mentioned above, it can be stated that the weed density was significantly reduced by using Kora variety at 45 DAE.

At 55 DAE the density of weed was the variety Quncho recorded significantly higher weed density ( $32.11 \text{ m}^{-2}$ ) for broad leaved weeds; the variety Quncho ( $57.72 \text{ m}^{-2}$ ) for grass weeds and Quncho variety ( $16.25 \text{ m}^{-2}$ ). Therefore, according to the results mentioned above, it can be stated that the amount of weeds has been significantly reduced by preparing Kora variety and sedge weeds at 55 DAE.

In harvest stage there was a density of weeds, the variety Quncho recorded significantly the maximum weed density ( $13.04 \text{ m}^{-2}$ ) for broad leaved weeds; the variety Quncho ( $60.87 \text{ m}^{-2}$ ) for grass weeds and Quncho variety ( $16.25 \text{ m}^{-2}$ ) thus, according to the above result during the harvest season, the amount of weeds is greatly reduced by using the Kora variety (Table 4).

Crops with different growth habits, such as different root systems, plant heights, seeding capacity, and foliar architecture, have the potential to compete with weeds. In addition to providing tall plants, these varieties also had the ability to dominate their strong standing tillers (Vander *et al.*, 2017).

Table 4. Weed density influenced by weed management and varieties of tef

Treatments	Weed density (m <sup>-2</sup> )								
	45DAE			55DAE			at harvest		
Varieties	Broadleaved	Grass	Sedges	Broadleaved	Grass	Sedges	Broadleaved	Grass	Sedges
Quncho	34.88 <sup>a</sup>	56.55 <sup>b</sup>	19.46 <sup>a</sup>	32.11 <sup>a</sup>	57.72 <sup>a</sup>	16.25 <sup>a</sup>	28.78 <sup>a</sup>	60.87 <sup>a</sup>	13.04 <sup>a</sup>
Kora	18.44 <sup>c</sup>	23.72 <sup>c</sup>	4.34 <sup>c</sup>	26.61 <sup>b</sup>	26.68 <sup>c</sup>	3.32 <sup>c</sup>	3.82 <sup>c</sup>	30.18 <sup>c</sup>	2.29 <sup>c</sup>
Dagim	24.82 <sup>b</sup>	60.27 <sup>a</sup>	11.85 <sup>b</sup>	10.83 <sup>c</sup>	53.62 <sup>b</sup>	9.76 <sup>b</sup>	20.04 <sup>b</sup>	48.05 <sup>b</sup>	7.63 <sup>b</sup>
LSD	0.65	0.54	0.5	0.49	1.31	0.4	0.59	0.6	0.39
<b>Weeding Management practices</b>									
CW	22.02 <sup>c</sup>	26.88 <sup>e</sup>	9.85 <sup>d</sup>	13.88 <sup>d</sup>	26.34 <sup>c</sup>	6.73 <sup>d</sup>	7.36 <sup>c</sup>	18.54 <sup>e</sup>	3.58 <sup>d</sup>
CW + one HW at 41 DAE	14.44 <sup>d</sup>	34.44 <sup>c</sup>	7.18 <sup>e</sup>	9.0 <sup>e</sup>	23.78 <sup>d</sup>	4.88 <sup>e</sup>	4.74 <sup>e</sup>	63.33 <sup>b</sup>	2.54 <sup>e</sup>
One HW	34.05 <sup>b</sup>	50.66 <sup>b</sup>	15.07 <sup>b</sup>	23.44 <sup>b</sup>	57.18 <sup>b</sup>	11.44 <sup>b</sup>	13.11 <sup>b</sup>	28.12 <sup>c</sup>	7.83 <sup>b</sup>
Two HW at 31 DAE and 41 DAE	21.61 <sup>c</sup>	31.55 <sup>d</sup>	11.58 <sup>c</sup>	15.33 <sup>c</sup>	26.42 <sup>c</sup>	8.23 <sup>c</sup>	5.67 <sup>d</sup>	21.08 <sup>d</sup>	4.86 <sup>c</sup>
Weed free	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>e</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>
Weedy check	64.16 <sup>a</sup>	137.55 <sup>a</sup>	37.61 <sup>a</sup>	69.44 <sup>a</sup>	142.32 <sup>a</sup>	27.37 <sup>a</sup>	74.4 <sup>a</sup>	147.13 <sup>a</sup>	27.12 <sup>a</sup>
LSD	0.93	0.76	0.71	0.7	1.85	0.57	0.83	0.85	0.55
CV	3.73	1.71	6.3	3.37	4.21	6.12	4.96	1.92	7.53
Grand mean	26.1	46.9	11.9	21.9	46	9.77	17.6	46.4	7.65

Average of three replications. Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: DAE (days after crop emergence), HW (hand weeding), CW (chemical weeding)

#### 4.1.2.3. Interaction effect of WM and varieties of tef on WD at 45 DAE

Weed density at 45 days after crop emergence varied with different tef cultivars and weeding methods (Table 5). For broadleaved weeds, the lowest density was recorded in the weed-free plots ( $0.0 \text{ m}^{-2}$ ), followed by the combination of the Kora variety with Pallas 45 OD ( $0.3 \text{ l ha}^{-1}$ ) at 31 DAE, supplemented with one hand weeding, which had a density of  $11.4 \text{ plants per m}^2$ . As the application rate of Pallas 45 OD increased, the amount of broadleaf weeds decreased. However, the weedy check plots with the Quncho variety had the highest density of broadleaved weeds ( $77.3 \text{ plants per m}^2$ ) compared to other weeding methods.

The interaction effect of the Dagim variety with no weeding method resulted in the highest grass weed density, with  $213 \text{ plants per square meter}$ . This was followed by the unwedded Quncho variety with  $156 \text{ plants per m}^2$ . The lowest grass weed density was observed in the weed-free plots of all varieties. The interaction effect of the Kora variety with the application of Pallas 45 OD ( $0.4 \text{ l ha}^{-1}$ ) at 31 days after emergence (DAE) resulted in a relatively low grass weed density of  $16.3 \text{ plants per m}^2$ . Additionally, the combination of the Kora variety with a lower chemical rate of  $0.3 \text{ l ha}^{-1}$  and supplemented with one hand weeding led to reduced monocot weed density.

Sedges weed density was lowest in the weed-free plots, followed by the interaction effect of the Kora variety with Pallas 45 OD ( $0.3 \text{ l ha}^{-1}$ ) at 31 DAE, supplemented with one hand weeding ( $1.5 \text{ m}^{-2}$ ). The highest density of sedges was recorded in the weedy check plots with the Quncho variety ( $48.2 \text{ m}^{-2}$ ), followed by the Dagim variety ( $25.6 \text{ m}^{-2}$ ). Increasing the application rate of the chemical and implementing two hands weeding at 31 DAE and 41 DAE significantly improved the control of sedges compared to the unwedded plots. The combination of tef varieties and weeding methods had a significant effect on the density of dicot, monocot, and sedge weeds. The unwedded plots had the highest average density of weed shoots per square meter.

Based on the above study, it can be concluded that weed density decreases from 45 days after crop emergence (DAE) to the harvest stage. The interaction effect of the weeding method using Pallas 45 OD ( $0.3 \text{ l ha}^{-1}$ ) at 31 days after crop emergence, supplemented with one hand weeding at 41 DAE and the Kora variety, greatly decreased weed density during crop growth. The presence of the Kora variety facilitated better competition for development inputs, crop

growth, early cover, and light interception, leading to successful weed control. This result was reported by Habtamu Gebrehiwot *et al.*, (2020) who found that Kora was more competitive than weeds, while other cultivars were less competitive. Similarly, Zahara Mohammed *et al.*, (2016) reported a significant reduction in weed density when applying the post-emergence herbicide Pallas.

Table 5. Interaction effect of WM and varieties of tef on WD at 45 DAE

Weeding Methods	Broad leaved			Grasses			Sedges		
	Quncho	Kora	Dagim	Quncho	Kora	Dagim	Quncho	Kora	Dagim
<b>CW</b>	33.8 <sup>d</sup>	14.26 <sup>h</sup>	18 <sup>fg</sup>	42 <sup>f</sup>	16.3 <sup>m</sup>	22.3 <sup>k</sup>	15.56 <sup>e</sup>	5.5 <sup>h</sup>	8.5 <sup>g</sup>
<b>CW + 1 HW</b>	17.33 <sup>g</sup>	11.4 <sup>i</sup>	14.6 <sup>h</sup>	44.33 <sup>e</sup>	25.66 <sup>j</sup>	33.3 <sup>i</sup>	13.9 <sup>f</sup>	1.5 <sup>j</sup>	6.2 <sup>h</sup>
<b>One HW</b>	51 <sup>c</sup>	17.5 <sup>g</sup>	33.66 <sup>d</sup>	60.0 <sup>c</sup>	39.0 <sup>g</sup>	53.0 <sup>d</sup>	21.16 <sup>c</sup>	5.9 <sup>h</sup>	18.1 <sup>d</sup>
<b>Two HW</b>	29.83 <sup>e</sup>	15.5 <sup>h</sup>	19.5 <sup>f</sup>	37 <sup>h</sup>	17.66 <sup>l</sup>	40.0 <sup>g</sup>	17.9 <sup>d</sup>	4.16 <sup>i</sup>	12.6 <sup>f</sup>
<b>Weed free</b>	0.0 <sup>j</sup>	0.0 <sup>j</sup>	0.0 <sup>j</sup>	0.0 <sup>n</sup>	0.0 <sup>n</sup>	0.0 <sup>n</sup>	0.0 <sup>k</sup>	0.0 <sup>k</sup>	0.0 <sup>k</sup>
<b>Weedy check</b>	77.33 <sup>a</sup>	52 <sup>c</sup>	63.16 <sup>b</sup>	156 <sup>b</sup>	43.66 <sup>e</sup>	213 <sup>a</sup>	48.2 <sup>a</sup>	9 <sup>g</sup>	25.6 <sup>b</sup>
LSD (0.05)		1.61			1.33			1.24	
CV (%)		3.73			1.71			6.3	

Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: DAE (days after crop emergence), HW (hand weeding), CW (chemical weeding), CV = coefficient of variation.

#### 4.1.2.4. Interaction effect of WM and varieties of tef on WD at 55 DAE

At 55 days after crop emergence (DAE), the density of broadleaved weeds was lowest in the weed-free treatment. The interaction results also showed that the combination of the Kora variety with a low rate of Pallas 45 OD ( $0.3 \text{ l ha}^{-1}$ ) at 31 DAE, supplemented with one hand weeding at 41 DAE, was as effective as the complete weed-free treatment in reducing the density of broadleaved weeds. Similarly, an increase in the application rate of Pallas 45 OD ( $0.4 \text{ l ha}^{-1}$ ) at 31 DAE, combined with the Kora variety, resulted in a significant reduction in broadleaved weed density. Additionally, the interaction effect of two hand-weeding at 31 and 41 DAE also proved to be significantly better in reducing the density of broadleaved weeds (Table 6). It is likely that late emerging weeds invaded the sites after hand weeding, contributing to the remaining weed density. The highest weed density was observed in the weedy check plots with the Quncho variety (96 plants per  $\text{m}^2$ ).

At 55 DAE, the study found that the lowest density of grass weeds was observed in the weed-free treatment. The interaction effect of applying Pallas 45 OD at  $0.3 \text{ l ha}^{-1}$  at 31 DAE, supplemented with one hand weeding at 41 DAE, and the Kora variety resulted in the lowest grass weed density (16.9 plants per  $\text{m}^2$ ), which was statistically comparable to the interaction effect of two hand-weeding at 31 and 41 DAE. However, late-emergent weeds that were not effectively controlled by the herbicide could grow from deep soil depths in areas without herbicide interference during germination, leading to their higher seed rates. Consequently, the highest weed density was recorded in the weedy check plots with the Dagim variety (181.7 plants per  $\text{m}^2$ ). The density of sedges was lowest in the complete weed-free treatments, followed by the interaction effect of applying Pallas 45 OD at  $0.3 \text{ l ha}^{-1}$  at 31 DAE, supplemented with one hand weeding at 41 DAE, and the Dagim variety (1.4 plants per  $\text{m}^2$ ). A lower rate of Pallas 45 OD resulted in the lowest sedge density when combined with one-hand weeding. The weedy check plots had a significantly higher density of sedges weed recorded (48.6 plants per  $\text{m}^2$ ) compared to other weed management practices.

Table 6. Interaction effect of WM and varieties of tef on WD at 55 DAE

weeding methods	Broad leaved			Grasses			Sedges		
	quncho	kora	Dagim	Quncho	kora	Dagim	quncho	Kora	Dagim
<b>CW</b>	23.33 <sup>f</sup>	7.0 <sup>ik</sup>	11.3 <sup>h</sup>	37.0 <sup>e</sup>	17.4 <sup>h</sup>	24.6 <sup>g</sup>	10.56 <sup>e</sup>	6.9 <sup>g</sup>	2.46 <sup>j</sup>
<b>CW + 1HW</b>	12.0 <sup>gh</sup>	6.0 <sup>k</sup>	9.0 <sup>i</sup>	32.36 <sup>f</sup>	16.9 <sup>h</sup>	22.1 <sup>g</sup>	5.3 <sup>h</sup>	5.75 <sup>h</sup>	1.4 <sup>k</sup>
<b>One HW</b>	36.33 <sup>c</sup>	11 <sup>h</sup>	23 <sup>f</sup>	72.7 <sup>c</sup>	36.3 <sup>e</sup>	62.6 <sup>d</sup>	12.86 <sup>d</sup>	9.2 <sup>f</sup>	3.8 <sup>i</sup>
<b>Two HW</b>	25.0 <sup>e</sup>	8 <sup>ij</sup>	13 <sup>g</sup>	32.7 <sup>f</sup>	15.9 <sup>h</sup>	30.7 <sup>f</sup>	12.93 <sup>d</sup>	9.3 <sup>f</sup>	4.0 <sup>i</sup>
<b>Weed free</b>	0.0 <sup>l</sup>	0.0 <sup>l</sup>	0.0 <sup>l</sup>	0.0 <sup>i</sup>	0.0 <sup>i</sup>	0.0 <sup>i</sup>	0.0 <sup>l</sup>	0.0 <sup>l</sup>	0.0 <sup>l</sup>
<b>Weedy check</b>	96 <sup>a</sup>	33 <sup>d</sup>	79.33 <sup>b</sup>	171.5 <sup>b</sup>	73.7 <sup>c</sup>	181.7 <sup>a</sup>	48.6 <sup>a</sup>	16.66 <sup>c</sup>	26.63 <sup>b</sup>
LSD (0.05)		1.22			3.21			0.99	
CV (%)		3.37			4.21			6.12	

Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: DAE (days after crop emergence), HW (hand weeding), CW (chemical weeding), CV = coefficient of variation.

#### 4.1.2.5. Interaction effect of WM and varieties of tef on WD at harvest

Regarding broadleaved weeds, the density at crop harvest also exhibited significant differences among the treatments (Table 7). The lowest weed density was observed in the weed-free treatment, followed by the interaction effect of the Kora variety with two hands weeding at 31 DAE and 41 DAE (0.7 plants per m<sup>2</sup>) statistically comparable to the interaction effect of applying Pallas 45 OD at 0.4 l ha<sup>-1</sup> at 31 DAE, and the Kora variety. The highest weed density was recorded in the weedy check plots with the Quncho variety (114 plants m<sup>-2</sup>). In this experiment, weeding methods had a greater effect on dicots compared to monocots, likely because dicots are easily removed during weeding, particularly in their early stages of growth. Weeding significantly reduced the density of dicots specifically and the overall cover of all weeds species.

The data for grasses density at crop harvest also showed significant differences among the treatments (Table 7). The lowest weed density was observed in the weed-free treatment, followed by the interaction effect of the Dagim variety with Pallas 0.3 l ha<sup>-1</sup>, supplemented with one hand weeding at 41 DAE (11.5 plants per m<sup>2</sup>). The highest weed density was recorded in the weedy check plots with the Quncho variety (187 plants per m<sup>2</sup>).

Generally, the labor provided by farmers' families is insufficient to prevent the weeds that reach the tef fields, necessitating regular removal as soon as they appear. Manual weeding of tef fields is time-consuming and often delayed, resulting in weed growth that hampers the

growth of crop plants. This task is especially challenging due to rainfall during the main crop season. Niguse Hundessa et al. (2023) addressed this issue and reported that the integrated effects of herbicide application and hand weeding significantly improved tef production and reduced weed infestation.

At crop harvest, the density of sedges weeds showed due to the interaction effect of two hands weeding at 31 and 41 DAE, resulting in a density of (0.8) plants per m<sup>2</sup>, statistically par with the application of Pallas 45 OD at 0.3 l ha<sup>-1</sup> at 31 DAE, supplemented with one hand weeding at 41 DAE, and the Kora variety. The management practices for weed control had an impact on sedges weed density, primarily due to late-emerging weeds that infested the plots after one hand-weeding, resulting in statistically comparable density to the complete weed-free treatment and significantly lower density compared to other weed management practices (Table-7). Hand weeding removed the emerged weeds, which were further suppressed by the crop canopy, leading to decreased weed density at crop harvest. The highest weed density was recorded in the weedy check plots with the Quncho variety (49 plants per m<sup>2</sup>). The weedy check plots resulted in significantly higher weed density compared to all other weed management practices, likely due to uncontrolled growth of early and late-emerging weeds.

Table 7. Interaction effect of weed management and varieties of tef on WD at harvest

weeding methods	Broad leaved weeds			Grasses			Sedges		
	Quncho	Kora	Dagim	Quncho	Kora	Dagim	Quncho	Kora	Dagim
<b>CW</b>	16.0 <sup>d</sup>	1.23 <sup>ij</sup>	4.86 <sup>h</sup>	72.0 <sup>e</sup>	33.5 <sup>g</sup>	17.33 <sup>j</sup>	5.56 <sup>ef</sup>	2.2 <sup>hi</sup>	3.0 <sup>h</sup>
<b>CW + 1HW</b>	8.16 <sup>g</sup>	1.96 <sup>i</sup>	4.1 <sup>h</sup>	18.36 <sup>j</sup>	27.96 <sup>h</sup>	11.5 <sup>l</sup>	4.6 <sup>g</sup>	1.3 <sup>ij</sup>	1.73 <sup>ij</sup>
<b>One HW</b>	21.9 <sup>c</sup>	5.43 <sup>h</sup>	12.0 <sup>f</sup>	150.5 <sup>b</sup>	27.0 <sup>h</sup>	13.83 <sup>k</sup>	11.16 <sup>c</sup>	4.7 <sup>fg</sup>	7.63 <sup>d</sup>
<b>Two HW</b>	12.33 <sup>ef</sup>	0.7 <sup>ij</sup>	4.0 <sup>h</sup>	84.5 <sup>d</sup>	26.8 <sup>h</sup>	39.0 <sup>f</sup>	7.93 <sup>d</sup>	0.8 <sup>jk</sup>	5.86 <sup>e</sup>
<b>Weed free</b>	0.0 <sup>j</sup>	0.0 <sup>j</sup>	0.0 <sup>j</sup>	0.0 <sup>m</sup>	0.0 <sup>m</sup>	0.0 <sup>m</sup>	0.0 <sup>k</sup>	0.0 <sup>k</sup>	0.0 <sup>k</sup>
<b>Weedy check</b>	114 <sup>a</sup>	13.6 <sup>e</sup>	95.3 <sup>b</sup>	187 <sup>a</sup>	103.9 <sup>c</sup>	150.5 <sup>b</sup>	49 <sup>a</sup>	4.76 <sup>fg</sup>	27.6 <sup>b</sup>
LSD (0.05)		1.44			1.48			0.95	
CV (%)		4.96			1.92			7.53	

Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: DAE (days after crop emergence), HW (hand weeding), CW (chemical weeding), CV = coefficient of variation

### 4.1.3. Effect of Weed Management and Varieties of Tef on WDW

Average weed dry weight ranged from 13.0 to 45.1 grams per square meter (Table 8) depending on weed management practices and the varieties in all treatments used. Weed dry weight has a significant impact on weed management methods.

#### 4.1.3.1. Effect of weed management on weed dry weight

At 45 DAE, weed dry weight was significantly higher ( $139.35 \text{ m}^{-2}$ ) for broadleaf weeds, ( $180.83 \text{ m}^{-2}$ ) for grass weeds, and ( $77.48 \text{ m}^{-2}$ ) for sedge weeds recorded at weedy check plots and lower weed dry weight ( $0.0 \text{ m}^{-2}$ ) from weed free plots. Chemical weeding at  $0.3 \text{ l ha}^{-1}$  at 31 DAE added to one hand weeding at 41 DAE resulted in less weed dry weight one hand weeding ( $6.15 \text{ m}^{-2}$ ) for grasses and ( $21.39 \text{ m}^{-2}$ ) for sedge weeds.

At 55 DAE, the highest weed dry weight was recorded in weed check treatment ( $77.48 \text{ m}^{-2}$ ) for broadleaf weed, ( $166.24 \text{ m}^{-2}$ ) for grass weed and ( $58.11 \text{ m}^{-2}$ ) for sedge weed while the lowest was recorded at. Weed free treatments with chemical weeding  $0.3 \text{ l ha}^{-1}$  at 31 DAE per hand weeding at 41 DAE added minimum weed dry weight per hand weeding ( $21.4 \text{ m}^{-2}$ ) for broadleaf weeds and ( $4.55 \text{ m}^{-2}$ ) for grasses and ( $11.12 \text{ m}^{-2}$ ) for sedge weeds.

At harvesting stage, weedy check plot ( $126.72 \text{ m}^{-2}$ ) for broad leaved weeds, ( $145.6 \text{ m}^{-2}$ ) for grass weeds, and ( $38.72 \text{ m}^{-2}$ ) for sedge weeds recorded the highest weed dry weight and the lowest weed density was recorded at weed free plots ( $0.0 \text{ m}^{-2}$ ) followed by chemical weeding  $0.3 \text{ l ha}^{-1}$  at 31 DAE supplemented by one hand weeding at 41 DAE produced less weed dry weight one hand weeding ( $3.7 \text{ m}^{-2}$ ) for broad leaved weeds and ( $2.7 \text{ m}^{-2}$ ) and  $0.75 \text{ m}^{-2}$  for sedges.

Total weed free, post-emergence herbicide (Pallas) and one-hand weeding reduced weed dry biomass, weed check plots recorded high weed dry biomass. This is due to the effectiveness of manual weeding and post-treatments to prevent weed growth. This finding is similar to Kolléh, 2016

#### 4.1.3.2. Effect of variety on weed dry weight

Weed dry weight had a significant effect on the growth sedge of the tef crop. The variety Quncho recorded significantly the maximum weed dry weight ( $37.33 \text{ m}^{-2}$ ) for broad leaved weeds, ( $63.22 \text{ m}^{-2}$ ) for grass weeds and ( $40.55 \text{ m}^{-2}$ ). Thus, on the basis of above results, it can be stated that weed dry weight was drastically reduced by using Kora variety at 45 DAE.

At 55 DAE weed weight Quncho recorded the highest weed dry weight ( $40.55 \text{ m}^{-2}$ ) for broadleaf weed, ( $60.67 \text{ m}^{-2}$ ) for grass weeds and ( $30.37 \text{ m}^{-2}$ ). Thus, on the basis of above results, it can be stated that weed dry weight was drastically reduced by using Kora variety at 55 DAE for all weeds.

At harvest stage the dry weight of weed was the variety Quncho recorded significantly the maximum weed dry weight ( $44.38 \text{ m}^{-2}$ ) for broad leaved weeds, ( $57.81 \text{ m}^{-2}$ ) for grass weeds and ( $20.2 \text{ m}^{-2}$ ) for sedges. Therefore, on the basis of above results, it can be stated that weed dry weight was drastically reduced by using Kora variety at harvest. Crops with different growth habits such as different root systems, plant heights, tillering potential, and foliar architecture have different competitive potential against weeds (Ali *et al.*, 2017).

Table 8. Weed dry weight influenced by weed management and varieties of tef

Treatments	Weed Dry Weight g m <sup>-2</sup>								
	45DAE			55DAE			at harvest		
Varieties	Broadleaved	Grass	Sedges	Broadleaved	Grass	Sedges	Broadleaved	Grass	Sedges
Quncho	37.33 <sup>a</sup>	63.22 <sup>a</sup>	40.55 <sup>a</sup>	40.55 <sup>a</sup>	60.67 <sup>a</sup>	30.37 <sup>a</sup>	44.38 <sup>a</sup>	57.81 <sup>a</sup>	20.2 <sup>a</sup>
Kora	24.26 <sup>c</sup>	26.47 <sup>c</sup>	19.35 <sup>c</sup>	19.35 <sup>c</sup>	23.8 <sup>c</sup>	11.95 <sup>c</sup>	20.95 <sup>c</sup>	21.7 <sup>c</sup>	4.5 <sup>c</sup>
Dagim	32.89 <sup>b</sup>	45.63 <sup>b</sup>	32.97 <sup>b</sup>	32.97 <sup>b</sup>	40.98 <sup>b</sup>	23.63 <sup>b</sup>	27.61 <sup>b</sup>	38.32 <sup>b</sup>	14.3 <sup>b</sup>
LSD	0.53	0.88	0.66	0.66	0.45	0.55	0.64	0.52	0.69
<b>Weeding Management practices</b>									
CW	6.12 <sup>d</sup>	10.78 <sup>d</sup>	24.14 <sup>c</sup>	24.14 <sup>c</sup>	11.37 <sup>d</sup>	17.1 <sup>c</sup>	8.55 <sup>c</sup>	12 <sup>d</sup>	10.07 <sup>c</sup>
CW + one HW at 41 DAE	2.93 <sup>e</sup>	6.15 <sup>e</sup>	21.39 <sup>e</sup>	21.4 <sup>e</sup>	4.55 <sup>e</sup>	11.12 <sup>d</sup>	3.7 <sup>e</sup>	2.7 <sup>e</sup>	0.75 <sup>d</sup>
One HW	29.28 <sup>b</sup>	54.83 <sup>b</sup>	39.88 <sup>b</sup>	39.88 <sup>b</sup>	52.42 <sup>b</sup>	29.23 <sup>b</sup>	40.1 <sup>b</sup>	54.47 <sup>b</sup>	18.54 <sup>b</sup>
Two HW at 31 DAE and 41 DAE	11.26 <sup>c</sup>	18.07 <sup>c</sup>	22.86 <sup>d</sup>	22.85 <sup>d</sup>	19.32 <sup>c</sup>	16.36 <sup>c</sup>	6.84 <sup>d</sup>	20.88 <sup>c</sup>	9.9 <sup>c</sup>
Weed free	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>e</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>d</sup>
Weedy check	139.35 <sup>a</sup>	180.83 <sup>a</sup>	77.48 <sup>a</sup>	77.48 <sup>a</sup>	166.24 <sup>a</sup>	58.11 <sup>a</sup>	126.72 <sup>a</sup>	145.6 <sup>a</sup>	38.72 <sup>a</sup>
LSD	0.76	1.24	0.94	0.94	0.64	0.77	0.91	0.73	0.98
CV	2.52	2.88	3.19	3.18	1.61	3.7	3	1.95	7.89
Grand mean	31.5	45.1	31	31	41.8	22	31	39.3	13

Average of three replications. Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: DAE (days after crop emergence), HW (hand weeding), CW (chemical weeding)

#### 4.1.3.3. Interaction of WM and varieties of tef on WDW at 45 DAE

The influence of weed management practices on weed dry weight was highly significant, with significant main effects and interaction effects observed for above-ground dry biomass weight ( $P < 0.05$ ) (Appendix - 3). At 45 days after crop emergence (DAE), the completely weed-free treatments showed no dry biomass of broad-leaved weeds. The dry biomass decreased with the interaction of applying Pallas 45 OD at a rate of  $0.3 \text{ l ha}^{-1}$  at 31 days after crop emergence, supplemented with one hand weeding at 41 DAE and the Kora variety ( $0.8 \text{ g m}^{-2}$ ) (Table - 9). The improved high-yielding variety, Kora, exhibited a strong competitive response to weeds, resulting in a reduction in weed density and dry weight. This variety not only produced taller plants but also had the ability to dominate their space through strong-standing tillers.

The results were consistent with the application treatments, particularly the interaction effect of two hands weeding at 31 and 41 DAE, and the Kora variety, and statistically par with the interaction effect of chemical weeding at 31 DAE with the Quncho variety, as well as Pallas  $0.3 \text{ l ha}^{-1}$  at 31 DAE, supplemented with one hand weeding at 41 DAE and the Dagim variety. The highest dry biomass of broad-leaved weeds ( $166 \text{ g m}^{-2}$ ) (Table - 9) was observed in the interaction effect of the Quncho variety and the weedy check treatment. This can be attributed to the absence of weed control in the non-weed treatments, allowing weeds to proliferate and compete more vigorously with the crop plants, resulting in higher dry biomass production as they accumulate more nutrients. This finding aligns with the results reported by Getachew Mekonnen (2022), where the highest dry weight was observed in broad-leaved weeds in the weedy check treatments compared to the use of 2, 4-D amine salt at  $1.5 \text{ kg ha}^{-1}$ , Pyroxsulam at a rate of  $0.6 \text{ kg ha}^{-1}$ , and two hands weeding at 30 and 45 days after crop emergence.

The highest dry biomass of grasses ( $261 \text{ g m}^{-2}$ ) was observed in the interaction effect of the Quncho variety and the weedy check treatment. Conversely, the data showed minimal weed dry biomass of grasses in the weed-free treatment, followed by the integrated effect of Pallas at a rate of  $0.3 \text{ l ha}^{-1}$  at 31 DAE, supplemented with one hand weeding at 41 days after crop emergence and the Kora variety ( $4.4 \text{ g m}^{-2}$ ). The use of chemical application combined with hand weeding practices effectively suppressed weeds by giving the crop plants a competitive advantage through smothering effects resulting from fast canopy development and/or the ability of densely populated plants to draw limited resources at a faster rate. The highest dry biomass of sedges ( $115.2 \text{ g m}^{-2}$ ) was observed in the interaction effect of the Quncho variety

and the weedy treatments. The data also showed minimal weed dry biomass of sedges in the weed-free treatment, followed by the integrated effect of Pallas 45 OD at a rate of 0.4 l ha<sup>-1</sup> at 31 DAE and the Kora variety (13.6 g m<sup>-2</sup>).

Table 9. Interaction of WM and varieties of tef on WDW at 45 DAE

Weeding Methods	Broad leaved			Grasses			Sedges		
	Quncho	Kora	Dagim	Quncho	Kora	Dagim	Quncho	Kora	Dagim
<b>CW</b>	9.98 <sup>h</sup>	3.1 <sup>j</sup>	5.3 <sup>i</sup>	13.86 <sup>h</sup>	7.82 <sup>j</sup>	10.66 <sup>i</sup>	31.36 <sup>e</sup>	13.6 <sup>k</sup>	27.5 <sup>f</sup>
<b>CW + 1HW</b>	5.4 <sup>i</sup>	0.8 <sup>k</sup>	2.56 <sup>j</sup>	8.06 <sup>j</sup>	4.4 <sup>k</sup>	5.9 <sup>k</sup>	20.5 <sup>i</sup>	22.2 <sup>h</sup>	21.5 <sup>hi</sup>
<b>One HW</b>	25.65 <sup>f</sup>	28 <sup>e</sup>	34.3 <sup>d</sup>	78 <sup>d</sup>	36 <sup>f</sup>	50.3 <sup>e</sup>	50.96 <sup>c</sup>	28.7 <sup>f</sup>	40 <sup>d</sup>
<b>Two HW</b>	16.9 <sup>g</sup>	5.7 <sup>i</sup>	11.2 <sup>h</sup>	18.4 <sup>g</sup>	15 <sup>h</sup>	20.4 <sup>g</sup>	25.31 <sup>g</sup>	18.6 <sup>j</sup>	24.6 <sup>g</sup>
<b>Weed free</b>	0.0 <sup>k</sup>	0.0 <sup>k</sup>	0.0 <sup>k</sup>	0.0 <sup>l</sup>	0.0 <sup>l</sup>	0.0 <sup>l</sup>	0.0 <sup>l</sup>	0.0 <sup>l</sup>	0.0 <sup>l</sup>
<b>Weedy check</b>	166 <sup>a</sup>	108 <sup>c</sup>	144 <sup>b</sup>	261 <sup>a</sup>	95 <sup>c</sup>	187 <sup>b</sup>	115.2 <sup>a</sup>	33 <sup>e</sup>	84.3 <sup>b</sup>
LSD (0.05)	1.32			2.16			1.63		
CV (%)	2.52			2.88			3.19		

Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: HW (hand weeding), CW (chemical weeding), CV = coefficient of variation

#### 4.1.3.4. Interaction of WM and varieties of tef on WDW at 55 DAE

At 55 days after crop emergence (DAE), the results showed that the lowest dry biomass of broad-leaved weeds (0.0 g m<sup>-2</sup>) was recorded in the weed-free treatment. This was followed by the integration effect of Pallas at a rate of 0.3 l ha<sup>-1</sup> at 31 DAE, supplemented with one hand weeding at 41 DAE and the Kora variety (1.4gm<sup>-2</sup>) (Table - 10). The results also revealed that the interaction effect of weeds in plots treated with Pallas 45 OD at a rate of 0.4 l ha<sup>-1</sup> and the Kora variety was statistically par with the integration effect of Pallas at a rate of 0.3 l ha<sup>-1</sup> at 31 DAE, supplemented with one hand weeding at 41 DAE and the Dagim variety. Conversely, the maximum dry biomass (168.3 g m<sup>-2</sup>) was observed in the Quncho variety in the weedy check treatments.

At 55 DAE, the minimum dry biomass of grasses (3 g m<sup>-2</sup>) was registered with the integrated effect of Pallas at a rate of 0.3 l ha<sup>-1</sup> at 31 DAE, supplemented with one hand weeding at 41 days after crop emergence and the Kora variety. In contrast, the analysis of the data showed that the maximum dry biomass of grasses (228 g m<sup>-2</sup>) was recorded in Quncho variety in the weed check treatment. Similarly, the lowest dry biomass of sedges in the weed-free treatment

and followed by (7.7 g m<sup>-2</sup>) was recorded in the interaction effect of Pallas at a rate of 0.4 l ha<sup>-1</sup> at 31 DAE and the Kora variety, while the maximum dry biomass of sedges (84.6 g m<sup>-2</sup>) was obtained with the treatment of the weedy check and the Quncho variety.

The advantage of twice hand weeding over one hand weeding may be attributed to a reduced soil seed bank, as well as the fact that the weeds that emerged after the second hand weeding were shorter in growth compared to those that emerged after the first hand weeding. Hand weeding effectively controlled the emerging weeds, and those that emerged later might have failed to accumulate sufficient dry matter due to competition from the crop plants at 55 DAE. In non-weeded treatments, weeds are more abundant and compete with crops, leading to higher dry biomass production as they accumulate more nutrients. These findings are further supported by the research conducted by Getachew Mekonnen, (2022) which demonstrated better control of grasses and broad-leaved weeds through reduced weed competition and limited space availability for nutrient ions, water molecules, and light quantum, thus improving their utilization by crops. However, late-emerging weeds are not eliminated by these minor competitions, resulting in higher dry biomass of sedges.

Table 10. Interaction effect of WM and varieties on WDW at 55 DAE

weeding Methods	Broad Leaved			Grasses			Sedges		
	Quncho	Kora	Dagim	Quncho	Kora	Dagim	Quncho	Kora	Dagim
<b>CW</b>	11.2 <sup>h</sup>	3.7 <sup>l</sup>	7.1 <sup>j</sup>	14.7 <sup>i</sup>	8.0 <sup>k</sup>	11.3 <sup>j</sup>	25.8 <sup>e</sup>	7.7 <sup>k</sup>	17.8 <sup>h</sup>
<b>CW + 1 HW</b>	5.7 <sup>k</sup>	1.4 <sup>m</sup>	3.03 <sup>l</sup>	6.5 <sup>l</sup>	3.0 <sup>n</sup>	4.16 <sup>m</sup>	10.73 <sup>ij</sup>	11.56 <sup>i</sup>	11.06 <sup>ij</sup>
<b>One HW</b>	44.3 <sup>d</sup>	26.0 <sup>f</sup>	33.5 <sup>e</sup>	85.1 <sup>d</sup>	32.7 <sup>f</sup>	39.4 <sup>e</sup>	38.8 <sup>c</sup>	18.16 <sup>h</sup>	30.7 <sup>d</sup>
<b>Two HW</b>	14.6 <sup>g</sup>	3.8 <sup>l</sup>	8.7 <sup>i</sup>	29.6 <sup>g</sup>	9.0 <sup>k</sup>	19.3 <sup>h</sup>	22.3 <sup>g</sup>	9.96 <sup>j</sup>	16.83 <sup>h</sup>
<b>Weed free</b>	0.0 <sup>n</sup>	0.0 <sup>n</sup>	0.0 <sup>n</sup>	0.0 <sup>o</sup>	0.0 <sup>o</sup>	0.0 <sup>o</sup>	0.0 <sup>l</sup>	0.0 <sup>l</sup>	0.0 <sup>l</sup>
<b>Weedy check</b>	168 <sup>a</sup>	101 <sup>c</sup>	131.2 <sup>b</sup>	228 <sup>a</sup>	90 <sup>c</sup>	171.7 <sup>b</sup>	84.6 <sup>a</sup>	24.3 <sup>f</sup>	65.4 <sup>b</sup>
LSD (0.05)		1.63			1.11			1.35	
CV (%)		3.18			1.61			3.7	

Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: DAE (days after crop emergence), HW (hand weeding), CW (chemical weeding), CV = coefficient of variation.

#### 4.1.3.5. Interaction effect of WM and varieties of tef on WDW at harvest

At the harvest stage, the lowest broadleaf weeds dry weight was recorded in the weed-free treatment. The integration of Pallas 45 OD at a rate of  $0.3 \text{ l ha}^{-1}$  at 31 DAE, supplemented with one hand weeding after 41 days after crop emergence and the Kora variety gave lower dry weight of broad leaved weeds ( $1.64 \text{ g m}^{-2}$ ) (Table-11). This can be attributed to effective weed control through herbicide application and the removal of subsequently emerged and tolerant weeds through hand weeding, resulting in a minimum weed density. After manual weeding, the growing weeds accumulated less biomass yield which ultimately resulted in lower weed biomass. Conversely, the highest dry biomass of broad-leaved weeds ( $172 \text{ g m}^{-2}$ ) was recorded in the weedy treatments. This greater weed dry weight can be attributed to a higher weed density per square meter, vigorous growth, and a higher accumulation of dry matter at harvest.

The minimum dry biomass of grasses was observed in the weed-free treatment, followed by the integration effect of Pallas 45 OD at a rate of  $0.3 \text{ l ha}^{-1}$  at 31 DAE, supplemented with one hand weeding after 41 DAE and the Kora variety (Table-11). Lower dry weight of grasses was documented with the integrated approach compared to sole herbicide application. The early removal of weeds with herbicides followed by hand weeding resulted in low weed density and subsequent weed growth with low dry biomass weight, ultimately resulting in a lower outcome. However, the maximum dry weight of grassy weeds ( $195.2 \text{ g m}^{-2}$ ) was noted in the Quncho variety, which was statistically different from all other treatments at harvest. This higher dry weight may be attributed to reduced competition and the opportunity for grassy weeds to access more abundant resources, resulting in maximum dry weight accumulation.

The analysis of data also showed that the minimum dry weight of sedges biomass ( $0.59 \text{ g m}^{-2}$ ) was recorded with the integration effect of Pallas 45 OD at a rate of  $0.3 \text{ l ha}^{-1}$  at 31 DAE, supplemented with one hand weeding after 41 days of crop emergence and the Kora variety. However, the maximum dry weight of sedges ( $54 \text{ g m}^{-2}$ ) was recorded in the Quncho variety in the weedy check plots. The higher weed dry weight in the weedy check plots may be due to a higher weed density, providing an opportunity for vigorous competition for nutrients, space, light, water, and carbon dioxide, resulting in higher biomass production. Application of

herbicides not only reduced the density of weeds but also suppressed weed growth, leading to lower dry weight.

Varietal differences can be attributed to variations in tillering potential, foliar architecture, plant height, biomass, and competitive potential against weeds. These results are consistent with the findings of Habtamu Gebrehiwot *et al.*, (2020), who reported that different tef varieties showed significant differences in weed dry weight, with the Kora variety exhibiting better crop competition and lower weed dry weight. The integration of herbicides with hand weeding further decreased weed dry matter. Similar results were reported by Niguse Dechasa *et al.*, (2023) where the application of Pallas 45 OD supplemented with one hand weeding significantly reduced weed dry weight compared to the weedy check. In the weed-free plots, no weed dry weight was recorded.

Table 11. Interaction of WM and varieties of tef on WDW at harvest

Weeding Methods	Broad Leaved weeds			Grasses			Sedges		
	Quncho	Kora	Dagim	Quncho	Kora	Dagim	Quncho	Kora	Dagim
<b>CW</b>	12.53 <sup>g</sup>	4.28 <sup>j</sup>	8.86 <sup>h</sup>	15.63 <sup>h</sup>	8.37 <sup>j</sup>	12.0 <sup>i</sup>	20.2 <sup>de</sup>	1.84 <sup>h</sup>	8.14 <sup>g</sup>
<b>CW + 1HW</b>	6.0 <sup>i</sup>	1.64 <sup>k</sup>	3.46 <sup>j</sup>	4.26 <sup>k</sup>	1.4 <sup>l</sup>	2.43 <sup>l</sup>	0.95 <sup>hi</sup>	0.59 <sup>hi</sup>	0.67 <sup>hi</sup>
<b>One HW</b>	63.33 <sup>d</sup>	24.1 <sup>f</sup>	32.7 <sup>e</sup>	92.34 <sup>c</sup>	30.3 <sup>f</sup>	40.6 <sup>e</sup>	26.69 <sup>c</sup>	7.56 <sup>g</sup>	21.3 <sup>d</sup>
<b>Two HW</b>	12.3 <sup>g</sup>	2.06 <sup>k</sup>	6.16 <sup>i</sup>	39.44 <sup>e</sup>	5.04 <sup>k</sup>	18.2 <sup>g</sup>	19.26 <sup>e</sup>	1.29 <sup>hi</sup>	9.08 <sup>g</sup>
<b>Weed free</b>	0.0 <sup>l</sup>	0.0 <sup>l</sup>	0.0 <sup>l</sup>	0.0 <sup>m</sup>	0.0 <sup>m</sup>	0.0 <sup>m</sup>	0.0 <sup>i</sup>	0.0 <sup>i</sup>	0.0 <sup>i</sup>
<b>Weedy check</b>	172 <sup>a</sup>	93.6 <sup>c</sup>	117 <sup>b</sup>	195.2 <sup>a</sup>	85 <sup>d</sup>	156 <sup>b</sup>	54.0 <sup>a</sup>	15.6 <sup>f</sup>	46.5 <sup>b</sup>
LSD (0.05)		1.58			1.27			1.70	
CV (%)		3.08			1.95			7.89	

Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: HW (hand weeding), CW (chemical weeding), CV = Coefficient of variation.

#### **4.1.4. Effect of Weed Management and Varieties of Tef on WCE**

On an average, weed control efficiency ranged from 39.6% to 63.8% (Table 12) depending on weed management practices and variety used in all treatments at all growth stages. The efficiency was significantly influenced by weed management practices.

##### **4.1.4.1. Effect of weed management practices on WCE**

At 45 DAE, the highest weed control efficiency was (93.45%) for broadleaf weeds, (94.4%) for grass weeds, and (91.11%) for sedge weeds in weed-free plots followed by chemical herbicides of Pallas 0.3 l ha<sup>-1</sup> at 31 DAE with one hand at 41 DAE for all Weeds (Table 12) and low weed control efficiency (0.0 m<sup>-2</sup>) were recorded from weed check plots.

At 55 DAE, the highest weed control efficiency (91%) for broad leaved weeds, (94.15%) for grass weeds, and (89.81%) for sedge weeds recorded at weed free plots followed by chemical weeding 0.3 l ha<sup>-1</sup> at 31 DAE supplemented by one hand weeding at 41 DAE for all weeds (Table-12) and lower weed control efficiency (0.0 m<sup>-2</sup>) from weedy check plots.

At 55 DAE, the highest weed control efficiency was (93.88%) for broadleaf weeds, (93.88%) for grass weeds, and (87.46%) for sedge weeds recorded at weed free plots followed by chemical weeding 0.3 l ha<sup>-1</sup> at 31 DAE supplemented by one hand weeding at 41 DAE for all weeds (Table-12) Whereas, Pallas 45 OD supplemented with one hand weeding resulted in effective however, frequent weeding of tef fields is one of the most difficult tasks faced by farmers, especially during the main production season. It requires 3-4 rounds of continuous weeding every season to keep the field weed free. Uprooting the weed is difficult due to its complex root system, and cutting it will only make the infestation worse. In addition, tef seedlings are uprooted and their yield is reduced and lower weed control efficiency (0.0 m<sup>-2</sup>) from weedy check plots.

##### **4.1.4.2. Effect of variety on weed control efficiency**

At 45 DAE, herbicide efficacy had a significant effect on the tef crop growth stage. The variety Kora recorded significantly the maximum efficiency (64.36%) for broad leaved weeds, Quncho variety (62.07%) for grass weeds and Quncho variety (47.27%) for sedges.

At 55 DAE, weed control efficiency was significantly influenced by varieties growth stages

of the tef crop. The variety Kora recorded significantly the maximum efficiency (47.27%) for broad leaved weeds, Dagim variety (61.65%) for grass weeds and Quncho variety (46.77%) for sedges.

Weed dry weight at harvest, the variety Kora had the highest weed dry weight (64.72%) of the broadleaf weed, Dagim variety (61.14%) for grass weeds and (52.96) for sedges. Therefore, based on the results obtained above, it can be stated that the use of Kora and Degim varieties during harvest was effective in preventing weeds.

Table 12. Variation of WCE as influenced by weed management and varieties of tef

Treatments	Weed control efficiency								
	45DAE			55DAE			at harvest		
	broadleaved	grass	sedges	broadleaved	grass	sedges	broadleaved	grass	sedges
<b>Varieties</b>									
Quncho	63.12 <sup>c</sup>	62.07 <sup>a</sup>	47.27 <sup>a</sup>	47.27 <sup>a</sup>	59.08 <sup>b</sup>	46.77 <sup>a</sup>	59.77 <sup>c</sup>	56.08 <sup>c</sup>	46.92 <sup>c</sup>
Kora	64.36 <sup>a</sup>	55.83 <sup>c</sup>	27.94 <sup>c</sup>	28.11 <sup>c</sup>	57.46 <sup>c</sup>	33.45 <sup>c</sup>	64.72 <sup>a</sup>	60.12 <sup>b</sup>	51.98 <sup>b</sup>
Dagim	63.81 <sup>b</sup>	61.05 <sup>b</sup>	43.55 <sup>b</sup>	43.33 <sup>b</sup>	61.65 <sup>a</sup>	46.09 <sup>b</sup>	61.88 <sup>b</sup>	61.14 <sup>a</sup>	52.96 <sup>a</sup>
LSD	0.51	0.62	0.51	0.54	0.44	0.47	0.44	0.29	0.72
<b>Weeding Management practices</b>									
CW	78.97 <sup>c</sup>	74.2 <sup>c</sup>	41.44 <sup>b</sup>	41.66 <sup>b</sup>	72.42 <sup>c</sup>	44.72 <sup>c</sup>	74.11 <sup>d</sup>	70.27 <sup>c</sup>	52.38 <sup>c</sup>
CW + one HW at 41 DAE	85.46 <sup>b</sup>	80.2 <sup>b</sup>	41.55 <sup>b</sup>	41.55 <sup>b</sup>	82.22 <sup>b</sup>	50.75 <sup>b</sup>	82.77 <sup>b</sup>	85.3 <sup>b</sup>	80.6 <sup>b</sup>
One HW	53.47 <sup>e</sup>	43.71 <sup>e</sup>	23.55 <sup>d</sup>	23.44 <sup>d</sup>	43.34 <sup>e</sup>	25.5 <sup>e</sup>	45.66 <sup>e</sup>	40.04 <sup>e</sup>	30.03 <sup>d</sup>
Two HW at 31 DAE and 41 DAE	70.73 <sup>d</sup>	65.4 <sup>d</sup>	39.88 <sup>c</sup>	39.77 <sup>c</sup>	64.26 <sup>d</sup>	41.85 <sup>d</sup>	76.33 <sup>c</sup>	65.21 <sup>d</sup>	53.27 <sup>c</sup>
Weed free	93.95 <sup>a</sup>	94.4 <sup>a</sup>	91.11 <sup>a</sup>	91 <sup>a</sup>	94.15 <sup>a</sup>	89.81 <sup>a</sup>	93.88 <sup>a</sup>	93.88 <sup>a</sup>	87.46 <sup>a</sup>
Weedy check	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>e</sup>	0.0 <sup>e</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>e</sup>
LSD	0.72	0.88	0.72	0.76	0.63	0.66	0.63	0.42	1.02
CV	1.18	1.54	1.9	2.01	1.1	1.65	1.06	0.74	2.1
Grand mean	63.8	59.7	39.6	39.6	59.4	42.1	62.1	59.1	50.6

Average of three replications. Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: DAE (days after crop emergence), HW (hand weeding), CW (chemical weeding)

#### 4.1.4.3. Interaction effect of WM and varieties of tef on WCE at 45 DAE

The result indicated that the main effects of varieties and weeding methods, as well as their interaction significantly influenced the suppression of broad-leaved weeds, grasses, and sedges (Appendix Table-13). The best weed suppression at 45 DAE was observed in the weed-free treatments, and the interaction between the Kora variety and the application of Pallas at a rate of  $0.3 \text{ l ha}^{-1}$  at 31 DAE, supplemented with one hand weeding at 41 DAE, showed higher efficiency (88.94%). Similarly, the interaction between the Quncho variety and the application of Pallas at a rate of  $0.3 \text{ l ha}^{-1}$  at 31 DAE, supplemented with one hand weeding at 41 DAE, exhibited higher efficiency in suppressing grasses (81.92%). In terms of sedge weeds, the interaction between the Quncho variety and the application of Pallas at a rate of  $0.3 \text{ l ha}^{-1}$  at 31 DAE, supplemented with one hand weeding showed high weed control efficiency (57.3%).

The higher efficiency in weed control observed in the aforementioned interactions may be attributed to the combined effect of herbicide application and hand weeding, which resulted in a reduction in weed populations. Weeds that escaped control during the first weeding might have been targeted and controlled during the second weeding. Additionally, the presence of a weed seed bank in the soil, accumulated over the years through seed dispersal, may have led to the emergence of weeds at different times, making the integrated measures more effective. Adewale *et al.*, (2019) reported a maximum reduction of total weed density of 94.9% in a hand-pulling treatment compared to an untreated weedy check. The poor weed suppression observed in the weedy check plots could be attributed to reduced crop density, which provided a favorable environment for weed establishment, growth, and survival (Table-13).

Table 13. Interaction effect of WM and varieties of tef on WCE at 45 DAE

Weeding	Broad leaved weeds			Grasses			Sedges		
	Quncho	Kora	Dagim	Quncho	Kora	Dagim	Quncho	Kora	Dagim
<b>CW</b>	74.95 <sup>f</sup>	81.9 <sup>d</sup>	80.05 <sup>e</sup>	76.57 <sup>de</sup>	70.4 <sup>g</sup>	75.5 <sup>e</sup>	47.33 <sup>g</sup>	34.33 <sup>j</sup>	42.66 <sup>i</sup>
<b>CW + 1 HW</b>	81.19 <sup>de</sup>	88.94 <sup>b</sup>	86.25 <sup>c</sup>	81.92 <sup>c</sup>	77.2 <sup>d</sup>	81.5 <sup>c</sup>	57.3 <sup>d</sup>	17.6 <sup>n</sup>	49.66 <sup>f</sup>
<b>One HW</b>	60.38 <sup>j</sup>	49.08 <sup>l</sup>	50.9 <sup>k</sup>	45.21 <sup>k</sup>	38.05 <sup>l</sup>	47.84 <sup>j</sup>	33 <sup>k</sup>	6.66 <sup>o</sup>	31.0 <sup>l</sup>
<b>Two HW</b>	67.7 <sup>i</sup>	72.9 <sup>g</sup>	71.51 <sup>h</sup>	73.14 <sup>f</sup>	56.48 <sup>i</sup>	66.5 <sup>h</sup>	52.66 <sup>e</sup>	21.0 <sup>m</sup>	46.0 <sup>h</sup>
<b>Weed free</b>	94.5 <sup>a</sup>	93.27 <sup>a</sup>	94.1 <sup>a</sup>	95.6 <sup>a</sup>	92.7 <sup>b</sup>	94.8 <sup>a</sup>	93.33 <sup>a</sup>	88.0 <sup>c</sup>	92.0 <sup>b</sup>
<b>Weedy check</b>	0.0 <sup>m</sup>	0.0 <sup>m</sup>	0.0 <sup>m</sup>	0.0 <sup>m</sup>	0.0 <sup>m</sup>	0.0 <sup>m</sup>	0.0 <sup>p</sup>	0.0 <sup>p</sup>	0.0 <sup>p</sup>
LSD (0.05)	1.25			1.52			1.25		
CV (%)	1.18			1.54			1.90		

Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: DAE (days after crop emergence), HW (hand weeding), CW (chemical weeding), CV = coefficient of variation

#### 4.1.4.4. Interaction effect of WM and varieties of tef on WCE at 55 DAE

At 55 DAE (days after emergence), the highest weed control efficiency in broad-leaved weeds, grasses, and sedges was observed in the weed-free check plots where manual weeding was performed. This is consistent with the findings reported by Fufa, (2016) who also observed maximum weed control efficiency in weed-free plots with manual weeding. The integration of Pallas 45 OD at a rate of 0.3 l ha<sup>-1</sup> applied at 31 DAE, supplemented with one hand weeding at 41 DAE, in combination with the Quncho variety, recorded the highest weed control efficiency (57.33%) in broad-leaved weeds. The lowest efficiency was observed in the weedy check plots, indicating the importance of weed management practices. Similarly, in grasses, the highest weed control efficiency was recorded in the interaction between the application of Pallas at a rate of 0.3 l ha<sup>-1</sup> at 31 DAE, supplemented with one hand weeding at 41 DAE, and the Dagim variety (83.57%), which was statistically comparable to the Quncho variety (Table 14). In sedges, the highest weed control efficiency (63.66%) was recorded in the interaction between the application of Pallas at a rate of 0.3 l ha<sup>-1</sup> at 31 DAE, supplemented with one hand weeding at 41 DAE, and the Quncho variety.

The application of herbicides supplemented with one hand weeding showed greater weed control efficiency compared to sole herbicide application. This finding is supported by Patro and Ray (2016), who reported that the use of chemicals combined with one hand weeding

significantly reduced weed dry biomass and increased weed control efficiency in wheat. Similar results were reported by Tesfaye Amare et al. (2014), who found that herbicide application combined with additional hand weeding provided better weed control efficiency compared to a weedy check.

Overall, these findings highlight the importance of integrating herbicide application with hand weeding for effective weed control and reducing weed biomass in crop fields.

Table 14. Interaction effect of WM and varieties of tef on WCE at 55 DAE

Weeding Methods	Broad Leaved weeds			Grasses			Sedges		
	Quncho	Kora	Dagim	Quncho	Kora	Dagim	Quncho	Kora	Dagim
<b>CW</b>	47.33 <sup>f</sup>	35.0 <sup>i</sup>	42.66 <sup>h</sup>	74.23 <sup>e</sup>	69.23 <sup>f</sup>	73.8 <sup>e</sup>	44.4 <sup>g</sup>	42.46 <sup>g</sup>	47.3 <sup>f</sup>
<b>CW + 1HW</b>	57.33 <sup>c</sup>	18.0 <sup>m</sup>	49.33 <sup>e</sup>	82.53 <sup>c</sup>	80.6 <sup>d</sup>	83.5 <sup>c</sup>	63.66 <sup>c</sup>	30.5 <sup>j</sup>	58.1 <sup>d</sup>
<b>One HW</b>	33.0 <sup>j</sup>	6.66 <sup>n</sup>	30.66 <sup>k</sup>	38.76 <sup>j</sup>	39.4 <sup>j</sup>	51.86 <sup>i</sup>	32.03 <sup>i</sup>	13.27 <sup>l</sup>	31.2 <sup>ij</sup>
<b>Two HW</b>	53.0 <sup>d</sup>	21.0 <sup>l</sup>	45.33 <sup>g</sup>	63.7 <sup>h</sup>	62.98 <sup>h</sup>	66.1 <sup>g</sup>	48.23 <sup>ef</sup>	28.67	48.66
<b>Weed free</b>	93.0 <sup>a</sup>	88.0 <sup>b</sup>	92.0 <sup>a</sup>	95.3 <sup>a</sup>	92.56 <sup>b</sup>	94.6 <sup>a</sup>	92.33 <sup>a</sup>	85.8 <sup>b</sup>	91.3 <sup>a</sup>
<b>Weedy check</b>	0.0 <sup>o</sup>	0.0 <sup>o</sup>	0.0 <sup>o</sup>	0.0 <sup>k</sup>	0.0 <sup>k</sup>	0.0 <sup>k</sup>	0.0 <sup>m</sup>	0.0 <sup>m</sup>	0.0 <sup>m</sup>
LSD (0.05)		1.32			1.09			1.15	
CV (%)		2.01			1.11			1.65	

Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: DAE (days after crop emergence), HW (hand weeding), CW (chemical weeding), CV = Coefficient of variation.

#### 4.1.4.5. Interaction effect of WM and varieties of tef on WCE at DAE

At harvest, the highest weed control efficiency was observed in weed-free plots, resulting in 95.16% control in broad-leaved weeds, 94.94% control in grasses, and 90.4% control in sedges (Table-15). In terms of broad-leaved weeds, the maximum weed control efficiency of 85.33% was recorded in the interaction effect between the application of Pallas at a rate of 0.3 l ha<sup>-1</sup> at 31 DAE, supplemented one hand weeding at 41 DAE, and the Kora variety. The application of herbicides supplemented with one hand weeding showed greater weed control efficiency compared to sole herbicide application.

Similarly, in grasses and sedges, higher efficiency of weed control was observed in treatments where the interaction effect of the application of Pallas at a rate of 0.3 l ha<sup>-1</sup> at 31 DAE, supplemented with cultural practices at 41 DAE, and the Dagim variety, resulting in 86.34%

and 84.2% weed control efficiency, respectively. This may be attributed to effective weed control achieved by applying herbicides at an early growth stage and removing both tolerant and late-emerging weeds through hand weeding, leading to reduced weed counts and ultimately decreasing the total dry weight of weeds at harvest. A similar result was reported by Geachew Mekonnen, (2022), who found that the use of herbicides supplemented with one hand weeding significantly reduced weed dry biomass and increased weed control efficiency in wheat. Similarly, Niguse Dechasa et al. (2023) explained that the combination of Pallas 45 OD herbicide application and one round of hand weeding resulted in effective weed destruction.

Overall, these findings emphasize the effectiveness of integrating herbicide application with cultural practices and hand weeding in achieving higher weed control efficiency, reducing weed biomass, and ensuring a cleaner harvest.

Table 15. Interaction of WM and varieties of tef on WCE at harvest

weeding Methods	Broad Leaved weeds			Grasses			Sedges		
	Quncho	Kora	Dagim	Quncho	Kora	Dagim	Quncho	Kora	Dagim
<b>CW</b>	72.0 <sup>g</sup>	77.66 <sup>c</sup>	72.6 <sup>g</sup>	71.29 <sup>f</sup>	67.78 <sup>g</sup>	71.79 <sup>f</sup>	38.3 <sup>i</sup>	61.66 <sup>f</sup>	57.2 <sup>g</sup>
<b>CW + 1HW</b>	81.0 <sup>d</sup>	85.33 <sup>c</sup>	81.6 <sup>d</sup>	84.4 <sup>d</sup>	85.09 <sup>d</sup>	86.34 <sup>c</sup>	83.76 <sup>bc</sup>	73.8 <sup>d</sup>	84.2 <sup>b</sup>
<b>One HW</b>	40.33 <sup>j</sup>	49.0 <sup>h</sup>	47.33 <sup>i</sup>	31.12 <sup>l</sup>	40.23 <sup>k</sup>	48.79 <sup>j</sup>	29.36 <sup>k</sup>	28.9 <sup>k</sup>	31.83 <sup>j</sup>
<b>Two HW</b>	72.66 <sup>g</sup>	80.6 <sup>d</sup>	75.66 <sup>f</sup>	54.8 <sup>i</sup>	75.3 <sup>e</sup>	65.5 <sup>h</sup>	39.73 <sup>i</sup>	65.2 <sup>e</sup>	54.8 <sup>h</sup>
<b>Weed free</b>	92.66 <sup>b</sup>	95.16 <sup>a</sup>	93.6 <sup>b</sup>	94.94 <sup>a</sup>	92.35 <sup>b</sup>	94.35 <sup>a</sup>	90.4 <sup>a</sup>	82.3 <sup>c</sup>	89.66 <sup>a</sup>
<b>Weedy check</b>	0.0 <sup>k</sup>	0.0 <sup>k</sup>	0.0 <sup>k</sup>	0.0 <sup>m</sup>	0.0 <sup>m</sup>	0.0 <sup>m</sup>	0.0 <sup>l</sup>	0.0 <sup>l</sup>	0.0 <sup>l</sup>
LSD (0.05)		1.1			0.72			1.76	
CV (%)		1.06			0.74			2.1	

Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: DAE (days after crop emergence), HW (hand weeding), CW (chemical weeding), CV = Coefficient of variation.

#### **4.1.5. Effect of Weed Management Practices on HEI**

At 45 DAE, the statistical analysis of the data showed that the highest herbicide efficiency index was (58.95%) for broadleaf weeds, (67.28%) for grass weeds, and (44.07%) for sedge weeds recorded at weed free plots followed by chemical weeding 0.3 l ha<sup>-1</sup> at 31 DAE supplemented by one hand at 41 DAE for all weeds (Table 16) and low weeding efficiency index (0.0 m<sup>-2</sup>) from weeding test plots.

At 55 DAE, quantitative analysis of the data showed that the highest herbicide efficiency index was (44.07%) for broadleaf weeds, (63.94%) for grass weeds, and (39.71%) for sedge weeds recorded at weed free plots followed by chemical weeding 0.3 l ha<sup>-1</sup> at 31 DAE supplemented by one hand weeding at 41 DAE for all weeds (Table 16) and lower herbicide efficiency index (0.0 m<sup>-2</sup>) from weedy check plots.

At harvest, the quantitative analysis of the data showed that the highest herbicide efficacy index was found at (56.64%) for broadleaf weeds and (65.83%) for grass weeds in treated plots, and (31.08%) for sedge weeds recorded at weed free plots followed by chemical weeding 0.3 l ha<sup>-1</sup> at 31 DAE supplemented by one hand weeding at 41 DAE for all weeds (Table 16) and lower herbicide efficiency index (0.0 m<sup>-2</sup>) from weedy check plots.

Table 16. HEI influenced by weed management and varieties of tef

Treatments	Herbicide efficiency index								
	45DAE			55DAE			at harvest		
Varieties	Broadleaved	grass	sedges	Broadleaved	grass	sedges	broadleaved	grass	sedges
Quncho	21.57 <sup>a</sup>	25.23 <sup>a</sup>	15.11 <sup>a</sup>	15.11 <sup>a</sup>	23.55 <sup>a</sup>	13.69 <sup>a</sup>	21.2 <sup>a</sup>	22.39 <sup>a</sup>	13.81 <sup>a</sup>
Kora	13.86 <sup>c</sup>	10.11 <sup>c</sup>	5.24 <sup>c</sup>	5.24 <sup>c</sup>	10.4 <sup>c</sup>	5.02 <sup>c</sup>	13.12 <sup>c</sup>	13.8 <sup>c</sup>	6.35 <sup>c</sup>
Dagim	18.87 <sup>b</sup>	18.61 <sup>b</sup>	11.11 <sup>b</sup>	11.11 <sup>b</sup>	18.3 <sup>b</sup>	11.07 <sup>b</sup>	17.38 <sup>b</sup>	18.42 <sup>b</sup>	11.98 <sup>b</sup>
LSD	1.1	0.28	0.36	0.29	0.29	0.15	0.12	0.07	0.39
<b>Weeding Management practices</b>									
CW	15.37 <sup>c</sup>	13.12 <sup>c</sup>	5.77 <sup>b</sup>	5.77 <sup>b</sup>	12.13 <sup>c</sup>	5.94 <sup>c</sup>	12.44 <sup>d</sup>	11.17 <sup>c</sup>	6.79 <sup>c</sup>
CW + one HW at 41 DAE	21.33 <sup>b</sup>	16.51 <sup>b</sup>	6.18 <sup>b</sup>	6.18 <sup>b</sup>	18.01 <sup>b</sup>	6.81 <sup>b</sup>	18.38 <sup>b</sup>	21.63 <sup>b</sup>	18.03 <sup>b</sup>
One HW	3.78 <sup>e</sup>	3.11 <sup>e</sup>	2.36 <sup>d</sup>	2.36 <sup>d</sup>	2.87 <sup>e</sup>	2.37 <sup>e</sup>	3.12 <sup>e</sup>	3.04 <sup>e</sup>	2.49 <sup>e</sup>
Two HW at 31 DAE and 41 DAE	9.17 <sup>d</sup>	7.89 <sup>d</sup>	4.56 <sup>c</sup>	4.56 <sup>c</sup>	7.54 <sup>d</sup>	4.73 <sup>d</sup>	12.81 <sup>c</sup>	7.55 <sup>d</sup>	5.89 <sup>d</sup>
Weed free	58.95 <sup>a</sup>	67.28 <sup>a</sup>	44.07 <sup>a</sup>	44.07 <sup>a</sup>	63.94 <sup>a</sup>	39.71 <sup>a</sup>	56.64 <sup>a</sup>	65.83 <sup>a</sup>	31.08 <sup>a</sup>
Weedy check	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>e</sup>	0.0 <sup>e</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>	0.0 <sup>f</sup>
LSD	1.56	0.4	0.51	0.41	0.42	0.22	0.17	0.1	0.55
CV	9.01	2.32	5.16	4.15	2.51	2.37	1.08	0.57	5.44
Grand mean	18.1	18	10.5	10.5	17.4	9.92	17.2	18.2	10.7

Average of three replications. Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: DAE (days after crop emergence), HW (hand weeding), CW (chemical weeding)

#### 4.1.5.1. Interaction effect of WM and varieties of tef on HEI at 45 DAE

According to the analysis of data, the highest herbicide efficiency index was observed in the interaction effect of plots treated with weed-free conditions and the Quncho variety, resulting in 191.8% efficiency in broad-leaved weeds, 240.6% efficiency in grasses, and 159.9% efficiency in sedge weeds (Table-17). Additionally, the interaction effect of applying Pallas at a rate of 0.3 l ha<sup>-1</sup> at 31 DAE, supplemented with one hand weeding at 41 DAE, showed comparable herbicide efficiency with the Quncho and Kora varieties in broad-leaved weeds. Similarly, in sedges, the maximum herbicide efficiency index of 7.2% was achieved with the interaction effect of applying Pallas at a rate of 0.4 l ha<sup>-1</sup> at 31 DAE and the Quncho variety. This can be attributed to the fact that higher herbicide rates lead to increased weed control efficiency, resulting in reduced weed density and dry biomass accumulation at harvest. By achieving lower weed pressure, a considerable yield can be obtained, ultimately leading to a higher herbicide efficiency index. This finding aligns with the results obtained by Yadav *et al.* (2020), who reported that the herbicide efficiency index increased with higher rates of herbicides due to improved weed control efficiency and lower weed index.

Table 17. Interaction effect of weed management and tef varieties on HEI

weeding Methods	Broad leaved weeds			Grasses			Sedges		
	Quncho	Kora	Dagim	Quncho	Kora	Dagim	Quncho	Kora	Dagim
CW	15.7 <sup>efg</sup>	7.6 <sup>fghi</sup>	9.5 <sup>fghi</sup>	16.7 <sup>de</sup>	4.3 <sup>fgh</sup>	7.7 <sup>efgh</sup>	7.2 <sup>def</sup>	1.9 <sup>efg</sup>	3.2 <sup>efg</sup>
CW + 1 HW	27.2 <sup>d</sup>	21.0 <sup>de</sup>	16.7 <sup>def</sup>	19.3 <sup>d</sup>	8 <sup>egh</sup>	12 <sup>defg</sup>	11.9 <sup>d</sup>	2.3 <sup>efg</sup>	4.5 <sup>efg</sup>
One HW	5.91 <sup>ghi</sup>	2.0 <sup>hi</sup>	3.05 <sup>hi</sup>	4.26 <sup>gh</sup>	1.6 <sup>h</sup>	2.86 <sup>h</sup>	3.5 <sup>efg</sup>	1.0 <sup>fg</sup>	2.2 <sup>efg</sup>
Two HW	11 <sup>efgh</sup>	8 <sup>fghi</sup>	9 <sup>fghi</sup>	14 <sup>def</sup>	4.6 <sup>fgh</sup>	7.6 <sup>efgh</sup>	7.76 <sup>de</sup>	2.4 <sup>efg</sup>	4 <sup>efg</sup>
Weed free	191.8 <sup>a</sup>	111 <sup>c</sup>	166.1 <sup>b</sup>	240.6 <sup>a</sup>	83.7 <sup>c</sup>	188 <sup>b</sup>	159.9 <sup>a</sup>	61.8 <sup>c</sup>	126 <sup>b</sup>
weedy check	0.0 <sup>i</sup>	0.0 <sup>i</sup>	0.0 <sup>i</sup>	0.0 <sup>h</sup>	0.0 <sup>h</sup>	0.0 <sup>h</sup>	0.0 <sup>g</sup>	0.0 <sup>g</sup>	0.0 <sup>g</sup>
LSD (0.05)		2.7			0.69			0.89	
CV (%)		9.01			2.32			5.16	

Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: DAE (days after crop emergence), HW (hand weeding), CW (chemical weeding), CV = Coefficient of variation

#### 4.1.5.2. Interaction effect of WM and tef varieties on HEI at 55 DAE

Among the treatments, the maximum herbicide efficiency index was recorded in the interaction effect of weed-free plots with the Quncho variety, resulting in 193.3% efficiency in broad-leaved weeds, 217.2% efficiency in grasses, and 132.2% efficiency in sedge weeds (Table-18). This was followed by 18.1% efficiency in broad-leaved weeds under the interaction effect of applying Pallas at a rate of 0.3 l ha<sup>-1</sup> at 31 DAE, supplemented with one hand weeding and the Quncho variety, which was statistically comparable to the Dagim and Kora varieties.

In grasses and sedge weeds at 55 DAE, higher herbicide efficiency index was also observed in the interaction effect of weeding practices and varieties compared to the weedy check. The depletion of the soil seed bank due to hand weeding may have brought weed seeds to the upper soil layer. Although these seeds germinated and emerged later, they were in their initial growth stage, resulting in less accumulated dry weight. The combination of varieties, and appropriate weed management practices, such as hand weeding, can significantly enhance herbicide efficiency. By reducing the soil seed bank and targeting weeds at their early growth stages, lower weed biomass can be achieved, leading to higher herbicide efficiency indexes.

Table 18. Effect of different weed management on HEI

Weeding Methods	Broad leaved			Grasses			Sedges		
	Quncho	Kora	Dagim	Quncho	Kora	Dagim	Quncho	Kora	Dagim
<b>CW</b>	14.7 <sup>def</sup>	6.5 <sup>fghi</sup>	8.05 <sup>efg</sup>	14.8 <sup>de</sup>	4.1 <sup>gh</sup>	7.15 <sup>fgh</sup>	6.83 <sup>de</sup>	2.2 <sup>fgh</sup>	3.56 <sup>efgh</sup>
<b>CW + 1 HW</b>	18.1 <sup>d</sup>	15.8 <sup>de</sup>	15 <sup>def</sup>	19.3 <sup>d</sup>	10 <sup>efg</sup>	14.6 <sup>def</sup>	9.13 <sup>d</sup>	2.7 <sup>efg</sup>	5.58 <sup>defg</sup>
<b>One HW</b>	4.52 <sup>ghi</sup>	2.1 <sup>hi</sup>	2.95 <sup>hi</sup>	3.8 <sup>gh</sup>	1.7 <sup>h</sup>	3.1 <sup>gh</sup>	3 <sup>efgh</sup>	1.18 <sup>gh</sup>	2.18 <sup>fgh</sup>
<b>Two HW</b>	12 <sup>defg</sup>	9.5 <sup>defg</sup>	9.8 <sup>defg</sup>	10 <sup>efg</sup>	5.8 <sup>gh</sup>	7 <sup>efgh</sup>	7.06 <sup>de</sup>	2.9 <sup>efg</sup>	5.04 <sup>def</sup>
<b>Weed free</b>	193.3 <sup>a</sup>	106 <sup>c</sup>	158.6 <sup>b</sup>	217.2 <sup>a</sup>	76.3 <sup>c</sup>	136 <sup>b</sup>	132.2 <sup>a</sup>	42.0 <sup>c</sup>	84.17 <sup>b</sup>
<b>Weedy check</b>	0.0 <sup>i</sup>	0.0 <sup>i</sup>	0.0 <sup>i</sup>	0.0 <sup>h</sup>	0.0 <sup>h</sup>	0.0 <sup>h</sup>	0.0 <sup>h</sup>	0.0 <sup>h</sup>	0.0 <sup>h</sup>
LSD (0.05)		0.72			0.72			0.39	
CV (%)		4.15			2.5			2.7	

Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: DAE (days after crop emergence), HW (hand weeding), CW (chemical weeding), CV = Coefficient of variation.

#### 4.1.5.3. Interaction effect of WM and varieties of tef on HEI at harvest

In the comparison of interaction effects within varieties and weeding methods, the highest weed killing potential was observed in the interaction effect of weed-free plots and the Quncho variety, resulting in 189.2% weed killing potential in broad-leaved weeds, 201.4% in grasses, and 110.5% in sedges (Table-19). It is worth noting that these herbicide combinations containing Pallas at the harvest stage of teff showed less phytotoxicity to the teff crop.

On the other hand, the lowest herbicide efficiency indices for all weeds were observed in the weedy check plots, indicating poor weed control in the absence of any weed management practices. This study highlights the effectiveness of applying herbicides supplemented with cultural practices for controlling all types of weeds. The combination of herbicides with practices such as hand weeding or other cultural methods was found to be more effective in controlling both annual and perennial weeds compared to applying a single herbicide alone. This integrated approach to weed management can lead to improved weed control and better overall crop performance.

Table 19. Interaction effect of weed management practices and varieties on HEI

weeding Methods	Broad leaved			Grass			Sedges		
	Quncho	Kora	Dagim	Quncho	Kora	Dagim	Quncho	Kora	Dagim
<b>CW</b>	8.1 <sup>fgh</sup>	5.93 <sup>hij</sup>	6.72 <sup>ghi</sup>	10.1 <sup>fg</sup>	3.94 <sup>hi</sup>	6.7 <sup>ghi</sup>	3.6 <sup>fgh</sup>	3.6 <sup>fgh</sup>	4.3 <sup>fgh</sup>
<b>CW + 1HW</b>	17.8 <sup>d</sup>	14 <sup>de</sup>	13.6 <sup>def</sup>	21.94 <sup>d</sup>	14.5 <sup>ef</sup>	18.6 <sup>de</sup>	24.56 <sup>d</sup>	9.57 <sup>e</sup>	23.7 <sup>d</sup>
<b>One HW</b>	3.84 <sup>ijk</sup>	2 <sup>jk</sup>	2.8 <sup>ijk</sup>	3.38 <sup>hij</sup>	1.7 <sup>ij</sup>	2.92 <sup>hij</sup>	3.27 <sup>fgh</sup>	1.4 <sup>gh</sup>	2.2 <sup>fgh</sup>
<b>Two HW</b>	5.8 <sup>hijk</sup>	12 <sup>def</sup>	11.2 <sup>efg</sup>	8.1 <sup>gh</sup>	7.5 <sup>ghi</sup>	7.46 <sup>ghi</sup>	5.9 <sup>efg</sup>	6.54 <sup>ef</sup>	5.7 <sup>efg</sup>
<b>Weed free</b>	189.2 <sup>a</sup>	82.7 <sup>c</sup>	113.6 <sup>b</sup>	201.4 <sup>a</sup>	78.83 <sup>c</sup>	173.2 <sup>b</sup>	110.5 <sup>a</sup>	32.8 <sup>c</sup>	95 <sup>b</sup>
<b>Weedy check</b>	0.0 <sup>k</sup>	0.0 <sup>k</sup>	0.0 <sup>k</sup>	0.0 <sup>j</sup>	0.0 <sup>j</sup>	0.0 <sup>j</sup>	0.0 <sup>h</sup>	0.0 <sup>h</sup>	0.0 <sup>h</sup>
LSD (0.05)		0.31			0.17			0.96	
CV (%)		1.08			0.57			5.44	

Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: DAE (days after crop emergence), HW (hand weeding), CW (chemical weeding), CV = Coefficient of variation

#### 4.1.6. Effect of Weed Management Practices and Variety of Tef on WI

##### 4.1.6.1. Effect of weed management practices on weed index

The data shows that the highest weed index was confirmed in the areas treated by the weed check (76.66%) followed by one hand weeding (Table 21), while the lower weed index recorded in weed free plots followed by application of chemical 0.3 l ha<sup>-1</sup> at 31 DAE and supplemented with one hand weeding at 41 DAE (4.77%).

##### 4.1.6.2. Effect of variety on weed index

Weed index significantly influenced the growth rate of tef crop. The Quncho variety recorded the highest index (26.61%) significantly; while the lowest weed index was recorded on the Kora variety (Table 21).

Table 20. Interaction of varieties and WM on WI

Weeding	Weed Index (%)		
	V1	V2	V3
W1	25.6 <sup>f</sup>	28.94 <sup>ef</sup>	24.46 <sup>f</sup>
W2	4.36 <sup>i</sup>	8.11 <sup>hi</sup>	4.59 <sup>i</sup>
W3	46.04 <sup>c</sup>	35.84 <sup>d</sup>	34.2 <sup>de</sup>
W4	13.4 <sup>gh</sup>	9.21 <sup>ghi</sup>	15.3 <sup>g</sup>
W5	0.0 <sup>j</sup>	0.0 <sup>j</sup>	0.0 <sup>j</sup>
W6	81.43 <sup>a</sup>	67.86 <sup>b</sup>	73 <sup>b</sup>
LSD (0.05)			
CV (%)			

In each column, having similar letters do not differ significantly, whereas figures bearing dissimilar letters differ at 5 % level of probability (as per LSD). V1= quncho, V2=kora, V3=dagim, w1 = Pallas 45 OD 0.4 l ha<sup>-1</sup> at 31 DAE, w2 = (Pallas 45 OD) 0.3 l ha<sup>-1</sup> at 31 days after crop emergence (DAE) with at 41 DAE one hand weeding, w3= one hand weeding at 31 DAE, w4 = two-hand weeding at 31 DAE and at 41 DAE, w5 = weed free, and w6 = weedy check, CV=Coefficient of variation

#### **4.1.7. Interaction Effect of Weed Management and Varieties of Tef on WI**

The weed index directly reflects weed infestation and competition, and it measures the effectiveness of a particular treatment compared to a weed-free condition. It is expressed as a percentage of grain yields under weed-free conditions, where a higher weed index indicates a greater loss of yield due to weeds.

In the case of tef, grain yield loss varied significantly depending on the combination of varieties and weed management practices. The lowest yield loss of 0.0% was recorded in the weed-free plots with hand weeding as soon as weeds emerged. This was followed by the interaction effect of applying Pallas 45 OD at 31 DAE (tiller stage), supplemented with one hand weeding at 41 DAE, and the Quncho variety, resulting in a yield loss of 4.36%. This yield loss was statistically comparable to the Dagim and Kora varieties, as well as the interaction effect of two hand weeding at 31 and 41 DAE with the Kora variety.

The lower grain yield loss in the weed-free treatment and the combination of chemical weeding with cultural practices can be attributed to the reduction in weed density, inhibition of weed growth, and biomass accumulation. With fewer weeds competing for nutrients, sunlight, and water, the tef crop can better utilize these resources, leading to improved photosynthesis and enhanced yield attributes such as the number of effective tillers, panicle length, and thousand-grain weight. These cumulative effects contribute to increased grain yield.

Habtamu Gebrehiwot *et al.* (2020) also reported that the tef varieties Kora and DZ-Cr-387 (Quncho) exhibit strong competition with weeds, as evidenced by their impact on weed density, dry weight, and cover. These varieties also showed higher yields at the end of the growing season compared to other varieties. However, they do experience some yield loss during their competition with both monocot and dicot weeds. For example, the variety 'Kora' lost up to 6% of its biomass yield and 18% of its grain yield, while the variety 'DZ-Cr-387' lost up to 17% of its biomass yield and 21% of its grain yield.

On the other hand, the highest yield loss of 81.43% was recorded in the weedy check plots for the Quncho variety, followed by 73% yield loss for the Dagim variety. This substantial grain yield loss in the weedy check plots for all varieties can be attributed to the presence of a higher weed density in the study.

These findings align with the study conducted by Tesfaye Amare *et al.*, (2015), which demonstrated that herbicide application combined with additional hand weeding can mitigate wheat yield losses more effectively than uncontrolled weeding practices.

## **4.2. Weed Management and Varieties on Yield Characteristics of tef**

### **4.3. Number of Effective Tillers per Plant**

Grain production is highly dependent on the number of tillers produced per plant (Nerson, 1980). According to the data presented in Table 21, the average number of plants in all treatments was 3.7 depending on the weed management practices and variety.

#### **4.3.1. Effect of Weed Management on Number of Tillers per Plant**

Weed-free treatments produced the highest number of plants per plant (5.16); followed by two hand weeding (4.45) at 31 DAE and 41 DAE, statistical par with application of chemical 0.3 l ha<sup>-1</sup> supplemented with one hand weeding (Table 21). However, the least number of tillers per plant (1.33) was recorded by weedy check. The decrease in the number of tillers per plant is due to the death of some of the last tillers due to the inability to compete for light and nutrients (Fageria, *et al.*, 1997). Weeding tef plots significantly increased tillering in this experiment. In addition, tiller numbers are reduced with inter and intra-specific competition has increased (Habtamu Gebrehiwot *et al.*, 2020)

#### **4.3.2. Effect of Variety on Number of Tillers per Plant**

There was a significant difference in the number of plants among the three varieties, when grown in the same method or set of practices, Kora (4.3), Degim (3.45) and Quncho (3.22). Thus, on the basis of above results, it can be mentioned that the tef yield (t ha<sup>-1</sup>) was significantly positively correlated with the number of tillers per plant. Kora cultivar produced a relatively high number of Quncho cultivars per plant.

#### **4.3.3. Interaction Effect of Weed Management and Variety of Tef on TN**

Tillering refers to productive and non-productive tillers from a single tef plant. The highest number of tillers (6.53) in weed-free cultivars, followed by the interaction effect of Pallas 45

OD 0.3 l ha<sup>-1</sup> added at 31 DAE with manual weeding at 41 DAE and kora variety (Table- 22). The interaction effect of weeding and varieties also had a significant effect on tillering of tef, and most of the varieties had more tillers on weeded plots and this is in agreement with the findings (Habtmu Gebrehiwot *et al.*, 2020) that tillering of late flowering and maturing of varieties had significantly more tillers than other varieties. Because when weeds are removed from tef plots, they leave an open space enabling the crop to have sufficient access to water, nutrients and sunlight to support itself and newly emerging tillers its basal nodes.

The result was agreed with the report of Getachew Mekonnen, (2022) who indicated that chemical in combination with manual weeding had a higher number of tillers than single application. Andrew *et al.* (2015) reported that tiller capacity gives great competitive ability in wheat in addition to many other competitive traits such as height and canopy structure. On the other hand, the lowest yield of tiller (0.96) was obtained with weed check. This small number may be due to high weed population, lack of available space, lack of nutrients and lack of moisture. The result is consistent with the findings of (Habtmu Gebrehiwot *et al.*, 2020) he pointed out that weed is naturally a strong competitor; they compete with crops for space, nutrients, moisture, light and carbon dioxide and can reduce parts of crop production. There was highly significant positive correlation ( $r = 0.89$  \*\*\*) between tiller numbers and yield (t ha<sup>-1</sup>) (Appendix figure 2).

#### **4.3.4. Panicle Length**

The average panicle length in the experiment was 41 cm (Table 21) and the statistical analysis of the data indicated that the panicle length varied significantly with the weed management practices and varieties.

#### **4.3.5. Effect of Weed Management on Panicle Length**

Higher panicle length was produced in the weed-free plot (45.83 cm) followed by 0.3 l ha<sup>-1</sup> chemical application supplemented by one-hand weeding, which was significant above the weed check plot (38 cm).

#### **4.3.6. Effect of variety on panicle length**

The highest panicle length was produced by the Dagim variety (41.5 cm) which was different from Quncho variety (40.2 cm) but 3.13% higher than Quncho variety.

#### **4.3.7. Interaction of Weed Management and Varieties of Tef on Panicle Length**

Statistical analysis of the data indicated that the interaction effect of weeding methods and varieties the panicle length significantly ( $p < 0.05$ ) differed (Table - 22). The longer panicle length was produced by the interaction of weed free and varieties (Table - 22), and statistically par with interaction effect of the application Pallas 45 OD 0.3 l ha<sup>-1</sup> at 31 DAE supplemented by one hand weeding at 41 DAE with Dagim and Kora varieties whereas the shortest panicle length was observed due to combined effect of varieties and un-weeded plots. The increase in panicle length interaction varieties and weeding practices might be attributed to better availability of growth resources for the crop. The result also reported by (Kassa Semagn *et al.*, 2021) not only genotypic variability, but also agronomic management practices of cereal crops have visible effect on plant height and panicle length. There was significant positive correlation ( $r=0.79^{***}$ ) between panicle length and grain yield (t ha<sup>-1</sup>) (Appendix figure- 2).

#### **4.3.8. Thousand Grain Weight**

The weight of a thousand grains is a stable dynamic characteristic, because the size of the grain is strictly controlled by the size of the shell (Yoshida, 1981). The average grain weight (thousand-grain weight) in the experiment was generally 0.3 g (Table 21) according to weed management practices and different combinations. Grain weight was significantly influenced by weed management practices and the interaction.

#### **4.3.9. Effect of Weed Management on Grain Weight**

Grain weight was found to be significantly higher with weed free (0.32 gm) as compared to chemical weeding (0.3 gm), two hand weeding at 31 and 41 DAE (0.28 gm), one hand weeding (0.28 gm), and weedy check (0.23 gm).

#### **4.3.10. Effect of Variety on Grain Weight**

Grain weight was influenced by variety Kora (0.3 gm) produced significantly higher grain weight than Dagim (0.28) and Quncho varieties (0.28 gm) and it was more by 6.6%.

#### **4.3.11. Interaction Effect of Weed Management and Varieties of Tef on GW**

The result of the present study showed that interaction of varieties and weeding practices had significant effect ( $p < 0.05$ ) on the thousand grain weight of tef. The grains under interaction effect of complete weed free plots with kora variety recorded the highest thousand grain weight (0.33 gm) which was statistically at par with interaction effect of application of Pallas 45 OD 0.3 l ha<sup>-1</sup> at 31 DAE supplemented with one hand weeding at 41 DAE with Kora variety followed by chemical weeding 0.4 l ha<sup>-1</sup> at 31 DAE. The plants raised under a complete weed free environment were free from weed competition. Thus, they utilized available resources to their maximum benefit leading to increased seed weight. Also, the more vigorous leaves under a weed free environment that improved the supply of assimilate to be stored in the seed, hence, the weight of thousand grains increased. The results were concomitant with (Getachew Mekonnen, 2022) findings who that, due to no competition for nitrogen resulting in enough uptakes during seed filling which plays an important role in maintaining green leaf area and thus assimilates supply to the growing seeds resulting in higher seed weight. This might be attributed to better availability of growth resources for the crop in weed free treatment which results in better assimilation production and translocation to sink (seed) (Zewditu Dawit, 2020). The lowest 1000 grain weight was observed in interaction of weedy check and Quncho variety (0.22 gm), (Table - 22). The lower thousand grain weight resulted in could be due to less nutrient movement of crop plants under weedy and competition with crop plants for limited resources.

#### **4.3.12. Grain yield**

Grain yield, which is the final product of growth and development, is controlled by dry matter at maturity (De Datta, 1981). The tef grain yield was found to be an average yield in the experiment being 1.9 ton ha<sup>-1</sup> (Table 21). Statistically both weed management and variety significantly influenced the grain yield.

#### **4.3.13. Effect of Weed Management Practices on Grain Yield of Tef**

Weed-free treatments resulted in higher grain yield (2.52 t ha<sup>-1</sup>) as compared to two hand weeding (2.14 t ha<sup>-1</sup>), chemical weeding (2.31 t ha<sup>-1</sup>), one hand weeding (1.56 t ha<sup>-1</sup>), and weedy check (0.5 t ha<sup>-1</sup>). The lowest grain yield was obtained in the weed check plot, which

was similar to the observations of Tomer (1987) and Phogat *et al.*, (1998) due to increased crop-weed competition, high weed dry matter, low tiller number and grain weight.

This might be due to the significantly higher number of tillers per plant. Higher grain yield from three weed management practices might be due to less weed competition, lower weed density (no. /m<sup>2</sup>), lower dry weight of weeds (g/m<sup>2</sup>) and higher weed control efficiency (%) resulting from better weed management. Vijayakumar and others (2006) reported that incorporation of weeds through mechanical weeding recorded the highest grain yield.

#### **4.3.14. Effect of Variety on Grain Yield of Tef**

Kora variety produced higher grain yield (2.02 t ha<sup>-1</sup>) compared to Quncho (1.83 t ha<sup>-1</sup>). The tef yield was significantly higher from the weeded plots and the tillering of tef was higher in plots with hand weeding. This is likely the result of improved availability of water and plant nutrients less competition for sunlight. Among all varieties, Kora gave the highest biomass yield. This variety was the highest producer followed by DZ-Cr-387 (Quncho) in previous studies (Kibebew Assefa *et al.*, 2017).

#### **4.3.15. Interaction Effect of WM and Varieties of Tef on Grain Yield**

The highest grain yield (2.72 ton ha<sup>-1</sup>) was recorded for weed free combined with the improved variety (Kora) followed by the value (2.5 ton ha<sup>-1</sup>) obtained from application of Pallas 0.3 l ha<sup>-1</sup> at 31 DAE supplemented with one hand weeding at 41 DAE with improved variety (Kora) which is statistically par with two hand wedding at 31 and 41 DAE and improved variety. The lowest grain yield recorded was 0.46 ton ha<sup>-1</sup> when combination of un-weeded and Quncho variety (Table -23).

Weeds appear to be more suitable for agro-ecology than our crops. Without human intervention, weeds easily destroy crop plants and reduce crop growth. The result is clearly supported by Getachew Mekonnen, (2022) more weeds are there, the fewer nutrients from the soil and the more competition they have with crops, ultimately damaging the grain development potential of the plant, resulting in a reduction in yield. The increase in grain yield with interaction effect of improved varieties and weeding practices might be due to enhanced uptake of essential nutrients by tef plants as a result of reduced competition of weeds. Variation in grain yield (83%) was recorded due to interaction effects of weed free and

improved varieties. This increase in high tef grain yield under weed-free conditions allows crop plants to be free from weed damage and to be in good condition using available resources, enhancing yield for increase in tef grain production. Similarly the result with (Niguse Hundessa *et al.*, 2023) in integrated management of weeds with the application of Pallas 45 OD supplemented with one hand weeding resulted in increased tef yield by about 70%. Similarly indicated by (Gebrekidan Feleke *et al.*, 2022) Maximum tef grain was obtained in weed free treatment.

Productivity improvement of tef can be achieved through effective control of weed growth, weed abundance and efficient use of crop resources for proper growth and development of crops resulting in increased yield and improved yield characteristics. The results of difference also indicated that superior tef grain yield was obtained from herbicides if applied and supplemented with one hand weeding as compared to their sole application. The reason behind that is by first applying herbicide and weed control by hand weeding, increasing the weed free period and providing suitable space for the crop which will eventually lead to high tef grain yield. The result was in agreement with the study of (Getachew Mekonnen, 2022) who stated that the highest grain yield was achieved in wheat through a combination of manual and chemical weed control methods.

Grain yield showed highly significant and positive linear relationship with total tiller number ( $r= 0.89^{***}$ ), panicle length ( $r= 0.79^{***}$ ), and above ground biomass ( $r= 0.94^{***}$ ) implying that improvement in these parameters is also associated with better grain yield. Also thousand grain weight ( $r= 0.02^{ns}$ ), positive correlation with days to physiological maturity ( $r= 0.62^{***}$ ), days of heading ( $r= 0.76^{***}$ ) (Appendix figure -2).

Table 21. Yield and yield components influenced by weed management and varieties

<b>Varieties</b>	Above ground biomass	Grain yield	Straw yield	Harvest index	Thousand grain weight	Total tiller number	Days of heading	Maturity days	Panicle length	Plant height	Weed index
Quncho	16.3 <sup>c</sup>	1.83 <sup>c</sup>	14.45 <sup>c</sup>	10.76 <sup>b</sup>	0.28 <sup>b</sup>	3.22 <sup>c</sup>	49.5 <sup>c</sup>	102.37 <sup>c</sup>	40.2 <sup>c</sup>	104.83 <sup>b</sup>	26.61 <sup>a</sup>
Kora	17.7 <sup>a</sup>	2.02 <sup>a</sup>	15.63 <sup>a</sup>	11.14 <sup>a</sup>	0.3 <sup>a</sup>	4.3 <sup>a</sup>	56.22 <sup>a</sup>	107.56 <sup>a</sup>	41.2 <sup>b</sup>	106.83 <sup>a</sup>	22 <sup>c</sup>
Dagim	17.1 <sup>b</sup>	1.91 <sup>b</sup>	15.15 <sup>b</sup>	10.79 <sup>b</sup>	0.28 <sup>b</sup>	3.45 <sup>b</sup>	51.4 <sup>b</sup>	103.97 <sup>b</sup>	41.5 <sup>a</sup>	103.16 <sup>c</sup>	23.88 <sup>b</sup>
LSD	0.4	0	0.3	0.3	0	0.1	0.5	1	0.1	1	0.4
<b>Weeding Management practices</b>											
CW	19.03 <sup>ab</sup>	2.31 <sup>c</sup>	16.72 <sup>a</sup>	12.19 <sup>b</sup>	0.3 <sup>b</sup>	3.8 <sup>c</sup>	52.42 <sup>c</sup>	106.07 <sup>c</sup>	41 <sup>c</sup>	106.11 <sup>a</sup>	8.33 <sup>d</sup>
CW + one HW at 41 DAE	19.4 <sup>a</sup>	2.41 <sup>b</sup>	16.97 <sup>a</sup>	12.46 <sup>b</sup>	0.3 <sup>b</sup>	4.35 <sup>b</sup>	53.35 <sup>b</sup>	107.5 <sup>b</sup>	42.8 <sup>b</sup>	106.11 <sup>a</sup>	4.77 <sup>e</sup>
One HW	15.34 <sup>d</sup>	1.56 <sup>e</sup>	13.78 <sup>d</sup>	10.19 <sup>c</sup>	0.28 <sup>c</sup>	2.57 <sup>d</sup>	51.55 <sup>d</sup>	103.74 <sup>d</sup>	40.2 <sup>e</sup>	104.22 <sup>b</sup>	38.11 <sup>b</sup>
Two HW at 31 DAE and 41 DAE	17.79 <sup>c</sup>	2.14 <sup>d</sup>	15.72 <sup>c</sup>	12.01 <sup>b</sup>	0.28 <sup>c</sup>	4.45 <sup>b</sup>	52.11 <sup>cd</sup>	105 <sup>cd</sup>	42.1 <sup>d</sup>	104.77 <sup>ab</sup>	17.11 <sup>c</sup>
Weed free	18.79 <sup>b</sup>	2.52 <sup>a</sup>	16.26 <sup>b</sup>	13.47 <sup>a</sup>	0.32 <sup>a</sup>	5.16 <sup>a</sup>	54.4 <sup>a</sup>	109.82 <sup>a</sup>	45.83 <sup>a</sup>	105.77 <sup>a</sup>	0.0 <sup>f</sup>
Weedy check	11.59 <sup>e</sup>	0.5 <sup>f</sup>	11 <sup>e</sup>	5.05 <sup>d</sup>	0.23 <sup>d</sup>	1.33 <sup>e</sup>	50.66 <sup>e</sup>	95.7 <sup>e</sup>	38 <sup>f</sup>	102.66 <sup>c</sup>	76.66 <sup>a</sup>
LSD	0.5	0.1	0.4	0.5	0	0.2	0.7	1.4	0.1	1.3	0.6
CV	3.1	3.3	2.9	4.3	3.4	4.8	1.5	1.4	1.1	1.3	2.5
Grand mean	17	1.9	15	11	0.3	3.7	52	105	41	105	24

Average of three replications. Mean separated by LSD and columns represented with same letters are not significantly different at 5% level of significance. Note: DAE (days after crop emergence), HW (hand weeding), CW (chemical weeding)

#### **4.3.16. Days to Heading**

There were differences in weed management methods and days to lead among species (Table 21). The average of heading recorded weeding management and varieties (52 days).

#### **4.3.17. Effect of Weeding Management on Days of Heading**

Flowering days are one of the most important seasonal changes in the biological life cycle (phenological parameter) of any crop plant that determine or modify the productive characteristics (Pandey *et al.*, 2009). The analyzed data presented in Table 21 shows that the flowering days have a significant impact on the weed management practices and variety. The earlier heading was recorded by weedy check plots (50.66 days), maximum days of heading shown by weed free treatments (54.4 days).

#### **4.3.18. Effect of Varieties on Days of Heading on Tef**

The variety Kora (56.22 days) showed significantly longer days to flower as compared to the variety Quncho (49.5 days) and the increment days to heading were 5.2%. Those that early emerge and early flowered varieties have earlier access to water, nutrients, and sunlight for their vegetative and reproductive growth and development. Similar results with Habtamu Gebrehiwot *et al.*, 2020); early flowering varieties have earlier access to water, nutrients and sunlight for vegetative and reproductive growth and development. So weeding may be the reason the maturity of the varieties is delayed because it allows the variety to use the soil resources efficiently and less competition from weeds.

#### **4.3.19. Interaction Effect WM and Varieties of Tef on DH**

Days to flowering was significantly ( $p < 0.05$ ) influenced by varieties, weeding methods and their interaction (Appendix 4). It was observed that longer time for heading in weed free treatments were (58, 56.6) days in Kora and Dagim respectively which was statistically par with interaction effect of the application Pallas 45 OD 0.3 l ha<sup>-1</sup> at 31 DAE supplemented with one hand weeding at 41 DAE and kora variety. This may be due to effective weed control with these treatments, reducing weed population density and reducing competition for resources available to the weed; this allowed more time for a crop to remain in vegetative growth, eventually leading to a longer period of up to 50% flowering. The reason for this is that there

is no competition with weeds for resources (such as moisture, nutrients, etc.) for a long time, which allows the plant to grow vegetative for a longer period without heading. This result is in line with the finding of (Mengesha Kebede *et al.*, 2015).

On the contrary, the statistical analysis of variance indicates that the shortest days (48.6 days) required for 50% was observed in interaction of the weedy area and Quncho variety. This earlier time that is required for 50% heading might be because plots with highest weed density had continuous antagonism for the same nutrients, moisture, and volume of space so plants under resource-limited conditions grow rapidly to compensate for this limitation and complete 50% of the head early. The result was agreed with (Mengesha Kebede *et al.*, 2015) who reported that as to the weeding effect, early heading of barley was recorded from the weedy.

#### **4.3.20. Physiological Maturity Days**

There were differences in days to maturity among weed management practices and varieties (Table 21). The average of heading recorded weeding management and varieties (105 days). So weeding may be the reason the maturity of varieties is delayed because they are allowed for different resources with no competition from weeds. Plots can predict stress (limited supply of water and nutrients) in the soil where competition with weeds may occur. In most cases, plants limited water and nutrient supply to facilitate different structures and their development and growth up as survival mechanisms for stress (Lambers *et al.*, 2008).

#### **4.3.21. Effect of Weeding Management on Days of Heading**

Physiological maturity date is one of the important biological life cycle parameters (phenological parameter) when determining or adjusting the yield improving characters of any crop plant. The analyzed data presented in Table 21 revealed that maturity days significantly influenced weed management practices and variety. The earlier maturity days recorded by weedy check plots (95.57 days), delay maturity shown by weed free treatments (109.82 days). Tef varieties arriving early with weedy check plots can be a way to avoid stress (due to the limited supply of water and nutrients in the soil) may occur due to crop competition with weeds (Habtamu Gebrehiwot *et al.*, 2020).

#### **4.3.22. Effect of Varieties on Days of Heading on Tef**

The variety Kora (107.56 days) showed significantly maximum days to maturity as compared to the variety Quncho (102.37 days) and the decreased days by 5.19 days (4.8%). Varieties of tef vary in their response to water, nutrients, light and heat stress (Vos *et al.*, 2013).

#### **4.3.23. Interaction Effect of Weed Management and Varieties on PM**

The interaction effect of varieties and weeding methods had a significant ( $p < 0.05$ ) effect on physiological maturity of the tef crop. The results showed that delayed maturity (116, 112) was observed at integrated weed free and Kora and Quncho varieties plots respectively which are statistically par with interaction effect of the application Pallas  $0.3 \text{ l ha}^{-1}$  at 31 DAE supplemented with one hand weeding at 41 DAE and Kora variety (Table-22). Thus, weeding might have caused delayed maturity of the varieties because it allowed the varieties to use resources more efficiently and with less competition from weeds (Habtamu Gebrehiwot *et al.*, 2020).

On the other hand, the statistical analysis of the data indicates that the earliest time for a crop to reach physiological maturity was observed at weedy check and Quncho variety plot (97.3 days) which was statistically on par with one hand weeding (Table - 22). This may be due to uncontrolled weed growth, resulting in limited resource availability and rapid plant growth and early completion of physiological maturity. On the other hand, early maturity of tef varieties in un-weeded plots might be a mechanism for escaping the stress (due to limited availability of water and nutrients in the soil) that could occur due to the competition of the crop with weeds. In most cases, plants allocate their limited water and nutrient supplies to their various structures to facilitate their growth and development during stress as a survival mechanism (Habtamu Gebrehiwot *et al.*, 2020). Tef varieties differ in their response to water, nutrients, light, and heat stress (Mengistu and Mekonnen, 2011).

#### **4.3.24. Plant Height**

Plant height is one of the important growth parameters as it determines or modifies the yield-determining characters of any crop plant and ultimately shapes the grain yield (Pandey *et al.*,

2009). For the tef variety, the height of the plant should be medium type (Reddy and Reddi, 1997). The analyzed data presented in Table 21 revealed that, on an average, plant height increased up to 105 (cm), depending on weed management practices and variety. Plant height was significantly influenced by all weed management practices and varieties.

#### **4.3.25. Effect of Weed Management on Plant Height**

The data showed that weed-free treatments produced significantly taller plants (105.77 cm); statistically par with chemical weeding supplemented with one hand weeding; chemical weeding alone, and two hands weeding, On the other hand, the weed check plot (102.66 cm) produced short plants. Plants respond to restricted sunlight due to weed competition by elongating their stems (Weiner, 1986)

#### **4.3.26. Effect of Variety on Plant Height**

The variety Kora (106.83 cm) showed significantly taller plants as compared to the variety Dagim (103.16 cm) and the increment plant height was 3.4%. The height of a plant is spatially variable depending on water, nutrients and sunlight. Normally in tef production, a good supply of water, nutrients and sunlight will result in high plants longer panicles for varieties.

#### **4.3.27. Interaction Effect of WM and Varieties of Tef on Plant Height**

The main effects of varieties and weeding practices and their interaction had a significant ( $p < 0.05$ ) effect on plant height (Appendix Table 4). The taller plant height was obtained from the interaction of all varieties at weedy check plots (109 cm) followed by interaction effect of two hand weeding at 3 and 5 WAE (107cm) on Kora variety. While the shortest plant height (102.6cm) as compared to weedy check was obtained from the interaction effects of Dagim varieties and application of 0.4 l ha<sup>-1</sup> Pallas 45 OD at 31 DAE and with weed free plot statistically par with Kora variety (Table- 22).

The result clearly showed that the plant attained its taller height where the competition was severe for light between crop as well as weed but at lower competition, the plant could not invest larger resources to attain its maxim. Not only genotypic variability, but also agronomic management practices of cereal crops have a conspicuous effect on plant height and panicle

length. Similar findings was reported from Bibi *et al*, (2008) who reported that in weedy check the wheat crop invests photosynthetic in attaining the vegetative superiority by shading weeds. Plant height is a unique trait that is more affected by genotype than environment; however, the interaction of factors significantly changed plant height at some level (Safdar *et al.*, 2011).

Table 22. Interaction of weed management and varieties on yield characters of tef

Variety x Weeding	Thousand Grain Weight	Number of tillers	Days to Heading	Days to Maturity	Panicle length	Plant height
<b>V1:W1</b>	0.3d <sup>e</sup>	3.56 <sup>hi</sup>	54.0 <sup>c</sup>	104 <sup>cde</sup>	41.2 <sup>bcde</sup>	105 <sup>cde</sup>
<b>V1:W2</b>	0.29 <sup>ef</sup>	3.73 <sup>gh</sup>	54.3 <sup>c</sup>	108 <sup>bcd</sup>	40.1 <sup>def</sup>	104.6 <sup>de</sup>
<b>V1:W3</b>	0.27 <sup>g</sup>	2.3 <sup>k</sup>	48.6 <sup>h</sup>	98 <sup>fg</sup>	41.5 <sup>bcd</sup>	104.33 <sup>ef</sup>
<b>V1:W4</b>	0.29 <sup>ef</sup>	4.1 <sup>efg</sup>	50.6 <sup>efg</sup>	101.3 <sup>efg</sup>	41 <sup>bcde</sup>	105.0 <sup>cde</sup>
<b>V1:W5</b>	0.31 <sup>cd</sup>	4.83 <sup>cd</sup>	56.3 <sup>b</sup>	112.6 <sup>ab</sup>	42.8 <sup>a</sup>	103.67 <sup>f</sup>
<b>V1:W6</b>	0.22 <sup>i</sup>	1.06 <sup>l</sup>	48.6 <sup>h</sup>	97.3 <sup>g</sup>	38 <sup>fg</sup>	108.66 <sup>a</sup>
<b>V2:W1</b>	0.32 <sup>bc</sup>	4.16 <sup>ef</sup>	52.3 <sup>d</sup>	105.3 <sup>cde</sup>	42.1 <sup>bcd</sup>	102.36 <sup>g</sup>
<b>V2:W2</b>	0.32 <sup>ab</sup>	5.33 <sup>b</sup>	56.0 <sup>b</sup>	112 <sup>ab</sup>	45.83 <sup>a</sup>	105.6 <sup>c</sup>
<b>V2:W3</b>	0.3d <sup>e</sup>	3.3 <sup>i</sup>	51.6 <sup>de</sup>	103.3 <sup>cdef</sup>	40.46 <sup>cd</sup>	104.71 <sup>de</sup>
<b>V2:W4</b>	0.29 <sup>ef</sup>	4.76 <sup>cd</sup>	52.3 <sup>d</sup>	104.6 <sup>cde</sup>	40.4 <sup>cde</sup>	107 <sup>b</sup>
<b>V2:W5</b>	0.33 <sup>a</sup>	6.53 <sup>a</sup>	58.0 <sup>a</sup>	116.0 <sup>a</sup>	45.2 <sup>a</sup>	102.0 <sup>g</sup>
<b>V2:W6</b>	0.24 <sup>h</sup>	1.96 <sup>k</sup>	50.6 <sup>efg</sup>	101.3 <sup>efg</sup>	35.9 <sup>gh</sup>	109.0 <sup>a</sup>
<b>V3:W1</b>	0.30 <sup>de</sup>	3.7 <sup>ghi</sup>	51.3 <sup>def</sup>	102.6 <sup>defg</sup>	42.36 <sup>bc</sup>	103.66 <sup>f</sup>
<b>V3:W2</b>	0.30 <sup>de</sup>	4.0 <sup>fg</sup>	53.8 <sup>c</sup>	104.9 <sup>cde</sup>	45.23 <sup>a</sup>	105.29 <sup>cd</sup>
<b>V3:W3</b>	0.28 <sup>fg</sup>	2.76 <sup>j</sup>	50 <sup>fgh</sup>	100 <sup>efg</sup>	39.67 <sup>ef</sup>	103.66 <sup>f</sup>
<b>V3:W4</b>	0.27 <sup>g</sup>	4.5d <sup>e</sup>	51.2 <sup>def</sup>	102.5 <sup>efg</sup>	39.8 <sup>ef</sup>	102.34 <sup>g</sup>
<b>V3:W5</b>	0.32 <sup>bc</sup>	5.03 <sup>bc</sup>	56.6 <sup>ab</sup>	108.6 <sup>bc</sup>	47.26 <sup>a</sup>	102.6 <sup>g</sup>
<b>V3:W6</b>	0.24 <sup>h</sup>	1.3 <sup>l</sup>	49.3 <sup>gh</sup>	101.3 <sup>efg</sup>	35.33 <sup>h</sup>	109.0 <sup>a</sup>
LSD (0.05)	0.02	0.41	1.33	5.4	2.1	0.7
CV (%)	3.42	6.64	1.53	3.14	3.1	0.4

In each column, having similar letters do not differ significantly, at 5 % level of probability. V1= Quncho, V2=Kora, V3=Dagim, w1 = Pallas 45 OD 0.4 l ha<sup>-1</sup> at 31 DAE, w2 = (Pallas 45 OD) 0.3 l ha<sup>-1</sup> at 31 days after crop emergence (DAE) with at 41 DAE one hand weeding, w3= one hand weeding at 31 DAE, w4 = two-hand weeding at 31 DAE and at 41 DAE, w5 = weed free, and w6 = weedy check, CV=Coefficient of variation

#### **4.3.28. Above Ground Dry Matter**

The average crop dry matter ( $17 \text{ t ha}^{-1}$ ) had a significant impact on weed management and varieties of tef.

#### **4.3.29. Effect of Weed Management Practices on Dry Matter Production**

Above ground dry matter accumulation was significantly higher at application of chemical  $0.3 \text{ l ha}^{-1}$  at 31 DAE supplemented with one hand weeding ( $19.4 \text{ ha}^{-1}$ ) statistically par with chemical weeding stem dry matter accumulation non-significant with chemical weeding  $0.4 \text{ l ha}^{-1}$ . While the lower dry matter is recorded by weedy check treatments (Table 21).

The amount of dry matter production depends on the efficiency of crop photosynthesis, which in turn depends on the large and efficient assimilation area, sufficient sunlight and carbon dioxide supply and suitable environmental conditions (Reddy and Reddi, 2002). The amount of economic production depends on the distribution of net dry matter produced in different parts of the plant, which determines the amount of dry matter production (Arnon, 1972).

#### **4.3.30. Effect of Variety of Tef on Dry Matter Production**

There was significant effect in terms of dry matter accumulation between the variety Kora ( $17.7 \text{ t ha}^{-1}$ ), variety Dagim ( $17.1 \text{ t ha}^{-1}$ ) and variety Quncho ( $16.3 \text{ t ha}^{-1}$ ). But these varieties were very different in terms of dry matter production. The increase in dry matter content of the top variety was 7.9%. Among all the varieties Kora has the highest biomass yield. This variety was followed by a high yielder DZ-Cr-387 (Quncho) in previous studies (Kebebew Assefa *et al.*, 2017).

#### **4.3.31. Interaction Effect of Weed Management and Varieties of Tef on Biomass**

Biomass yield represents the overall growth performance of the plant as well as the crop and is considered to be the essential yield parameter to get useful information about the overall growth of the crop. It is highly inclined by competitive varieties and weed control practices. Interaction of genotypic variation and weeding practices resulted in the difference in biomass. The highest biomass yield ( $20.35 \text{ ton ha}^{-1}$ ) was obtained from treatment combination of Pallas

0.4 l ha<sup>-1</sup> at 31 DAE and Kora improved tef variety which is statistically par with weed free and Dagim variety as well as interaction effect of application of Pallas 0.3 l ha<sup>-1</sup> at 31 DAE supplemented with one hand weeding at 41 DAE and Kora and Dagim varieties (Table- 23).

The increase in biomass yield with use of improved varieties and weeding practices could be attributed to increased availability of nutrients and soil moisture for the crop as a result of reduced competition. Furthermore, the greatest biological yield was attained with the use of herbicides, their sole application as well as chemicals accompanied with hand weeding. While the lowest value was 10.8 ton ha<sup>-1</sup> un-weeded plot for the variety (Quncho) indicating 88.4% variation in above ground biomass due to treatment interaction (Table -23). Similarly, (Gbrekidan Feleke et al., 2022) reported that the reduced biomass yield in uncontrolled plots might be due to increased competition for resources; this increased competition between increased weed population and low weed control effectiveness leads to thin and weak stems reduced tiller number and reduced total biomass yield. There was significant positive correlation ( $r = 0.94$  \*\*\*) between above ground biomass and yield (t ha<sup>-1</sup>) (Appendix figure-2). This is because weeding at an appropriate time by herbicide and supplementing with cultural practices could provide a favorable environment for the crop providing a plenty of chance to utilize available resources which ultimately leads to better biological yield.

#### **4.3.32. Straw Yield**

Analysis of the data (Table 21) showed an average straw yield of 15 t ha<sup>-1</sup> across the experimental trials. The straw yield was significantly influenced by weed management and variety.

#### **4.3.33. Effect of Weed Management on Straw Yield of Tef**

Chemical Pallas 0.4 l ha<sup>-1</sup> at 31 DAE weeding (16.72 t ha<sup>-1</sup>) had the highest straw yield statistically compared to chemical (0.3l ha<sup>-1</sup>) weeding with one hand weeding and was significantly higher than weed check (11 t ha<sup>-1</sup>), one hand weeding (13.78 t ha<sup>-1</sup>), two hand weeding (15.72 t ha<sup>-1</sup>). Therefore, according to the findings, weeding resulted in the highest straw yield and statistically it was equal to that of chemical weeding improved by one hand weeding.

#### **4.3.34. Effect of Variety on Straw Yield of Tef**

There was significant variation among the Kora variety (15.63 t ha<sup>-1</sup>), and Dagim (15.15 t ha<sup>-1</sup>) for producing straw yield but the variety Quncho (14.45 t ha<sup>-1</sup>) produced 7.5% lower straw yield than the Kora variety.

#### **4.3.35. Interaction Effect of WM and Varieties of Tef on Straw Yield**

Analysis of the data showed the maximum straw yield (18.42 ton ha<sup>-1</sup>) resulted from the interaction effect of Pallas 45 OD 0.4 l ha<sup>-1</sup> at 31 DAE and Quncho variety followed by interaction effect of Pallas 45 OD 0.3 l ha<sup>-1</sup> at 31 DAE supplemented with one hand weeding at 41 DAE and Kora variety. The lowest result recorded in treatment of unweeded combination with Quncho variety (10.35 ton ha<sup>-1</sup>).

The data revealed that in the un-weeded plots the yield straw was significantly lower than the other weed management practices and the interaction effect of weeding methods and tef varieties were significant effects of straw yield. This is result also a result reported by (Tamado Tana *et al.*, 2015) controlling weed leads to more vigorous plants, which may increase biological yield especially in straw because of healthier roots and greater density of root hairs.

#### **4.3.36. Harvest Index**

Grain yield in cereals is related to biological yield and grain harvest index (Donald and Hamblin, 1976). The value of the rice yield indicator varies greatly among cultivars, locations, seasons and ecosystems, ranging from 0.35 to 0.62, indicating that this variable is important for yield simulation (Kiniry *et al.*, 2001). The average value (Table 21) of the harvest index in the experiment was 11 %. Harvest Index was significantly different among weed management practices and significant difference between three varieties. Snyder and Carlson (1984) reviewed harvest index for selected annual crops and variations 23 to 50% for rice.

#### **4.3.37. Effect of Weed Management Practices on Harvest Index of Tef**

Weed free treatments (13.47%) produced the highest harvest index, which was significantly different from one hand weeding (10.19%) and weedy check (5.05%). Two hand weeding

(12.01%). Chemical weeding supplemented by one hand weeding (12.46 %) produced higher than harvest index statistically par with chemical weeding. The effects of weed management practices on the tef plant height, biomass yield, and grain yield and harvest index were significantly different from the management practices in the study.

#### 4.3.38. Effect of Variety on Harvest Index of Tef

There was a significant difference in the harvest index produced by the variety Kora (11.14%) and Quncho (10.76 %), Dagim (10.79%). Interaction Effect of Weed Management and Varieties of Tef on HI

The results of interaction resulted in the varieties and weeding practices had a significant ( $p < 0.05$ ) influence on crop harvest index. Highly significant harvest index (14.85%) was observed as an integration effect of the improved variety (Kora) with the weeding practices found when the crop was kept weed free throughout the growing season (Table -23). This was followed by application of Pallas 0.3 l ha<sup>-1</sup> at 31 DAE supplemented with one hand weeding at 41 DAE and Quncho variety statistically par with interaction effect of two hands weeding at 31 and 41 DAE with Quncho variety. Significant varietal differences in harvest index have also been reported by (Dejene Gemechu and Tolera Abebe , 2020) improved Kora and Quncho varieties of tef had significantly higher harvest index. The weedy check showed the minimum harvest index (4.27%) recorded in the Quncho variety. This lower harvest index might be due to severe weed competition with the crop for the growth factors, which restricted the growth and development of the crop in weedy check plots. Tesfaye Amare et al., (2014) concluded that the harvest index increased with decreased weed competition. There was highly significant positive correlation ( $r = 0.95$  \*\*\*) between harvest index and yield (t ha<sup>-1</sup>) (Appendix figure- 2).

Table 23. Interaction of varieties and WM on yield of tef

variety * weeding	AGB (t ha-1)	GY (t ha-1)	SY t/ha	HI (%)
<b>V1:W1</b>	18.0 <sup>de</sup>	1.9 <sup>de</sup>	16.11 <sup>de</sup>	10.49 <sup>efg</sup>
<b>V1:W2</b>	18.4 <sup>cde</sup>	2.43 <sup>b</sup>	15.96 <sup>e</sup>	13.23 <sup>bc</sup>
<b>V1:W3</b>	15.4 <sup>gh</sup>	1.36 <sup>g</sup>	14.03 <sup>f</sup>	8.8 <sup>h</sup>

<b>V1:W4</b>	16.8 <sup>f</sup>	2.19 <sup>c</sup>	14.69 <sup>f</sup>	13.02 <sup>bc</sup>
<b>V1:W5</b>	18.3 <sup>cde</sup>	2.5 <sup>ab</sup>	15.77 <sup>e</sup>	13.88 <sup>ab</sup>
<b>V1:W6</b>	10.8 <sup>j</sup>	0.46 <sup>i</sup>	10.35 <sup>i</sup>	4.27 <sup>j</sup>
<b>V2:W1</b>	20.35 <sup>a</sup>	1.9d <sup>e</sup>	18.42 <sup>a</sup>	9.52 <sup>gh</sup>
<b>V2:W2</b>	20.14 <sup>a</sup>	2.5 <sup>b</sup>	17.64 <sup>ab</sup>	12.45 <sup>cd</sup>
<b>V2:W3</b>	16.18 <sup>fg</sup>	1.74 <sup>ef</sup>	14.4 <sup>f</sup>	10.79 <sup>ef</sup>
<b>V2:W4</b>	18.96 <sup>bc</sup>	2.46 <sup>b</sup>	16.49 <sup>cde</sup>	13.01 <sup>bc</sup>
<b>V2:W5</b>	18.3 <sup>cde</sup>	2.72 <sup>a</sup>	15.62 <sup>e</sup>	14.85 <sup>a</sup>
<b>V2:W6</b>	12.2 <sup>i</sup>	0.87 <sup>h</sup>	11.39 <sup>h</sup>	7.09 <sup>i</sup>
<b>V3:W1</b>	18.81 <sup>cd</sup>	1.94 <sup>d</sup>	16.87 <sup>bcd</sup>	10.36 <sup>fg</sup>
<b>V3:W2</b>	19.7 <sup>ab</sup>	2.45 <sup>b</sup>	17.3 <sup>bc</sup>	12.42 <sup>cd</sup>
<b>V3:W3</b>	14.57 <sup>h</sup>	1.69 <sup>f</sup>	12.87 <sup>g</sup>	11.61 <sup>de</sup>
<b>V3:W4</b>	17.91 <sup>e</sup>	2.17 <sup>c</sup>	15.73 <sup>e</sup>	12.15 <sup>cd</sup>
<b>V3:W5</b>	19.89 <sup>a</sup>	2.57 <sup>ab</sup>	17.32 <sup>bc</sup>	12.93 <sup>bc</sup>
<b>V3:W6</b>	11.62 <sup>ij</sup>	0.69 <sup>h</sup>	10.92 <sup>hi</sup>	5.97 <sup>i</sup>
LSD (0.05)	1.0	0.2	1.0	1.0
CV (%)	3.1	6.0	4.0	7.0

In each column, having similar letters do not differ significantly, whereas figures bearing dissimilar letters differ at 1% and 5 % level of probability (as per LSD). V1= Quncho, V2=kora, V3=dagim, w1 = Pallas 45 OD 0.4 l ha<sup>-1</sup> at 31 DAE, w2 = (Pallas 45 OD) 0.3 l ha<sup>-1</sup> at 31 days after crop emergence (DAE) with at 41 DAE one hand weeding, w3= one hand weeding at 31 DAE, w4 = two-hand weeding at 31 DAE and at 41 DAE, w5 = weed free, and w6 = weedy check, CV=Coefficient of variation

#### 4.4. Cost Benefit Analysis

A cost-benefit analysis showed that significant differences in marginal revenue (MR) and benefit cost ratio (BCR) were observed among the experimental treatments evaluated (Table 24). By comparing the combination of management practices and different varieties tef, the most prominent MR (97,312 and 94,855 birr ha<sup>-1</sup>) and BCR (3.2 and 3.2) were calculated from application of Pallas 0.3 l ha<sup>-1</sup> supplemented with hand weeding and varieties of Kora and Dagim, respectively. Conversely, the lowest MR (9628 and -2984 birr ha<sup>-1</sup>) and BCR (1.3 and 0.9) were computed from weedy check and varieties of Dagim and Quncho, respectively. The MR and BCR obtained from the marketing of goods for Pallas application supplemented

with hand weeding of the Kora variety increased by 103 and 67 % as compared to the variety of Quncho with weedy check.

Cost-benefit analysis indicated that integration of Pallas 45 OD with supplementary hand weeding exhibited the topmost MR (97,312 Birr ha<sup>-1</sup>) and BCR (3.2). In general, co-application of broadleaf kill herbicides with additional hand weeding and variety of Kora provides better MR and BCR than single weed management practices (Table 24). This analysis is in agreement with the study of (Suresh kumar, 2016; Niguse Hundesa et al., 2023).

Table 24. Economic Feasibility Analysis for Weed Management and varieties of tef

Treatments	Total variable cost	Yield	Adjusted yield	Yield benefit	Straw yield	Straw benefit	Gross benefit	Marginal Revenue	Benefit Cost Ratio
	ETB ha <sup>-1</sup>	kg ha <sup>-1</sup>	kg ha <sup>-1</sup>	ETB ha <sup>-1</sup>	kg ha <sup>-1</sup>	ETB ha <sup>-1</sup>	ETB ha <sup>-1</sup>	ETB ha <sup>-1</sup>	
<b>V1:W1</b>	35628	1890	1701	102060	15670	5369	107429	71801	3.0
<b>V1:W2</b>	43736	2433	2190	131400	15960	5469	136869	93133	3.1
<b>V1:W3</b>	40768	1368	1232	73890	14010	4800	78690	37922	1.9
<b>V1:W4</b>	49768	2198	1979	118710	14780	5064	123774	74006	2.5
<b>V1:W5</b>	67768	2543	2289	137340	15800	5414	142754	74986	2.1
<b>V1:W6</b>	31768	467	420	25200	10460	3584	28784	-2984	0.9
<b>V2:W1</b>	35628	1931	1738	104256	17980	6161	110417	74789	3.1
<b>V2:W2</b>	43736	2500	2250	135000	17650	6048	141048	97312	3.2
<b>V2:W3</b>	40768	1747	1573	94356	14440	4948	99304	58536	2.4
<b>V2:W4</b>	49768	2469	2222	133344	16580	5681	139025	89257	2.8
<b>V2:W5</b>	67768	2723	2451	147060	15640	5359	152419	84651	2.2
<b>V2:W6</b>	31768	870	783	46980	11520	3947	50927	19159	1.6
<b>V3:W1</b>	35628	1943	1749	104940	16510	5657	110597	74969	3.1
<b>V3:W2</b>	43736	2457	2211	132660	17310	5931	138591	94855	3.2
<b>V3:W3</b>	40768	1693	1524	91440	12890	4417	95857	55089	2.4
<b>V3:W4</b>	49768	2177	1960	117576	15820	5421	122997	73229	2.5
<b>V3:W5</b>	67768	2573	2316	138960	17330	5938	144898	77130	2.1
<b>V3:W6</b>	31768	697	627	37620	11020	3776	41396	9628	1.3

Price of Pallas 45 OD, 3556 ETB ha<sup>-1</sup>; for spraying, 300 ETB/ha<sup>-1</sup>(Ethiopian birr ha<sup>-1</sup>); One-time hand weed price, 30 people at ETB 300/person; Cost of post-production works, ETB 300/person; the selling price of tef is 0.34 Birr/kg.

## 5. SUMMARY AND CONCLUSIONS

Tef (*Eragrostis tef* (Zucc) Trotter) is one of the most important small grain crops that have been used for food in Ethiopia for many centuries. In the country, it is the most extensively cultivated cereal crop in terms of area coverage. However, there are many important features such as cultivation and production value, its productivity is relatively low compared to other grains. Improper weed control has been identified as one of the factors limiting tef productivity in Ethiopia. Effective weed management is critical to reducing crop losses and costs associated with weed control. Therefore, the objective of this study was to investigate appropriate weed management practices to help improve tef performance and sustainable production in the study area.

According to the results of this study, the main weed species recorded in the experimental field are broad-leaved weeds, grasses and sedges. Higher weed density and weed dry weight resulted in weedy-check combined with Quncho variety, while significant reduction of weed dry weight, weed index, and weed control efficiency and herbicide efficiency index in the weed-free treatment. The study further revealed that tef crops variety when sown Kora and kept free from weed delay heading and maturity significantly as compared other varieties and weedy check. The results also showed that treatments left weedy for all growth stage resulted in increased plant height of tef. On the other hand, the highest grain yield (2.72 ton ha<sup>-1</sup>), above ground dry matter, thousand grain weight, panicle length, tiller number, and harvest index were recorded in weed free combined with Kora variety.

Based on the partial budget analysis the most economically feasible treatments were obtained from the application of combined effect of Kora variety and Pallas 45 OD 0.3 l ha<sup>-1</sup> at 31 DAE supplemented with one hand weeding at 41 DAE. Generally, the average benefit cost ratio (3.2) was recorded from interaction effects of the Kora variety and Pallas 45 OD 0.3 l ha<sup>-1</sup> at 31 DAE supplemented with one hand weeding at 41 DAE. Since, this study was conducted only in one location and one year it is difficult to give a conclusive recommendation. Therefore this study should be replicated over locations and year to improve productivity of tef on areas with similar agro-ecology with the study area.

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## 7. APPENDICES

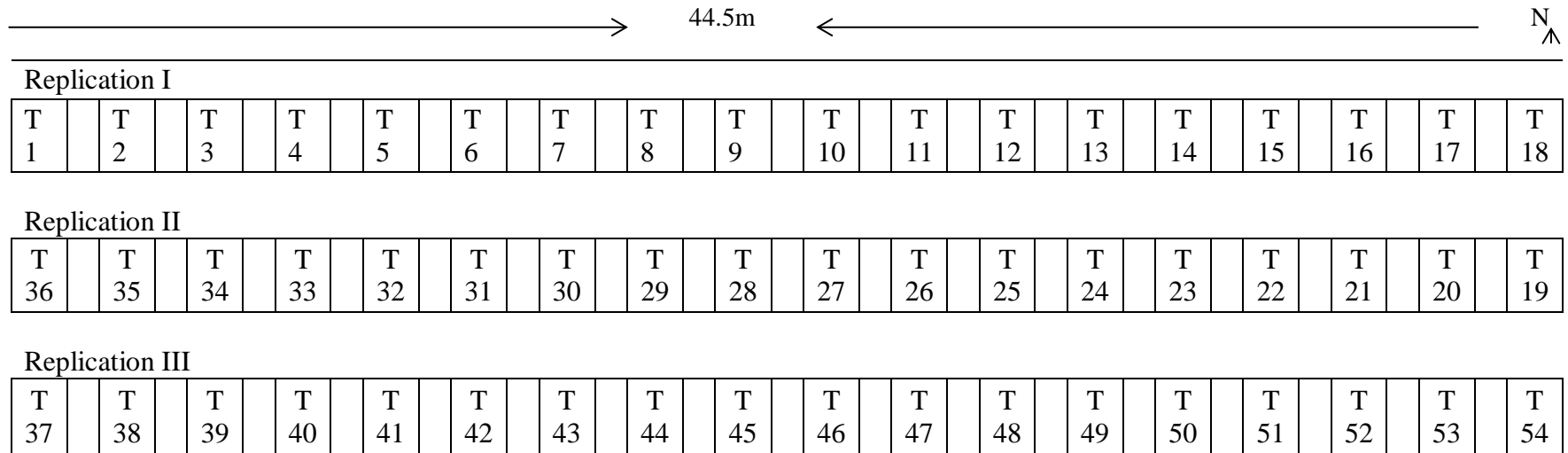


Figure 1. Layout of field

**Note,** T = treatment

Width= 3m

Length= 2m

Plot Size= 3m x 2m = 6m<sup>2</sup>

Width of Expt. = 11m

Length of Expt. = 44.5m

Path between Rep. = 1m

Path between plots = 0.5m

Total Area Required 11 \*44.5 = 489.5m<sup>2</sup>

Table 1. Details of the treatment combinations in the experiment

Treatment combination	Symbol
Quncho and Pallas 0.4 l ha <sup>-1</sup> at 31 DAE	v1w1
Quncho and Pallas 0.3 l ha <sup>-1</sup> at 31 DAE with one hand weeding at 41 DAE	v1w2
Quncho and weed free	v1w5
Quncho and weedy check	v1w6
Quncho and two hand weeding at 31 and 41 DAE	v1w4
Quncho and One hand weeding at 31 DAE	v1w3
Dagim and weedy check	v3w6
Dagim and one hand weeding at 31 DAE	v3w3
Kora and two hand weeding at 31 and 41 DAE	v2w4
Kora and one hand weeding at 31 DAE	v2w3
Dagim and Pallas 0.3 l ha <sup>-1</sup> at 31 DAE with one hand weeding at 41 DAE	v3w2
Kora and Pallas 0.4 l ha <sup>-1</sup> at 31 DAE	v2w1
Dagim and weed free	v3w5
Dagim and two hand weeding at 31 and 41 DAE	v3w4
Kora and Pallas 0.3 l ha <sup>-1</sup> at 31 DAE with one hand weeding at 41 DAE	v2w2
Kora and weedy check	v2w6
Kora and weed free	v2w5
Dagim and Pallas 0.4 l ha <sup>-1</sup> at 31 DAE	v3w1

Table 2. MSAV for weed density in varieties of tef and weed management

source	df	45DAE			55DAE			At harvest		
		broad leaf	Grass	Sedges	broad leaf	grass	Sedges	Broad leaf	Grass	sedges
<b>Rep</b>	2	0.6 <sup>ns</sup>	10.4 <sup>***</sup>	2.12 <sup>*</sup>	12.1 <sup>***</sup>	6.0 <sup>ns</sup>	1.45 <sup>*</sup>	1.7 <sup>ns</sup>	1.1 <sup>ns</sup>	0.48 <sup>ns</sup>
<b>V</b>	2	1236.4 <sup>***</sup>	7284.6 <sup>***</sup>	1028.32 <sup>***</sup>	2045.1 <sup>***</sup>	5119 <sup>***</sup>	752.72 <sup>***</sup>	2887.8 <sup>***</sup>	4277.8 <sup>***</sup>	520 <sup>***</sup>
<b>W</b>	5	4259.1 <sup>***</sup>	20201.9 <sup>***</sup>	765.03 <sup>***</sup>	5429.1 <sup>***</sup>	23008 <sup>***</sup>	798.66 <sup>***</sup>	7142.9 <sup>***</sup>	25807.6 <sup>***</sup>	878 <sup>***</sup>
<b>v x w</b>	10	120.5 <sup>***</sup>	3315 <sup>***</sup>	134.21 <sup>***</sup>	420.8 <sup>***</sup>	1471 <sup>***</sup>	162.9 <sup>***</sup>	1244.4 <sup>***</sup>	739.6 <sup>***</sup>	208 <sup>***</sup>
<b>error</b>	34	0.9	0.6	0.56	0.5	4.0	0.36	0.8	0.8	0.33

R= replication, V= variety, W= weed management, df = degree of freedom mean values followed by the same letter with in a column for a given treatment level are not significantly different at 5% probability level \*\*\* and \*\* denote significant differences at P < 0.01 and P < 0.05 probability levels, respectively.

Table 3. MSAV for weed dry biomass in varieties and weed management

Source	df	45DAE			55DAE			At harvest		
		Broadleaf	Grass	Sedges	Broad leaf	Grass	Sedges	Broadleaf	Grass	Sedges
<b>Rep</b>	2	2.8 <sup>*</sup>	1 <sup>ns</sup>	2.4 <sup>ns</sup>	2.4 <sup>ns</sup>	11 <sup>***</sup>	1.6 <sup>ns</sup>	4.4 <sup>*</sup>	4.9 <sup>*</sup>	4.56 <sup>*</sup>
<b>V</b>	2	795.1 <sup>***</sup>	6081 <sup>***</sup>	2077 <sup>***</sup>	2077.3 <sup>***</sup>	6129 <sup>***</sup>	1564 <sup>***</sup>	2624.4 <sup>***</sup>	5880.4 <sup>***</sup>	1132.02 <sup>***</sup>
<b>W</b>	5	26098.6 <sup>***</sup>	43158 <sup>***</sup>	6132 <sup>***</sup>	6132.1 <sup>***</sup>	34968 <sup>***</sup>	3626 <sup>***</sup>	21670 <sup>***</sup>	27897 <sup>***</sup>	1853.01 <sup>***</sup>
<b>V x W</b>	10	397.2 <sup>***</sup>	3216 <sup>***</sup>	754 <sup>***</sup>	754 <sup>***</sup>	2225 <sup>***</sup>	393 <sup>***</sup>	752.5 <sup>***</sup>	1550.7 <sup>***</sup>	180.94 <sup>***</sup>
<b>Error</b>	34	0.6	2.0	1.0	1.0	0.1	0.7	0.9	0.6	1.05

R= replication, V= variety, W= weed management, DF = degree of freedom Mean values followed by the same letter with in a column for a given treatment level are not significantly different at 5% probability level. \*\* And \* denote significant differences at P < 0.01 and P < 0.05 probability levels, respectively.

Table 4. MSAV for yield components in varieties and weed management

Source	DF	AGB(t ha <sup>-1</sup> )	GY(t ha <sup>-1</sup> )	SY(t ha-1)	HI (%)	TGW (g)	TTN	DH	DM	PL	PH (cm)
<b>Rep</b>	2	1.207*	0.0081 <sup>ns</sup>	0.746*	1.212**	0.02074 <sup>ns</sup>	0.0069 <sup>ns</sup>	1.076 <sup>ns</sup>	17.916 <sup>***</sup>	0.4 <sup>ns</sup>	27.056 <sup>***</sup>
<b>V</b>	2	8.452 <sup>***</sup>	0.1595 <sup>***</sup>	6.414 <sup>***</sup>	0.793*	0.24463 <sup>***</sup>	5.6191 <sup>***</sup>	216.059 <sup>***</sup>	127.094 <sup>***</sup>	4.29 <sup>**</sup>	60.667 <sup>***</sup>
<b>W</b>	5	82.63 <sup>***</sup>	4.8788 <sup>***</sup>	47.544 <sup>***</sup>	83.941 <sup>***</sup>	0.87352 <sup>***</sup>	18.0886 <sup>***</sup>	13.958 <sup>***</sup>	212.323 <sup>***</sup>	82 <sup>***</sup>	16.478 <sup>***</sup>
<b>V x W</b>	10	1.476 <sup>***</sup>	0.0224 <sup>***</sup>	1.581 <sup>***</sup>	2.308 <sup>***</sup>	0.02152*	0.2433 <sup>**</sup>	1.732 <sup>**</sup>	5.781*	10.1 <sup>**</sup>	5.778 <sup>**</sup>
<b>Error</b>	34	0.285	0.004	0.19	0.222	0.0098	0.0612	0.582	2.06	2.0	1.977

R= replication, V= variety, W= weed management, DF = degree of freedom Mean values followed by the same letter with in a column for a given treatment level are not significantly different at 5% probability level. \*\* And \* denote significant differences at P < 0.01 and P < 0.05 probability levels, respectively

Table 5. MSAV for HEI due to varieties and weed management

source	df	45DAE			55DAE			Harvest		
		broadleaf	grass	Sedges	Broadleaf	grass	sedges	Broadleaf	Grass	Sedges
<b>rep</b>	2	15 <sup>**</sup>	5.4 <sup>***</sup>	3.81 <sup>***</sup>	3.73 <sup>***</sup>	5.4 <sup>**</sup>	3.81 <sup>***</sup>	0.3 <sup>**</sup>	2.62 <sup>**</sup>	35.2 <sup>*</sup>
<b>v</b>	2	276 <sup>***</sup>	1035.2 <sup>***</sup>	443.35 <sup>***</sup>	443.21 <sup>***</sup>	1035.2 <sup>***</sup>	443.35 <sup>***</sup>	293.5 <sup>***</sup>	272.45 <sup>***</sup>	1252 <sup>***</sup>
<b>w</b>	5	4138.3 <sup>***</sup>	5583.8 <sup>***</sup>	2484.11 <sup>***</sup>	2484.18 <sup>***</sup>	5583.8 <sup>***</sup>	2484.11 <sup>***</sup>	3767.1 <sup>***</sup>	1241.26 <sup>***</sup>	8439 <sup>***</sup>
<b>v x w</b>	10	198.9 <sup>***</sup>	423.9 <sup>***</sup>	217.35 <sup>***</sup>	217.38 <sup>***</sup>	423.9 <sup>***</sup>	217.35 <sup>***</sup>	251.8 <sup>***</sup>	125.06 <sup>***</sup>	807 <sup>***</sup>
<b>Error</b>	34	2.7	0.2	0.29	0.19	0.2	0.29	0.1	0.34	1

R= replication, V= variety, W= weed management, DF = degree of freedom Mean values followed by the same letter with in a column for a given treatment level are not significantly different at 5% probability level. \*\*\* and \*\* denote significant differences at P < 0.01 and P < 0.05 probability levels, respectively

Table 6. MSAV for WCE due to varieties and weeding methods

Source	Df	45DAE			55DAE			Harvest		
		Broadleaf	Grass	Sedges	Broadleaf	Grass	Sedges	Broadleaf	Grass	Sedges
<b>Rep</b>	2	1.3 <sup>ns</sup>	1.2 <sup>ns</sup>	0.4 <sup>ns</sup>	0.5 <sup>ns</sup>	2.4 <sup>**</sup>	2.5 <sup>*</sup>	0.5 <sup>ns</sup>	0.2 <sup>ns</sup>	3.7 <sup>ns</sup>
<b>V</b>	2	6.9 <sup>***</sup>	201.8 <sup>***</sup>	1894 <sup>***</sup>	1843.9 <sup>***</sup>	80.1 <sup>***</sup>	1013.7 <sup>***</sup>	110.8 <sup>***</sup>	128.7 <sup>***</sup>	189.1 <sup>***</sup>
<b>w</b>	5	10501.6 <sup>***</sup>	10237.1 <sup>***</sup>	8075.3 <sup>***</sup>	8062.6 <sup>***</sup>	10274.8 <sup>***</sup>	7931.1 <sup>***</sup>	10640.6 <sup>***</sup>	10646.9 <sup>***</sup>	9455.2 <sup>***</sup>
<b>V x w</b>	10	42.4 <sup>***</sup>	28.9 <sup>***</sup>	213.6 <sup>***</sup>	213 <sup>***</sup>	25.5 <sup>***</sup>	143.2 <sup>***</sup>	11.4 <sup>***</sup>	88.9 <sup>***</sup>	187.4 <sup>***</sup>
<b>Error</b>	34	0.6	0.8	0.6	0.6	0.4	0.5	0.4	0.2	1.1

R= replication, V= variety, W= weed management, DF = degree of freedom Mean values followed by the same letter with in a column for a given treatment level are not significantly different at 5% probability level. \*\* and \* denote significant differences at P < 0.01 and P < 0.05 probability levels, respectively

Table 7. Details of cultural operations of tef under weed management and varieties

No	Particular Operations	2022
1	Field preparation	20 June -22 Aug
2	Seed sowing & NPSB with half of UREA application	22 Aug
3	One hand weeding at 31 DAE	22 Sep
4	Two hand-weeding at 31 DAE and 41 DAE	22 Sep & 2 Oct
5	Completely weed free	As weed emerged
6	Pallas 45 OD 0.3 l ha <sup>-1</sup> and one hand weeding	22 Sep & 2 Oct
7	Pallas 45 OD 0.4 l ha <sup>-1</sup> spraying	22 Sep
8	UREA top-dressing	24 Sep
9	Weed assessment	29 Aug -20 Dec
10	Crop measurement	10 Oct - 20 Dec
11	Harvesting	20 Dec
12	Threshing, cleaning and weighing	27 Dec

Table 8. General Cost of tef production under weed management and varieties of tef

Particulars	Unit	Qty.	Rate(ETB)	Total(ETB)
General cost cultivation				
Plough	Round	3	3500	10500
Urea	Kg	100	37.8	3780
NPSB	Kg	100	38.88	3888
Fertilizer transportation	Kg	200	0.5	100
Tef seed	Kg	10	80	800
Application of fertilizer and seed	Labor	2	300	600
Chemical /kartine	ml	200	800	800
Spraying of chemical	Labor	1	300	300
Harvesting	Labor	18	300	5400
Threshing	Labor	10	300	3000
Cleaning, drying and storage	Labor	2	300	600
Transport and packing materials	-	-	-	2000
<b>Total cost</b>				<b>31768</b>

Table 9. Variable Cost of tef production (Ethiopia birr: ETB)

Treatment	Particulars	Unit	Qty.	Rate (ETB)	Total (ETB)
T1	General cost of cultivation				31768
	Cost of chemical	l	0.4		3560
	Application of herbicide	Labor	1	300	300
	Total				35628
T2	General cost of cultivation				31768
	Cost of Pallas 45 OD	l	0.3		2668
	Application of herbicide	Labor	1	300	300
	One hand weeding	Labor	30	300	9000
	Total				43736
T3	General cost of cultivation				31768
	First hand weeding	Labor	30	300	9000
	Second hand weeding	Labor	30	300	9000
	Third hand weeding	Labor	30	300	9000
	Fourth hand weeding	Labor	30	300	9000
	Total				67768
T4	General cost of cultivation				31768
	Total				31768
T5	General cost of cultivation				31768
	One hand weeding	Labor	30	300	9000
	Two hand weeding	Labor	30	300	9000
	Total				49768
T6	General cost of cultivation				31768
	One hand weeding	Labor	30	3000	9000
	Total				40768
T7	General cost of cultivation				31768
	Total				31768
T8	General cost of cultivation				31768
	One hand weeding	Labor	30	300	9000
	Total				40768

T9	General cost of cultivation				31768
	First hand weeding	Labor	30	300	9000
	Second hand weeding	Labor	30	300	9000
	Total				49768
T10	General cost of cultivation				31768
	One hand weeding	Labor	60	300	9000
	Total				40768
T11	General cost of cultivation				31768
	Cost of Pallas 45 OD	l	0.3		2668
	Application of herbicide	Labor	1	300	300
	One hand weeding	Labor	30	300	9000
	Total				43736
T12	General cost of cultivation				31768
	Cost of chemical	l	0.4		3560
	Application of herbicide	Labor	1	300	300
	Total				35628
T13	General cost of cultivation				31768
	First hand weeding	Labor	30	300	9000
	Second hand weeding	Labor	30	300	9000
	Third hand weeding	Labor	30	300	9000
	Fourth hand weeding	Labor	30	300	9000
	Total				67768
T14	General cost of cultivation				31768
	First hand weeding	Labor	30	300	9000
	Second hand weeding	Labor	30	300	9000
	Total				49768
T15	General cost of cultivation				31768
	Cost of Pallas 45 OD	L	0.3		2668
	Application of herbicide	Labor	1	300	300
	One hand weeding	Labor	30	300	9000
	Total				43736

T16	General cost of cultivation				31768
	Total				31768
T17	General cost of cultivation				31768
	First hand weeding	Labor	30	300	9000
	Second hand weeding	Labor	30	300	9000
	Third hand weeding	Labor	30	300	9000
	Fourth hand weeding	Labor	30	300	9000
	Total				67768
T18	General cost of cultivation				31768
	Cost of chemical	1	0.4		3560
	Application of herbicide	Labor	1	300	300
	Total				35628

Table 10. Correlation coefficient among yield contributing and yield of tef

Parameters	GY	NT	SY	AGB	PL	DM	DH	TGW
HI	0.95 <sup>***</sup>	0.90 <sup>***</sup>	0.81 <sup>***</sup>	0.86 <sup>***</sup>	0.74 <sup>***</sup>	0.60 <sup>***</sup>	0.70 <sup>***</sup>	0.10 <sup>ns</sup>
GY		0.89 <sup>***</sup>	0.92 <sup>***</sup>	0.94 <sup>***</sup>	0.79 <sup>***</sup>	0.62 <sup>***</sup>	0.76 <sup>***</sup>	0.02 <sup>ns</sup>
NT			0.80 <sup>***</sup>	0.84 <sup>***</sup>	0.79 <sup>***</sup>	0.74 <sup>***</sup>	0.81 <sup>***</sup>	0.08 <sup>ns</sup>
SY				1.00 <sup>***</sup>	0.76 <sup>***</sup>	0.52 <sup>***</sup>	0.64 <sup>***</sup>	0.00 <sup>ns</sup>
AGB					0.77 <sup>***</sup>	0.55 <sup>***</sup>	0.67 <sup>***</sup>	0.02 <sup>ns</sup>
PL						0.59 <sup>***</sup>	0.72 <sup>***</sup>	0.07 <sup>ns</sup>
DM							0.86 <sup>***</sup>	-0.08 <sup>ns</sup>
DH								-0.01 <sup>ns</sup>

Correlation is significant at the 0.001 level 2-tailed; AGB, above ground biomass t ha<sup>-1</sup>, SY straw yield, PL panicle length, DM, maturity day, DH, days of heading, HI, harvest index in %, GY, grain yield t ha<sup>-1</sup>, NT, tiller Number per plant, TGW, thousand grain weight

