

Research Article

Field Bindweed (*Convolvulus arvensis*) Control in Tef (*Eragrostis tef* (Zucc.) Trotter) through Various Herbicide Combinations

Gebrekidan Feleke ¹, Dereje Chala,² and Bizuwork Tafes¹

¹Agronomy and Crop Physiology Research Program, Debre Zeit Agricultural Research Center (DGARC), Ethiopian Institute of Agricultural Research (EIAR), P. O. Box 32, Debre Zeit, Ethiopia

²Weed Science Research Program, Debre Zeit Agricultural Research Center (DZARC), Ethiopian Institute of Agricultural Research (EIAR), P. O. Box 32, Debre Zeit, Ethiopia

Correspondence should be addressed to Gebrekidan Feleke; mekuriagebrekidan78@gmail.com

Received 26 May 2022; Accepted 6 August 2022; Published 24 August 2022

Academic Editor: Addi Mohamed

Copyright © 2022 Gebrekidan Feleke et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Field bindweed is the major weed problem for tef producers across the central highlands of Ethiopia. Herbicide application alone or coupled with once or twice hand weeding for field bindweed control is difficult due to its biological features, labor-intensive, and time-consuming. The field trial was carried out at Debre Zeit from 2020 to 2021 cropping seasons to investigate different postemergence herbicides against the grass and broadleaf weeds, in general, and field bindweed in particular, in tef farming, using a randomized complete block design with three replications. As a result, we could see that the herbicide combination had no visible effect on durum wheat's overall performance, which makes us recommend it for the control of field bindweed. In the sequential application, a wide spectrum of herbicides (Musket Power OD 460, Pallas 45 OD, and Sekator OD 375) were applied at tillering stage, and other selective herbicides (Derby 175 SC and 2,4-diamine salt 720 g/L 720 g/L) were applied at the heading stage, and the last nonselective herbicide (Roundup) was applied at physiological maturity of tef when the *Convolvulus arvensis* was regrowth naturally/latecomer weed. All postemergence herbicide treatments reduced significantly both broadleaf and grass weeds, in general, and *C. arvensis* infestation, in particular, when compared to the weedy control. Of these, Musket Power OD 460 at tillering stage integrated with 2,4-diamine salt 720 g/L at the heading stage was more effective than other herbicides for eliminating all weeds and *C. arvensis* in particular throughout the crop life. This weed management option resulted in considerably enhanced weed control efficiency and weed killing potential, reduced weed dry biomass and yield loss, improved grain yield, and economic benefit with an acceptable marginal rate of return for tef growers.

1. Introduction

Ethiopia is the source of many economically important crops, including tef *Eragrostis tef* (Zucc.) Trotter, which belongs to the grass or Poaceae family and the genus *Eragrostis* [1]. It is the only country in the world that uses tef as a cereal crop [2] and is mostly grown as an insurance or rescue crop to preserve the Ethiopian population [3]. Of the main cereal crops grown in the country, tef remains a crucial food crop with area coverage, production size, food, nutritional, and commercial value [4]. Tef grain is currently the most important staple grain for over 72% of Ethiopia's population, which is expected to reach 110 million people. This suggests

that tef is an important and valuable crop for the country's agricultural system and food security.

The cultivation of tef predates historical records by Ethiopian farmers, and it has a relative advantage over other cereals in both farming and utilization aspects [5]. Even though tef has versatile agro-ecological adaptations under diverse climatic, edaphic, and socioeconomic conditions, relative tolerance to both drought and flooding conditions and suitability for a variety of cropping systems and sustainable farming, tef productivity is still far below its potential, with an average grain yield of only 1.7 tons per hectare in Ethiopia, compared to maize (4 tons per hectare) and wheat (2.7 tons per hectare) [6]. Among the major yield-

limiting biotic factors in tef production, annual and perennial grass and broadleaf weeds are the backbreaking, labor-intensive, and time-consuming operations in tef husbandry. Of these, the most important weeds of tef in Ethiopia have been identified by Fessehaie and Tadele [7] and Kassahun and Damte [8]. They also listed other problematic weeds in tef including the parasitic witchweed (*Striga hermonthica*), the introduced alien invasive weed commonly known as congress weed (*Parthenium hysterophorus*), field bindweed, and other noxious weeds. Because of morphological features, especially its short and delicate stem, small leaves and shallow fibrous root system, and low seedling stand establishment, tef has a limited ability to compete with weeds. Consequently, both the yield and the quality of the grain and the straw are severely reduced/affected by the weed. Engstrom [9] found that weedy check plots produced 130 kg ha⁻¹ grain yield compared to 2,460 kg ha⁻¹ in weed-free plots, indicating that tef has a low competitive ability against weeds. Similarly, weed competition has been reported to cause a yield loss of 48 to 49% in the western Amhara Amhara region [7]. Likewise, Slotvisov et al. [10] revealed an 18% yield loss due to weeds, while Ketema [3] reported a 52% yield reduction without weed control.

Field bindweed was initially introduced to Ethiopia with lentil seed in the 1980s and has become a threat to tef producers in most tef-growing areas, particularly in the highland areas of Ethiopia [11]. This weed has a large mass of lush green foliage, may have grown to full maturity above crop height, and can smother crops causing difficulty for harvest, increasing the cost of harvesting and aggravating tef shattering, reducing harvesting material speed, reducing threshing efficiency, impeding cultural operations, and increasing separation losses and means; otherwise, dry grain will have higher harvested moisture content due to condensation transfer from green wet vegetation [12]. According to later studies, hand weeding has been used as the primary method of weed management for many years, even though labor shortages are becoming more of a constraint. Because of such shortcomings, a single application of postemergence selective herbicides (such as Starane M 64% B EC, Derby 175 SC, Mustang, and 2,4-diamine salt 720 g/L Amine Salt 72% S) about 25 to 30 days after crop emergence has proved effective in controlling the dominant broadleaf weeds in tef, thereby giving significant yield increase. However, for noxious weeds such as *Convolvulus arvensis*, due to its biological features, once or twice supplementary hand weeding in addition to the single postemergence application of herbicides may be needed depending on the weed flora infestation and effectiveness of the herbicides to maximize yields. However, this herbicide plus hand weeding cannot provide satisfactory control of the field bindweed because of labor-intensive and time-consuming operations in tef husbandry. On the other hand, due to the weed's regenerative ability and extensive root system, a single application of chemical field bindweed control is ineffective and challenging [13, 14]. As a result, combining herbicides has many benefits over using a single active ingredient, including lower farming costs due to labor and time saving,

reduced soil compaction due to fewer operations, and a delay in the emergence of herbicide-resistant weeds [15]. To overcome this problem, the application of economically visible herbicides more than once the application in different tef stages is an ideal means for controlling late comer weed, particularly *C. arvensis*. Therefore, an investigation was planned to evaluate the sequential application of post-emergence herbicides for field bindweed management in tef with the following objectives: to see how field bindweed and weed control efficiency in tef is affected by herbicide application in sequence; to examine the impact of sequential herbicide application on tef grain yield; and to work out the cost: benefit ratio of herbicides.

2. Materials and Methods

2.1. Description of the Study Areas. The field trial was carried out at Debre Zeit Agricultural Research Center on-station under rain-fed conditions from 2020 to 2021. This location is one of the most important tef growing areas in Ethiopia, as well as the national center of tef breeding program excellence. Its geographical extent ranges from 08° 45' 15" to 08° 46' 45" N latitude and from 38° 59' 45" to 39° 01' 00" E longitude with an altitude of 1,900 m a. s. l. A first-class meteorological station within the DZARC measures different climatic elements. The records from 1972 to 2021 show that the mean annual rainfall is 815.7 mm. It has a unimodal rainfall pattern with an extended rainy season from June to September. However, July is the busiest month, followed by August (Figure 1). The mean annual maximum temperature is 26.3°C, and monthly values range between 24°C in July and 28.8°C in March. The mean annual minimum temperature is 10.7°C, and monthly values range between 7.5°C in December and 12.5°C in July and August. The major soil type of the trial fields is heavy black soil (Vertisol).

2.2. Experimental Treatments, Design, and Application Procedure. The experiment was carried out in three replications using a randomized complete block design. The plot size was 3 × 4 m with a harvestable area of 2.5 × 3.5 m and footpaths of 1 m between plots and 1.5 m between replications. There were twelve treatments in the experiment, six postemergence herbicide treatments that were applied either integrated or sequentially, one weed-free check (hand weeding), one with a weedy check for *C. arvensis*, and one weedy check for all weeds (Table 1). All postemergence herbicides were applied at recommended rates to three different tef growing stages when the weeds were at the early flowering stage. The first sprayed postemergence herbicides (Musket Power, Pallas, and Sekator) were broad-spectrum herbicides applied at the tillering crop stage. The other selective herbicides (Derby 175 SC and Agriherba) were used at the heading stage. The last nonselective herbicide (Roundup) was applied at 90% physiological maturity of tef when the *C. arvensis* regrew naturally. All naturally occurring field bindweed populations were selected during experimentation. Tef cultivar, namely, Dagim, was used as

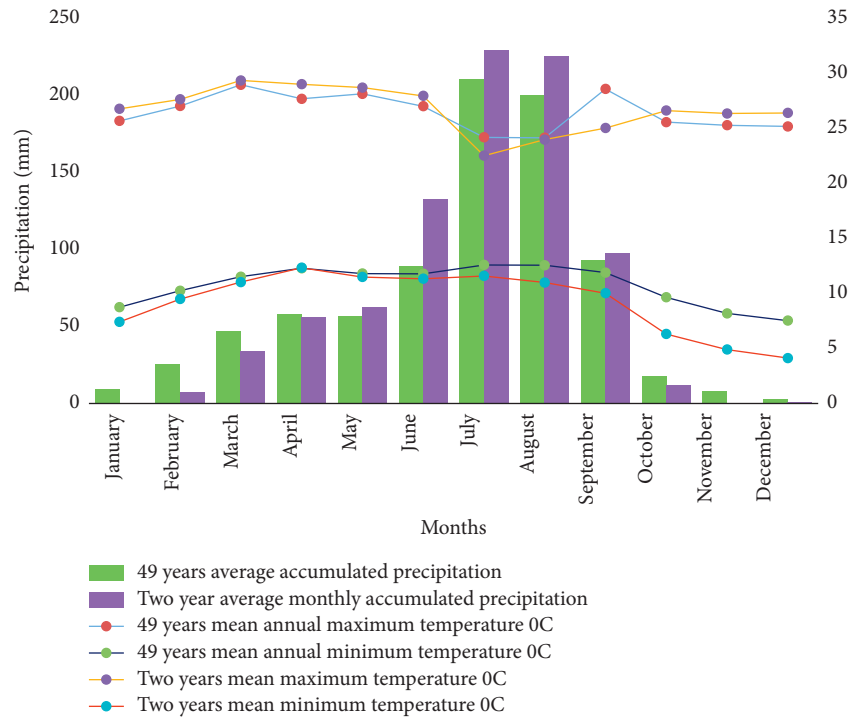


FIGURE 1: Monthly two- and forty-nine-year average precipitation (bar) and maximum and minimum air temperature(line) at the experimental site from November 1972 to December 2021.

TABLE 1: Description of treatments.

Common name	Trade name	Dose (kg ha^{-1})
Pyroxsulam + 2,4-damine salt 720 g/L amine salt 720 g/L amine salt 720 g/L	Pallas 45 OD + Agriherba	0.45L + 1L
Pyroxsulam + flurasulam 75 g/L + flumetsulam 100 g/L	Pallas 45 OD + Derby 175 SC	0.45L + 0.06L
Pyroxsulam + glyphosate	Pallas 45 OD + Roundup	0.45L + 1L
2,4-D-2-ethylhexyl esters + lodosulfuron-methyl-sodium + 2,4-damine salt 720 g/L amine salt 720 g/L	Musket Power OD 460 (+) Agriherba	1L + 1L
2,4-D-2-ethylhexyl ester + lodosulfuron-methyl-sodium + flurasulam 75 g/L + flumetsulam 100 g/L	Musket Power OD 460 (+) Derby 175 SC	1L + 0.06L
2,4-D-2-ethylhexyl ester + lodosulfuron-methyl-sodium + Glyphosate	Musket Power OD 460 (+) Roundup	1L + 1L
Amidosulfuron + iodosulfuron-methyl sodium (+) 2,4-damine salt 720 g/L amine salt 720 g/L	Sekator OD 375 (+) Agriherba	0.15L + 1L
Amidosulfuron + iodosulfuron-methyl sodium (+) flurasulam 75 g/L + flumetsulam 100 g/L	Sekator OD 375 (+) Derby 175 SC	0.15L + 0.06L
Amidosulfuron + iodosulfuron-methyl sodium (+) glyphosate	Sekator OD 375 (+) Roundup	0.15L + 1L
Weed-free check		
Weedy check for all weeds`		
Weedy check for <i>Convolvulus arvensis</i>		

the test crop and sown at a recommended rate of 10 kg ha^{-1} in all plots by manual 20 cm row planting method. Fertilizers were used at the rate of 69 kg N ha^{-1} urea and 100 kg NPS ha^{-1} (19 N, 37 P_2O_5 , and 7.6 S) as fertilizer sources. N 1/3 and NPS were entirely drilled in rows at the time of sowing, and the remaining 2/3 of N through urea was applied at the shoot elongation stage of the crop. Postemergence application of herbicides was sprayed uniformly on the weeds at the specified date per treatment using a manually pumped knapsack sprayer. The seedbed in both years was prepared using a moldboard plow followed by disking.

2.3. Data Collection and Procedures. The weed population count was taken with the help of 0.5 m \times 0.5 m quadrant, was thrown randomly at once in each plot before and after herbicide application, and was identified and converted into population density per m^2 . The biomass was harvested from each plot during crop harvest after the weed population was recorded. The harvested weeds were separated into paper bags and dried in a 65°C oven for 24 hours until they reached a constant weight, after which the dry weight was measured and converted to kg ha^{-1} .

2.3.1. *Weed Control Efficiency.* The magnitude of weed reduction caused by the weed control treatment is denoted by

$$WCE(\%) = \frac{\text{The dry weight of weeds in weedy check} - \text{Dry weight of weeds in treatment plots}}{\text{A dry weight of weeds in weedy check}} * 100. \quad (1)$$

The weed index (WI) or relative yield loss is the percentage reduction in crop yield due to the presence of weeds when compared to weed-free plots. To put it another way,

$$WI(\%) = \frac{\text{Yield from the weed - free plot} - \text{Yield from the other treatment plot}}{\text{Yield from the weed - free plot (kg)}} * 100. \quad (2)$$

Herbicide efficiency index (HEI) measures the herbicide treatment's weed-killing ability as well as the crop's phytotoxicity:

$$HEI = \frac{\text{Yield of treated plot} - \text{yield of control (unweeded plot/yield of control (unweeded plot))}}{\text{Weed dry weight in treated plot/Weed dry weight in control (unweeded) plot}}. \quad (3)$$

Aboveground dry biomass yield, grain yield, and harvesting index were recorded. The final product was measured and adjusted to 12.5% moisture content with the help of the following formula: Adjusted grain yield ($kg\ ha^{-1}$) = Actual yield * 100 - M/100 - D, where *M* denotes the grain's measured moisture content and *D* denotes the designated moisture content.

Harvest index (%) was calculated by $HI(\%) = (\text{Grain yield}/\text{Total above ground dry biomass yield}) * 100$.

2.4. *Partial Budget Analysis.* The partial budget analysis was done to evaluate the cost involvement (fixed costs and variable costs as well) and benefits of herbicide treatment as described in the procedure of CIMMYT [16]. Yield from experimental plots was adjusted downward by 15%, that is, 10% for management difference and 5% for plot size differences. The number of laborers needed for manual weeding management (twice for tef weed-free treatment) and the herbicide application cost per hectare of land were 100 and 1, respectively. A person per day of labor cost was 200 ETB. The cost of herbicides was calculated based on the current local market price. Accordingly, the cost of Pyroxsulam was 3,000 ETB litre⁻¹; the cost of 2,4-diamine salt 720 g/L was 400 ETB litre⁻¹; the cost of flurasulam 75 g/L + flumetsulam 100 g/L was 600 ETB litre⁻¹; the cost of 2,4-D-2-ethylhexyl ester + Iodosulfuronmethyl-sodium sodium was 1,800 ETB litre⁻¹; the cost of glyphosate was 450 ETB litre⁻¹; and the cost of amidosulfuron + Iodosulfuron-methyl sodium was 1,900 ETB litre⁻¹. Price of current tef grain (50 ETB kg⁻¹) and price of straw (7.6 ETB kg⁻¹) data were obtained

weed control efficiency. The following formula was used to calculate the weed control efficiency:

the weed index measures weed competition by a percentage reduction in yield due to its presence in the field:

from the Add'a district's Office of Trade and Transportation marketing case team.

2.5. *Statistical Analysis.* All data were subjected to analysis of variance using PROC GLM procedure in SAS [17]. Analysis of variance (ANOVA) was carried out to examine the effects of postemergence herbicides on weed density, weed biomass, yield, and yield contributing characters of tef. Except "weed free" as a check treatment, weedy check for all weeds and weedy check for *C. arvensis* were used as a control treatment and compared to the other treatments. Similarly, in terms of yield, "weed free" was used as a control treatment and statistically compared to other treatments, as well as weedy check for all weeds and weedy check for *C. arvensis*. Mean separation of significant treatments was carried out using the least significant difference (LSD) test at a 5% level of probability.

3. Results and Discussion

3.1. *Flora and Biomass of Weeds.* Tef was infested with broadleaf weeds, sedges, and grasses in both cropping seasons, with broadleaf weeds taking the lead. Before the application of the postemergence herbicide, the weed community consisted of 18 species representing eight different families (Table 2). The families Poaceae and Asteraceae predominated, the other families having more species.

The application of all herbicides significantly reduced the total dry biomass of all weeds (Table 3). Among these, Musket Power OD 460 at tillering stage plus 2,4-diamine salt 720 g/L at the heading stage (34.3 kg ha⁻¹) followed by Pallas

TABLE 2: The major broadleaf and grass weed species observed during the experimental season.

Family	Species
Amaranthaceae	<i>Amaranthus hybridus</i> and <i>Achyranthes aspera</i>
Commelinaceae	<i>Commelina benghalensis</i>
Convolvulaceae	<i>Convolvulus arvensis</i>
Asteraceae	<i>Bidens Pilosa</i> , <i>Cichorium intybus</i> , <i>Xanthium strumarium</i> , and <i>Galinsoga parviflora</i>
Poaceae	<i>Dinebra retroflexa</i> , <i>Phalaris paradoxa</i> , <i>Digitaria</i> spp., <i>Setaria pumila</i> , <i>Eragrostis cilianensis</i> , and <i>Cynodon nlemfuensis</i>
Plantaginaceae	<i>Plantago lanceolata</i>
Cyperaceae	<i>Cyperus</i> spp.
Papaveraceae	<i>Argemone ochroleuca</i>

TABLE 3: Effects of weed control methods on grain yield, aboveground biomass, weed dry biomass and harvest index of tef (combined mean of 2020 and 2021 years).

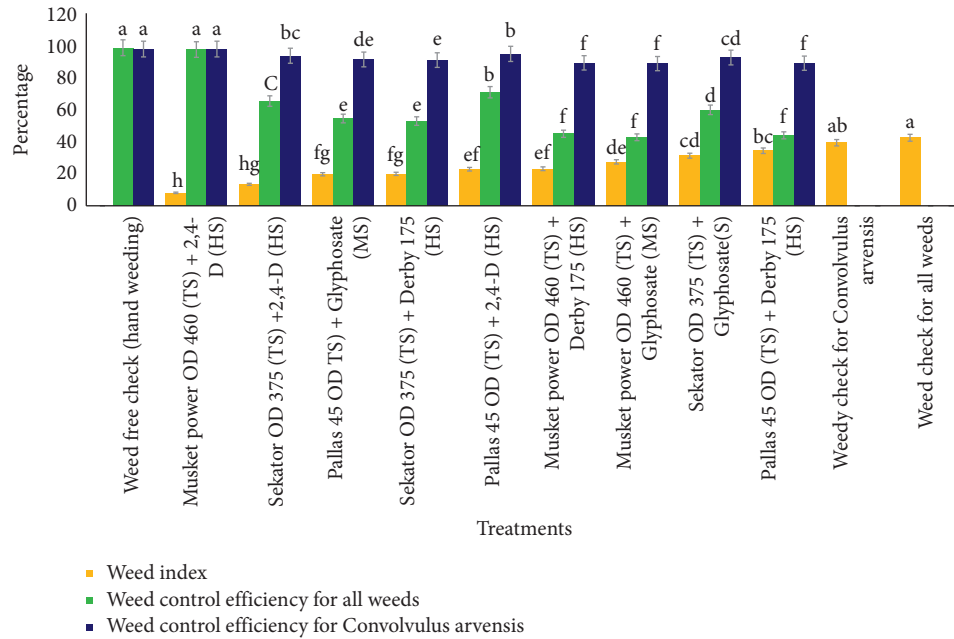
Treatments	Grain yield (Kg ha ⁻¹)	Aboveground biomass (Kg ha ⁻¹)	Weed dry biomass (Kg ha ⁻¹)	Harvest index
Musket Power OD 460 (TS) + glyphosate (MS)	1,395.7 ^{de}	8,379.6 ^{ab}	168.4 ^c	17.1 ^{de}
Musket Power OD 460 (TS) + 2,4-damine salt 720 g/L (HS)	1,768.8 ^b	9,152.8 ^a	34.6 ^g	19.6 ^{bcd}
Musket Power OD 460 (TS) + Derby 175 (HS)	1,482.2 ^d	8,231.5 ^b	161.2 ^{cd}	17.9 ^{cde}
Pallas 45 OD (TS) + 2,4-damine salt 720 g/L (HS)	1,486.6 ^d	7,592.6 ^{bcd}	78.2 ^{fg}	19.9 ^{bcd}
Pallas 45 OD (TS) + Derby 175 (HS)	1,541.4 ^{cd}	7,203.7 ^{de}	164.4 ^{cd}	17.7 ^{cde}
Pallas 45 OD (TS) + glyphosate (MS)	1,266.7 ^{ef}	7,625 ^{bcd}	131.0 ^{cde}	20.5 ^{bc}
Sekator OD 375 (TS) + 2,4-damine salt 720 g/L (HS)	1,670.4 ^{bc}	8,083.3 ^{bc}	95.7 ^{ef}	21.4 ^{ab}
Sekator OD 375 (TS) + Derby 175 (HS)	1,538.4 ^{cd}	7,726.9 ^{bcd}	135.7 ^{cde}	20.8 ^{bc}
Sekator OD 375 (TS) + glyphosate (MS)	1,325.2 ^e	7,888.9 ^{bcd}	113.7 ^{def}	17.1 ^{de}
Weed-free check (hand weeding)	1,933.0 ^a	8,138.9 ^{bc}	25.8 ^g	24.7 ^a
Weedy check for all weeds	1,101.1 ^g	7,037 ^f	1,489.2 ^a	15.8 ^e
Weedy check for <i>Convolvulus arvensis</i>	1,162.6 ^{fg}	7,352 ^{cde}	305.3 ^b	15.8 ^e
LSD (0.05)	154.1	814.2	52.3	3.3
CV (%)	6.2	6.1	12.7	10.3

Note. TS, tillering stage; HS, heading stage; and MS, maturity stage. Means followed by the same letter within a column are not significantly different according to Fisher's protected LSD at $P < 0.05$.

45 OD tillering stage plus 2,4-diamine salt 720 g/L at the heading stage (78.2 kg ha⁻¹) offered the highest reduction in total dry weed biomass. The results showed that dual-purpose herbicide, Musket Power OD 460, controlled the weeds effectively during the early stages of crop growth, and in later stages, the regenerative ability weeds effectively was controlled by 2,4-D, which is a broadleaf control herbicide. However, the lowest weed dry biomass was observed in Musket Power OD 460 at tillering stage plus glyphosate at 90% physiological maturity of tef, which is statistically parity with Musket Power OD 460, Sekator OD 375, and Pallas 45 OD at tillering stage plus Derby 175 at the heading stage and Pallas 45 OD at tillering stage plus glyphosate 90% physiological maturity of tef. In general, the dry biomass difference among herbicides could be due to the herbicide killing potential and the weed tolerance to the tested herbicide. This finding is consistent with Sareta et al. [18], who found that postemergence herbicide application alone was not as effective as other agronomic practices.

3.2. Weed Control Efficiency and Weed Index. The weed control efficiency results (Figure 2) show that all nine herbicide treatments could reduce weed infestation in general and *C. arvensis* in particular in tef cultivation. Regardless of the weed-free check (hand weeding), the range of

weed control efficiency of herbicide applications was 88.6–97.7% compared to the weed check for all weeds and 42.7–97.4% compared to the weedy check for *C. arvensis*. Among these herbicides, Musket Power OD 460 at tillering stage plus 2,4-diamine salt 720 g/L at heading stage followed by Pallas 45 OD at tillering stage plus 2,4-diamine salt 720 g/L at heading stage recorded the maximum (97.7 and 94.7%) weed efficiency of all weed species compared to the weedy check for all weeds. While the lowest weed control efficiency was obtained from the application of Musket Power OD 460 at tillering stage plus glyphosate at 90% physiological maturity as postemergence treatment, which was statistically parity with the application of Musket Power OD 460 at tillering stage plus Derby 175 SC at heading stage and Pallas 45 OD at tillering stage plus Derby 175 SC at heading stage. Results were also obtained in case of weedy check for *C. arvensis*, herbicide application of Musket Power OD 460 at tillering stage plus 2,4-diamine salt 720 g/L at heading stage followed by Pallas 45 OD at tillering stage plus 2,4-diamine salt 720 g/L at heading stage offered the highest (97.4 and 70.8%) weed control efficiency, respectively. However, the lowest (42.7%) weed density reduction was achieved in plots treated by Musket Power OD 460 at tillering stage plus glyphosate at 90% physiological maturity as postemergence treatment. The lower field bindweed reduction could be the regenerative ability of *C. arvensis* after



TS, tillering stage; HS, heading stage; MS, maturity stage. Means followed by the same letter in the bargraphs are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

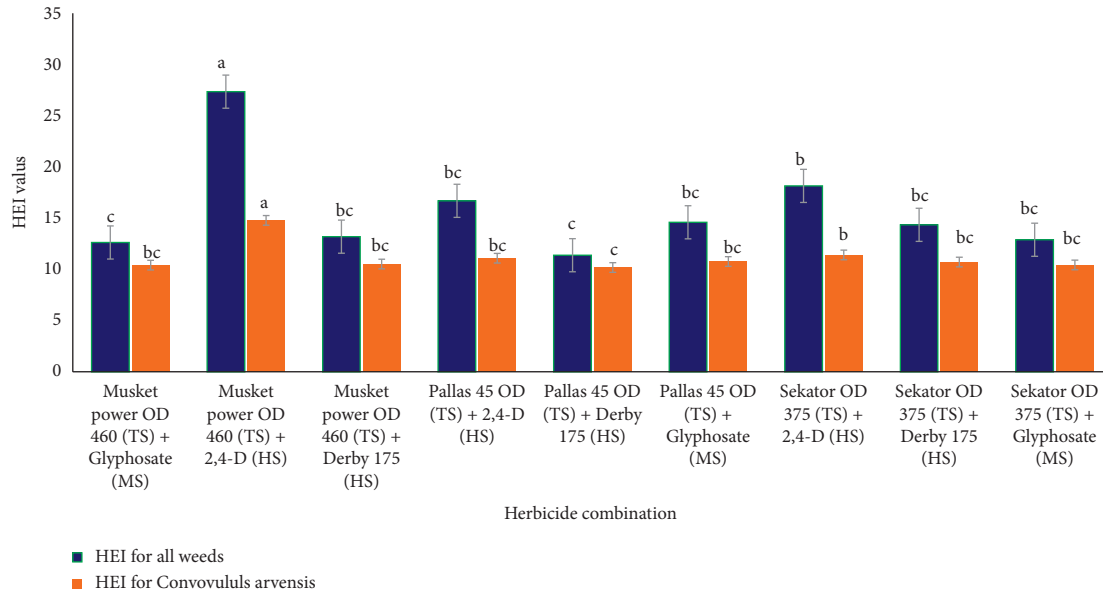
FIGURE 2: Different weed control treatments' effects on the weed index, herbicide control efficiency for all weeds, and *Convolvulus arvensis* in tef (combined mean of 2020 and 2021 years). TS, tillering stage; HS, heading stage; and MS, maturity stage. Means followed by the same letter in the bar graphs are not significantly different according to Fisher's protected LSD at $P < 0.05$.

the first spray becomes harder and it reaches more advanced developmental stages at 90% physiological maturity of the crop. Unsurprisingly, herbicide efficacy is affected not only by the herbicide but also by other factors such as weed species and climatic conditions. These results agree with Hassan [19] who reported that a combination of Pyroxasulfone plus metribuzin plus dicamba improved field bindweed control, providing at least 89% control compared with the sole application of postemergence herbicides and weedy check. Recently, Maryam and Meisam [20] also stated that *C. arvensis* had the highest susceptibility to herbicide combination iodosulfuron-methyl Na + amidosulfuron + safener mefenpyr-diethyl + fenoxaprop-ethyl, and triasulfuron + dicamba.

Grain yield loss of tef was significantly different due to weed management practices, with the lowest yield loss (0.0%) recorded at weed-free check plot (hand weeding), followed by Musket Power OD 460 at tillering stage plus 2,4-diamine salt 720 g/L at heading stage offering the least (8.1%) yield loss of tef compared to the nine herbicide treatments combination (Figure 2). The lowermost loss of tef grain yield in weed-free treatment and sequential herbicide application (Musket Power OD 460 at tillering stage plus 2,4-diamine salt 720 g/L at heading stage) practices could be due to the absence/reduction of weed density, inhabit growth, and biomass accumulation of weeds. The crop that freely utilizes nutrients, sunlight, water, and better utilization of photosynthesis and improved yield attributes traits such as the number of effective tillers m^{-2} , panicle length, culm length, and thousand-grain weight cumulatively increased grain yield. However, the

highest (42.4%) yield loss was recorded in a weedy check for all weeds followed by (39.3%) a weedy check for *C. arvensis* in Figure 2. This loss of tef grain yield both in weedy check for all and weed check for *C. arvensis* plots might be due to the presence of a greater density of weeds in the current study. These findings are consistent with Amare et al. [21], who found that herbicide application combined with supplemented hand weeding reduces wheat yield loss more than uncontrolled weed treatment.

3.3. Herbicide Efficiency Index. Comparing the weed management indices of postherbicides, significantly, the highest (27.4 and 14.8) weed killing potential for all weeds, in general, and *C. arvensis*, in particular, with less phytotoxicity at tef were obtained from herbicide combinations containing Musket Power OD 460 at tillering stage plus 2,4-diamine salt 720 g/L at heading stage of tef, respectively. However, the lowest (11.2 and 10.2) herbicide efficiency indices for all weeds and *C. arvensis*, in particular, were obtained from Pallas 45 OD at tillering stage plus Derby 175 at the heading stage of tef, respectively (Figure 3). This study found that applying herbicides in the sequence was more effective for controlling field bindweed (which has a regenerative ability, a large root system, and latecomer weeds) and was better than applying a single herbicide for annual weed control. However, understanding the possible interactions between herbicides and environmental factors such as precipitation may improve the effectiveness of this herbicide on field bindweed. Similar results were observed by [22].



HEI, herbicide efficiency index; TS, tillering stage; HS, heading stage; MS, maturity stage. Means followed by the same letter in the bar graphs are not significantly different according to Fisher's Protected LSD at $P < 0.05$.

FIGURE 3: Effect of different weed control treatments on herbicide efficiency index in tef (combined mean of 2020 and 2021 year). HEI, herbicide efficiency index; TS, tillering stage; HS, heading stage; and MS, maturity stage. Means followed by the same letter in the bar graphs are not significantly different according to Fisher's protected LSD at $P < 0.05$.

3.4. Grain Yield, and Total Aboveground Biomass of Tef. Grain yield and harvest index of tef showed significant ($P < 0.05$) differences due to the sequential application of postemergence herbicides and the three weedy check treatments in the combined analysis (Table 3). The highest (1,933 kg ha⁻¹ and 24.7) grain yield and harvest index were recorded in weed-free check, followed by Musket Power OD 460 (1,769 kg ha⁻¹) at tillering stage plus 2,4-diamine salt 720 g/L at the heading stage and Sekator OD 375 (21.4) at tillering stage plus 2,4-diamine salt 720 g/L at the heading stage, respectively. However, the lowest (1,101 kg ha⁻¹ and 15.8) grain yield and harvest index were recorded in the weedy check for all weeds, which was statistically partly with a weedy check for *C. arvensis*. Yield wise, both hand weeding and Musket Power OD 460 (1,769 kg ha⁻¹) at tillering stage plus 2,4-diamine salt 720 g/L at the heading stage outperformed the weedy check for all weeds by 43 and 38%, respectively. Both the above-mentioned treatment improves the grain yield by 40 and 34%, respectively. The improvement of tef grain productivity might be due to efficient control of weed growth, weed density, and efficient utilization of resources by crops, which lead to proper growth and development of crops that favour an increase in yield and yield attributes. The minimum grain yield was due to weed infestation, accumulation of high dry matter in weeds, and occurrence of different weed species in weedy plots. In line with this result, Brhane [23] reported that the highest grain yield of tef was obtained in weed-free treatment, while the lowest grain yield was obtained in the weedy check. Similarly, Norberg Felix [24] reported that tef grain production was greater with herbicide application treatment compared to the weedy check treatment.

Total aboveground biomass yields as affected by weed management methods ranged from 7,037 to 9,152.8 kg ha⁻¹ (Table 3). The highest biomass yield (9,152.8 kg ha⁻¹) was recorded from sprayed of Musket Power OD 460 at tillering stage plus 2,4-diamine salt 720 g/L at the heading stage, while the minimum biomass was recorded at weedy check for all weeds with the mean of 7,037 kg ha⁻¹. The increased biomass yield might be due to decreased weed population and dry weight caused by better utilization of growth resources and translocation of assimilates from source to seed since plants with better access to environmental resources had better photosynthate photosynthesis formation, and in turn, it is expressed on biomass. 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 efficacy leads to thin and weak stems reduced tiller number and reduced total biomass yield. Similarly, Hanson [19] reported that the mixture of herbicides produced a higher biomass yield than weedy check plots.

3.5. Partial Budget Analysis. A partial budget analysis was run to understand the efficiency and economics of input-output of tef production. According to the results, the highest net benefit was obtained from the application of Musket Power OD 460 at tillering stage plus 2,4-diamine salt 720 g/L at the heading stage, followed by Sekator OD 375 at tillering stage plus 2,4-diamine salt 720 g/L at the heading stage and Musket Power OD 460 at tillering stage plus Derby 175 at heading stage and weed-free check (Table 4). However, due to dominance analysis, most of the treatments were dominated by the highest net benefit treatments. To identify treatments with maximum return on the

TABLE 4: Partial budget analysis for combined mean of 2020 and 2021 years.

Treatments	Adjusted grain yield kg ha ⁻¹	Adjusted straw yield kg ha ⁻¹	Gross field benefit (ETB)	TVC (ETB)	NB (ETB)	MRR (%)
Musket Power OD 460 + 2,4-damine salt 720 g/L	1,503.5	6,276.4	122,874.6	2,600	120,274.6	4,625.9
Musket Power OD 460 + glyphosate	1,186.3	5,936.3	104,433.2	2,650	101,783.2	DM
Sekator OD 375 + 2,4-damine salt 720 g/L	1,419.8	5,451.0	112,419.3	2,700	109,719.3	DM
Sekator OD 375 + glyphosate	1,126.4	5,579.1	98,722.5	2,750	95,972.5	DM
Musket Power OD 460 + Derby 175	1,259.9	5,736.9	106,594.0	2,800	103,794.0	DM
Sekator OD 375 + Derby 175	1,307.6	5,260.2	105,359.7	2,900	102,459.7	DM
Pallas 45 OD + 2,4-damine salt 720 g/L	1,263.6	5,190.1	102,625.3	3,800	98,825.3	DM
Pallas 45 OD + glyphosate	1,076.7	5,404.6	94,909.4	3,850	91,059.4	DM
Pallas 45 OD + Derby 175	1,310.2	4,813.0	102,088.0	4,000	98,088.0	DM
Weed-free check	1,643.1	5,275.0	122,242.6	20,000	102,242.6	DM

farmers' investment, marginal analysis was performed on nondominated treatments. Thus, based on the marginal rate of return (MRR), Musket Power OD 460 at tillering stage plus 2,4-diamine salt 720 g/L at the heading stage was superior (4625.9%) rewarding treatment combination, and it was recorded above the acceptable minimum rate of return. This implies that for Birr 1.0 investment in tef production, the producer can get ETB 45.25. From this finding, it was observed Musket Power OD 460 at tillering stage plus 2,4-diamine salt 720 g/L at the heading stage was crucial for the control of field bindweed in tef cultivation areas.

4. Conclusions

Grain yield of tef can be reduced up to 42.4 and 39.3% due to weed infestation in all weeds and *C. arvensis* in particular, respectively. Field bindweed and other weeds in general in tef cultivation could be managed effectively by the combined application of postemergence herbicides. Among different herbicide treatments, Musket Power OD 460 at tillering stage plus 2,4-diamine salt 720 g/L at the heading stage gave better results in terms of weed management index and a profitable alternative to the existing recommendation of weed control (twice hand weeding or herbicide application alone and/or plus other agronomic practices) for tef yield in Ethiopia. Generally, combining herbicides can reduce all weed species, including field bindweed, because of the weed's regenerative ability and extensive root system, as well as reduce farming costs by saving labor and time and delaying the appearance of herbicide-resistant weeds.

Data Availability

The data used for the analysis of this research results are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors extend their appreciation to the Ethiopia Institute of Agricultural Research, Debre Zeit Agricultural

Research Center, EIAR, and Department of Crop Protection for funding our research work.

References

- [1] N. I. Vavilov, "The origin, variation, immunity and breeding of cultivated plants," 1951, https://journals.lww.com/soilsci/citation/1951/12000/the_origin_variation_immunity_and_breeding_of.18.aspx.
- [2] L. Gugsu, G. Belay, and S. Ketema, "The cytogenetics of teff in narrowing the rift: teff research and development," in *Proceedings of the International Workshop on Teff Genetics and Improvement*, Debre Zeit, Ethiopia, 2000.
- [3] S. Ketema, "Tef (*Eragrostis tef* (zucc.) trotter). 50," *Promoting the Conservation and Use of Underutilized and Neglected Crops*, Institute of Plant Genetics and Crop Plant Research, Rome, Italy, 1997.
- [4] S. Chanyalew, S. Ferede, T. Damte et al., "Significance and prospects of an orphan crop teff," *Planta*, vol. 250, no. 3, pp. 753–767, 2019.
- [5] B. Minten, A. S. Taffesse, and P. Brown, "The economics of teff: exploring ethiopia's biggest cash crop," 2018, <https://www.ifpri.org/publication/economics-teff-exploring-ethiopia-biggest-cash-crop-synopsis#:~:text=Teff%20is%20the%20staple%20food,expand%20domestic%20or%20international%20markets>.
- [6] Central Statistical Authority (Csa), "Federal democratic republic of ethiopia, central statistical agency agricultural sample survey: report on area and production of major crops (private peasant holdings, meher season)," 2018/19, [https://www.scirp.org/\(S\(351jmbntvnsjt1aadkozje\)\)/reference/referencespapers.aspx?referenceid=2952450](https://www.scirp.org/(S(351jmbntvnsjt1aadkozje))/reference/referencespapers.aspx?referenceid=2952450).
- [7] R. Fessehaie and Z. Tadele, "Weed research in tef in narrowing the rift: teff research and development," in *Proceedings of the International Workshop on Teff Genetics and Improvement*, Addis Ababa: Ethiopian Institute of Agricultural Research, Debre Zeit, Ethiopia, 2000.
- [8] Z. Kassahun and T. Damte, "Weed research in tef in achievements and prospects of teff improvement," in *Proceedings of the Second International Teff Workshop*, Debre Zeit, Ethiopia, 2011.
- [9] E. Engstrom, *Crop Production Trials 1967–72*, CADU Publication, Ethiopia, 1974.
- [10] R. J. Slotvisov, A. N. Ranikov, and T. Tegen, *Yield Losses of Cereal Crops Due to Weeds and Perspectives of Their Control*, Conference at the Institute of Agricultural Research, Addis, Ababa, Ethiopia, 1979.

- [11] T. Damte, G. Feleke, S. Adisu, K. Assefa, and H. Tesfaye, "Pests of belg and irrigated tef (*Eragrostis tef*) in the Amhara region, Ethiopia," *Ethiopian Journal of Agricultural Science*, vol. 29, no. 3, pp. 63–71, 2019.
- [12] R. Khan, M. A. Khan, M. Waqas et al., "Bioherbicidal activity of some winter weeds against some crops," *Pak.J. Weed Science. Research*, vol. 18, no. 4, pp. 561–569, 2012.
- [13] R. B. Lindenmayer, S. J. Nissen, P. P. Westra, D. L. Shaner, and G. Brunk, "Aminocyclopyrachlor absorption, translocation and metabolism in field bindweed (*Convolvulus arvensis*)," *Weed Science*, vol. 61, no. 1, pp. 63–67, 2013.
- [14] S. Mafakheri, M. Zargar, and K. Fakhri, "The best application time and dose of herbicide for optimum weed management in two red bean cultivars," *Indian Journal of Science and Technology*, vol. 5, no. 1, pp. 1–3, 2012.
- [15] L. Galon, F. A. De David, C. T. Forte et al., "Chemical management of weeds in corn hybrids," *Weed Biology and Management*, vol. 18, no. 1, pp. 26–40, 2018.
- [16] Cimmyt, "From agronomic data to farmer recommendations: an economics workbook," 1988, https://books.google.co.in/books/about/From_Agronomic_Data_to_Farmer_Recommenda.html?id=GPDDLqglVFUC&redir_esc=y.
- [17] SAS Institute Inc, *SAS/STAT 9.22 User's Guide*, SAS Institute Inc, Cary, NC, USA, 2009.
- [18] H. Sareta, W. Worku, and B. Begna, "Economics of herbicide weed management in wheat in Ethiopia," *African Crop Science Journal*, vol. 24, no. 1, pp. 109–116, 2016.
- [19] G. Hassan, B. Faiz, K. B. Marwat, and M. Khan, "Effect of planting methods and tankmixed herbicides for controlling grassy and broadleaf weeds and their effect on wheat," *Pakistan Journal weed science research*, vol. 9, no. 1-2, pp. 1–11, 2003.
- [20] M. Bayat and M. Zargar, "Field bindweed (*Convolvulus arvensis*) control and winter wheat response to post herbicides application," *Journal of Crop Science and Biotechnology*, vol. 23, no. 2, pp. 149–155, 2020.
- [21] T. Amare, C. V Raghavaiah, and T. Zeki, "Productivity, yield attributes and weed control in wheat (*Triticum aestivum* L.) as influenced by integrated weed management in central high lands of Ethiopia, east africa," *Advance Crop Science Technology*, vol. 4, no. 1, p. 206, 2015.
- [22] V. P. Singh, S. P. Singh, A. Kumar et al., "Comparative efficacy of quizalofop-ethyl against weeds in groundnut," *Indian Journal of Weed Science. VI*, vol. 46, no. 4, pp. 389–391, 2014.
- [23] G. Brhane, "Response of yield and yield components of tef [*Eragrostis tef* (Zucc.) Trotter] to tillage, nutrient, and weed management practices in Dura Area, Northern Ethiopia," *International Scholarly Research Notices*, vol. 2014, 2014.
- [24] O. S. Norberg and J. Felix, "Response of Teff, Barnyardgrass, and broadleaf weeds to post-emergence herbicides," *Weed Technology*, vol. 28, no. 2, pp. 371–376, 2014.