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Effects of Post-emergence Herbicides and Hand Weeding to Control Weeds on Wheat under Irrigation Condition in West Gondar Zone, Ethiopia

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ABSTRACT

Bread wheat is one of the most important cereal crops grown in Ethiopia. However, its productivity in the country is low because of abiotic and biotic stress including annual broadleaf and grass weeds. The present experiment was conducted to evaluate six (6) post-emergence herbicides and a hand weeding as a check and weedy control during 2021 and 2022 under irrigation conditions at Metema experimental site using a Randomized Complete Block design replicated three times. The Kekeba wheat variety was used at a seed rate of 125 kg ha^{-1} and plot size of 9 m^2 was used. All post-emergence herbicides and hand weeding significantly suppressed both types of weed populations over weedy check. Among the treatments Richway 750 WDG (55.9 m^2), Top Harvest 80 EC (40.7 m^2), twice hand weeding (49 m^2) and Atlantis OD 37.5 (53.7 m^2) highly significantly reduced weed populations with substantial improvement of grain yield. However, the maximum cost/benefit ratio was obtained on plots that received Top Harvest 80 EC and Atlantis OD 37.5. Therefore, it can be concluded that Top Harvest 80 EC and Atlantis OD 37.5 effectively controlled weeds and gave maximum grain yield and may be recommended for the lowland areas of west Gondar and similar agro-ecologies.

Keywords: Bread wheat, broadleaf weed, control, grass weed, hand weeding, herbicides, yield.

INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is a key cereal crop grown extensively in the highland regions of Ethiopia. Optimal conditions for wheat cultivation are typically found at elevations ranging from 1,900 to 2,700 meters above sea level (Hailu, 2003). As one of the most widely grown cereal crops globally, wheat plays a critical role in global food security, contributing approximately 20% of the protein and caloric intake for the world's population (FAO, 2013).

Bread wheat is one of the most important crops among the large number of smallholder farmers involved (4,579,491.00), while total area coverage is 1,897,405.05 hectares, and total annual production is about 5,780,130,596.00 kg ha^{-1} in the main season (CSA, 2021). The Amhara Region contributes significantly to Ethiopia's wheat production, accounting for 32.7% of the total cultivated area and 30.3% of the country's wheat output. Despite this, the region's average wheat yield stands at 2,530 kg per hectare, which is lower than the national average of 2,740 kg per hectare and significantly below the potential yield of 7,500 kg per hectare achievable through the adoption of improved varieties and enhanced production practices. Wheat production in the region plays a vital role in the national economy, with both the area under cultivation and productivity showing a steady upward trend. (CSA, 2021).

Despite its significant nutritional and economic value, wheat productivity faces numerous challenges stemming from both biotic and abiotic factors. The most yield-reducing elements include declining soil fertility, the presence of weeds, diseases, and insect pests, as described by Haile& Girma (2010). Weeds pose a substantial threat to wheat yields by competing for resources, exhibiting allelopathic effects, and providing habitats for pathogens, while also serving as

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alternate hosts for various insects and fungi, thereby increasing harvest costs, as discussed by Haile& Girma (2010).

Research conducted in Ethiopia indicates that weed competition can lead to an average yield reduction of up to 36% (Hailu ,2003). And further corroborate that weeds can cause yield losses of up to 70% in certain growing seasons. In the Ethiopian context, inadequate weed management practices, along with suboptimal plant populations employed by farmers, significantly hinder wheat productivity (Zegeye et al., 2001).

Research has demonstrated that the application of broad-spectrum herbicides significantly reduces the dry weight of weeds compared to untreated plots, while simultaneously enhancing yield components and overall grain yield of wheat. Numerous studies have focused on managing broadleaf weeds through hand weeding and the application of post-emergence herbicides for both broadleaf and grass weed control in wheat cultivation in Ethiopia (Megersa et al., 2017). In recent years, the adoption of chemical weed control has gained traction both globally and specifically within Ethiopia, largely driven by the challenges of labor scarcity and high costs of weeding during peak growing seasons (Haile & Girma, 2010). Moreover, the repeated use of a single herbicide or those belonging to the same chemical family can lead to the development of weed resistance, the persistence of herbicides in the environment, and the accumulation of harmful residues within the food chain, posing risks to both human and animal health (Rezene, 1985). Therefore, it is essential to explore the introduction of economically viable and agronomically sound weed management technologies for wheat cultivation.

In the study area there is a lack of improved management packages targeting irrigated wheat production in the region, and farmers have no experience with irrigated wheat production. Moreover, it is imperative to provide fast-track weeds management options on available irrigated wheat production technologies to farmers and extension agents; hence, the study was aimed at evaluating the efficacy of different herbicides on wheat farms under irrigation conditions.

MATERIALS AND METHODS

The research was carried out at the Metema experimental site under the Gondar Agricultural Research Center (GARC) during the 2021 and 2022 irrigation-cropping seasons. The district is known for cultivating a variety of crops, including rice, sesame, cotton, soybeans, and finger millet. Detailed site-specific information is provided in Table 1.

Experimental materials for the study:

Post-emergence herbicides and an improved bread wheat variety ‘Kekaba’ was used as a seed source.

Experimental design and treatments:

A field experiment was carried out over two consecutive irrigation seasons in 2021 and 2022, utilizing a Randomized Complete Block Design (RCBD) with three replications. The experiment was arranged in three replications on 3 m x 3 m plot size and spacing between plots and blocks were 1 m and 1.5 m, respectively.

Treatments were selected based on target weed types and their expected efficacy. Hence, the experiment consisted of eight treatments, including the weedy control. The treatments were Milvin 8% EC/W/V), Top Harvest 80 EC, Richway 750 WDG, Ethio 2, 4-D 720 SL, Atlantis OD 37.5, Auxo EC 337, two times hand weeding and weedy check (Table 2). An improved bread wheat variety ‘Kekaba’ was used as a seed source. The seeding rate was 125 kg per hectare and recommended fertilizer rates, of 64 and 46 kg ha per hectare N and P2O5, were applied, respectively. All NPS

Table 1. Site descriptions of the study area

Location	Elevation (m)	Total RF (mm)	Temperature Min	Temperature Max	Latitude	Longitude	Soil type
Metema	550-1608	1030.2	19.5	35.9	12 95°N	36 15°E	Vertisol

RF = rain fall, Min = minimum, Max = maximum, source (IPMS, 2005) as Yohannes et al.,(2021) cited.

Table 2. Description of treatments evaluated for their efficacy against wheat weeds

Code	Treatments	Recommendation rate (Lt, gm ha $^{-1}$)	Remarks
T1	Milvin 8% EC	1	For grass weed management
T2	Top Harvest 80 EC	0.8	For grass weed management
T3	Ethio 2, 4-D 720 SL	1.5	For broadleaf weed management
T4	Richway 750 WDG	25	For broadleaf weed management
T5	Atlantis OD 37.5	1	Both
T6	Auxo EC 337	1.5	Both
T7	Hand weeding	Two rounds of weeding	20 and 50 days after emergence
T8	Weedy control	Untreated plot	-

fertilizer was applied at planting while nitrogen fertilizer was applied in split amounts, ½ at planting, ¼ at tillering, and ¼ at head initiation. Harvesting was done manually using hand sickles at the harvesting stage.

Experimental producer:

Weed infestation had been assessed and data were collected on weed population by number and type of species using a 30 cm x 30 cm quadrant. The weed population composite was taken on 3 randomly selected spots in each experimental plots one day before spray and after 20 days of treatment application. Wheat plant base data on thousand seed weight and grain yield were collected from harvestable rows in each plot. Applications of herbicides were done based on factory recommendations when enough weed density and stage of wheat reached early tillering (20 DAE), using a knapsack sprayer.

Data collection:

Weed parameters

In the experimental field plots, some of the broad leaf types such as *Commelina benghalensis L, Ageratum conyzoides L*, *Agemone Mexican* and *Amarantus spinosus* and grass weed types such as *Cyperus rotundus, Cynodon dactylon, Cyperus assimiles* and *Echinoclo colona (L)* were the most common and dominantly observed weeds during the experimentation period. The weed parameter was recorded in each plot at three points in composite way along the diagonal of the plots using 30 x 30 cm (0.09 m^2) quadrant randomly.

Yield gains were determined by comparing the differences in yields between treated (sprayed) and untreated (unsprayed) plots, expressed as a percentage of the yields from the untreated plots (Jail et al., 2014).

Grain yield gain (%) = <u>(Grain yield of sprayed – Grain yield of unsprayed)</u>/Grain yield of unsprayed X100

Data analysis:

The collected data were analyzed using analysis of variance (ANOVA) following the methodology outlined by Gomez and Gomez (1984), with SAS software (version 2002) employed for statistical computations. Mean comparisons were conducted using Duncan's Multiple Range Test (DMRT) to determine significant differences among treatments.

Economic analysis:

Partial budget analysis was also done following CIMMYT 1988 guidelines.

RESULTS

Efficacy of herbicides on wheat weeds:

The analysis of variance of weed population showed that there was no statistically significant variation in broadleaf and grass weed population counts per m^2 before application of herbicides and hand weeding for both growing seasons (Tables 3, 4 and 5). However, there was enough weed population from each type in each experimental unit. On the other hand, after twenty days of application of all the treatments (herbicides and hand weeding) except for the untreated weedy control, were effective in managing the target annual grass and broadleaf weeds across both seasons (Tables 3, 4 and 5).

During the 2021 irrigation cropping season, the result indicated that the plots received a single spray of Atlantis OD 37.5(44.4 m^2), Richway 750 WDG (48.1 m^2), Ethio 2, 4-D 720 SL (70.4 m^2) and two rounds of hand weeding (25.9^d) harbored the lowest broadleaf weed population. However, those plots that received Milvin 8% EC (229.63 m^2) and the untreated control (340.73 m^2) harbored comparatively higher broadleaf weed populations (Table 3). A highly significant reduction in grass weed population was also observed on plots that received two rounds of hand weeding (59.3 m^2) and Top harvest 80 EC (62.9 m^2) followed by those that received Atlantis OD 37.5 (85.1 m^2) and Auxo EC 337 (155.57 m^2). However, plots that received no treatment/weedy control (381.47 m^2) harbored a relatively higher grass weed population during the experimental season (Table 3).

During the 2022 irrigation cropping season, the plots that received foliar spray of Atlantis OD 37.5 (24.73 m^2), Richway 750 WDG (28.47 m^2), and were hand weeded twice (6.20 m^2) had a very significantly reduced population of broadleaf weeds, followed by those treated with Ethio-2,4-D 720 SL (50.6 m^2). However, a higher weed population was recorded in plots that received no treatment/weedy control (321.1 m^2) (Table 4). Those plots that were sprayed with Top harvest 80 EC (58.27 m^2), Atlantis OD 37.5 (80.5 m^2) and were hand weeded twice (54.6 m^2) showed significant reduction in grass weed population while the highest population of grass weed was recorded on plots that received no treatment (376.8 m^2) (Table 4).

Yield and yield components:

The analysis of variance indicated that the treatments had a statistically significant ($P < 0.05$) effect on grain yield. However, no statistically significant difference was found among treatments on biomass yield and thousand seed weight in both cropping seasons (Tables 3, 4 and 5). During the 2021 irrigation cropping season, the plots that received Top harvest 80 EC (3260.4 kg ha-1), Atlantis OD 37.5(3096.3 $kgha^{-1}$) and two rounds of hand weeding (2788.4 $kgha^{-1}$) gave significantly higher grain yield followed by those that received Richway 750 WDG (2754.0 kgha-1).On the other hand, the smallest grain yield was found on plots that received a single spray of Auxo EC 337 (2221.0 kgha-1) after 20 days of emergence and on the untreated control (2290.0 $kgha^{-1}$) during the experimental season (Table 3). The increase in variation might be because of the suppression effect of the herbicides targeting broadleaf, grass or both weed types. On the other hand, the reduction in grain yield could be due to the computational effect of the weeds together with the lower efficacy of the herbicides for their target weeds.

During the 2022 irrigation cropping season, all plots treated with herbicide gave significantly higher grain yields than untreated plots. The plots that received foliar spray of Atlantis OD 37.5 (3078.7 $kgha^{-1}$), Richway 750 WDG (3119.6 $kgha^{-1}$) and Ethio 2, 4-D 720 SL (3126.1 kgha-1) gave higher grain yields followed by those that received hand weeding twice (2983.0 $kgha^{-1}$), Milvin 80% EC (2924.1 $kgha^{-1)}$ and Top harvest 80 EC (2908.3 $kgha^{-1}$). However, the lowest grain yield was harvested on untreated plots (2191.6 $kgha^{-1)}$ (Table 4).

The combined analysis of variance across both years showed no significant differences among treatments in terms of the population of both weed types prior to the application of any treatments (Table 5). However, there was a significant difference among treatments (herbicides and hand weeding) on weed population after twenty days of spray (Table 5). The lowest number of broadleaf weeds was recorded on plots treated with two

Table 3. Effects of different herbicides on wheat weed population under irrigation and their corresponding yield components and yield response at Metema during 2021.

Treatments	BLWBS (m^2)	BLWAS (m^2)	GWBS (m^2)	GWAS (m^2)	GY ($kgha^{-1}$)	BM ($tonha^{-1}$)	TSW (g)
Milvin 8% EC	254.59	229.63^{b}	214.8	129.63^{cd}	2639.3^{bcd}	7455	28.87
Top Harvest 80 EC	203.7	155.57^{bc}	222.23	62.97^{e}	3260.4^{a}	9747	32.47
Ethio2,4-D 720 SL	259.26	70.37^{cd}	229.63	248.17^{b}	2454.5^{cd}	8259	31.4
Richway 750 WDG	203.68	48.17^{d}	248.13	270.37^{b}	2754.0^{bc}	7426	33.47
Atlantis OD 37.5	262.97	44.43^{d}	200	85.17^{de}	3096.3^{ab}	8601	33.27
Auxo EC 337	233.33	140.73^{bc}	196.3	155.57^{c}	2221.0^{d}	6786	31.4
Hand weeding x 2	218.5	25.9^{d}	207.4	59.3^{e}	2788.4^{ab}	7961	31.23
Weedy control	255.57	340.73^{a}	277.77	381.47^{a}	2290.9^{cd}	8140	32.37
Mean	236.57	131.94	224.53	174.07	2688.1	8047	31.84
Sig. level	ns	**	ns	***	**	ns	ns
CV	15.62	37.47	16.13	18.05	9.68	27.08	7.29

TSW = thousand seed weight, BLWBS = broad leaved weeds before spray, BLWAS = broad leaved weeds after spray, GWBS = grass weed before spray, GWAS = grass weed after spray, BM = biomass, GY = grain yield

Table 4. Effects of different herbicides on wheat weed population under irrigation and their corresponding yield components and yield response at Metema for the year 2022

Treatments	BLWBS (m^2)	BLWAS (m^2)	GWBS (m^2)	GWAS (m^2)	GY ($kgha^{-1}$)	BM ($kgha^{-1}$)	TSW (g)
Milvin 8% EC	191.27	209.93^{b}	105.2	124.97^{cd}	2924.1^{ab}	5888.0	30.67
Top Harvest 80 EC	139.4	135.87^{bc}	112.67	58.27^{e}	2908.3^{ab}	5179.7	30.08
Ethio-2,4-D 720 SL	194.97	50.67^{cd}	120.03	243.47^{b}	3126.1^{a}	5033.9	29.1
Richway750 WDG	139.4	28.47^{d}	108.6	165.70c	3119.6^{a}	5362.6	30.1
Atlantis OD 37.5	198.67	24.73^{d}	90.43	80.53^{de}	3078.7^{a}	4635.4	29.43
Auxo EC 337	169.03	121.03^{bc}	86.7	150.90^{c}	2766.0^{b}	5052.1	32.47
Hand weeding x 2	154.2	6.20^{d}	97.8	54.60^{e}	2983.0^{ab}	4291.7	26.83
Weedy control	191.27	321.03^{a}	138.2	376.80^{a}	2191.6^{c}	4375.0	27.2
Mean	172.27	112.24	114.95	169.40	2887.2	4977.2	29.48
Sig. level	ns	**	ns	***	***	ns	ns
CV	21.45	34.04	31.51	18.55	4.27	21.28	6.95

NB: TSW = thousand seed weight, BLWBS = broad leaved weeds before spray, BLWAS = broad leaved weeds after spray, GWBS = grass weed before spray, GWAS = grass weed after spray, BM = biomass, GY = grain yield rounds of hand weeding (52.8 m^2) and Richway 750 WDG (55.9 m^2), followed by those treated with Atlantis OD 37.5(91.4 m^2). However, plots that received no treatment harbored higher number of broadleaf weeds (236.4 m^2) (Table 5). Similarly, the highest grass weed population reduction was also obtained on plots treated with Top Harvest 80 EC (40.7 m^2) and hand weeding (49.1 m^2) but a higher weed population was recorded on plots that received no treatment (209.8 m^2) (Table 5).

DISCUSSION

The findings demonstrated that all treatments, including herbicides and hand weeding, were effective in managing the target annual broadleaf and grass weeds, with the exception of the untreated weedy control. These results align with the findings of Tag-El-Din et al. (2008), who reported that herbicide application during the tillering stage effectively controls annual grass and broadleaf weeds in irrigated wheat fields.

The combined analysis of variance on grain yield revealed that a highly significant increment of grain yield was found on plots that received Atlantis OD 37.5 (3087.5 $kgha^{-1}$) and Top Harvest 80 EC(3084.4 $kgha^{-1}$) followed by those that received two rounds of hand weeding (2885.0 $kgha^{-1}$), Richway 750 WDG (2936.0 $kgha^{-1}$), Milvin 80% EC (2781.5 $kgha^{-1}$) and Ethio 2, 4-D 720 SL (2790.7 $kgha^{-1}$). However, those plots that

Table 5. Combined over years (effects of different herbicides on wheat weed population yield response)

Treatments	BLWBS (m^2)	BLWAS (m2)	GWBS (m^2)	GWAS (m2)	GY (kg ha^{-1})	GYG (%)	BM (kg ha^{-1})	TSW (g)
Milvin 8% EC	308.6	162.9^{ab}	121.6	78.4^{cd}	2781.5^{b}	24.1	6671.7	29.8
Top Harvest 80 EC	282.7	146.6^{bc}	116.7	40.7^{e}	3084.4^{a}	37.6	7463.4	31.3
Ethio-2,4-D 720 SL	206.8	135.3^{bc}	122.2	130.6^{b}	2790.7^{b}	24.5	6646.4	30.3
Richway750 WDG	227.2	55.9^{d}	134.6	150.6^{b}	2936.0^{ab}	31.0	6394.1	31.8
Atlantis OD 37.5	330.2	91.4^{cd}	114.2	53.7^{cde}	3087.5^{a}	37.7	6618.3	31.4
Auxo EC 337	202.5	147.8^{bc}	104.9	86.1^{c}	2493.5^{c}	11.2	5918.9	31.9
Hand weeding x 2	221.6	52.8^{d}	119.1	$49.1d^{e}$	2885.0^{ab}	28.7	6126.5	29.0
Weedy control	208.0	236.4^{a}	155.6	209.8^{a}	2241.6^{d}	-	6257.4	29.8
Mean	248.4	116.7	123.6	99.8	2787.5	-	6512.1	30.6
Sig. level	ns	**	ns	***	***	-	ns	ns
CV	41.46	35.83	21.96	27.26	7.31	-	26.30	7.14

NB: TSW = thousand seed weight, BLWBS = broad leaved weeds before spray, BLWAS = broad leaved weeds after spray, GWBS = grass weed before spray, GWAS = grass weed after spray, GY = grain yield, GYG (%) = grain yield gain

Table 6. Economic analysis for the management of bread wheat weeds using post emergence herbicides

Variables	T1	T2	T3	T4	T5	T6	T7	T8
Adj. yield kg/ha(Y*0.9)	2503.5	2775.9	2511.6	2642.4	2778.5	2244.2	2596.5	2017.4
Farm gate price of wheat (Birr kg^{-1})	32	32	32	32	32	32	32	32
Sale revenue	80112	88828.8	80371.2	84556.8	88912	71814.4	83088	64556.8
Cost of herbicide (ETB ha^{-1})	930	600	750	850	700	760	-	-
Cost of labor for spray (ETB ha^{-1})	400	400	400	400	400	400	3700	-
Total variable cost (ETB ha^{-1})	1330	1000	1150	1250	1100	1160	3700	-
Net benefit (ETB ha^{-1})	78782	87828.8	79221.2	83306.8	87812	70654.4	79388	64556.8
Cost benefit ratio	59.2	87.8	68.8	66.6	79.8	60.9	21.4	

Cost of labor = 100 Ethiopian Birr Day^{-1} $labor^{-1}$, price of wheat grain = 32.00 Ethiopian Birr kg^{-1} T1 = Milvin 8% EC, T2 = Top Harvest 80 EC, T3 = Ethio-2, 4-D 720 SL, T4 = Richway750 WDG T5 = Atlantis OD 37.5, T6 = Auxo EC 337, T7 = Hand weeding x 2, T8 = weedy control received Auxo EC 337 (2493.5 kgha^{-1}) gave relatively lower grain yield as compared to plots that received other herbicides. The lowest grain yield was obtained in plots that received no treatment (2241.6 kgha^{-1}) (Table 5). The variation in grain yield could be because of the efficacy of each herbicide on the target weed types, which determines the number of weeds both in type and in density; therefore, the lower the density the computation and the more the wheat farm became productive. This variation could be because of the efficiency of the herbicides in targeting weeds in irrigated wheat fields during the experimental seasons (Dadari & Mani, 2005 & Chaudhary et al., 2021).

The result also showed that the highest grain yield was obtained from plots that received foliar application of Atlantis OD 37.5 (37.7%) and Top Harvest 80 EC (37.6%) followed by those that received Richway 750 WDG (31.0%), while the lowest was found in those treated by Auxo EC 337 (11.2%) (Table 5). Rezene (2005), who recorded a yield loss of above 36.3% in wheat in untreated control plots, reported similar findings.

Partial budget analysis indicated that the application of Top Harvest 80 EC (87,828.8 ETB) and Atlantis OD 37.5 (87,812) had the highest net benefits as compared to other treatments (Table 6). Hence, plots received a single spray of Top Harvest 80 EC (1:87.7) and Atlantis OD 37.5 (1:79.8) at twenty days after emergence had shown the highest cost / benefit ratio compared to other treatments. Similar trends were observed in research done by Bogale et al. (2020).

In conclusion, this study confirmed that all treatments, excluding the untreated control, were effective in managing the target annual broadleaf and grass weeds in irrigated bread wheat fields. Wheat plots that received hand weeding twice, Atlantis OD 37.5 and Richway 750 WDG contained significantly reduced broadleaf population and plots that received hand weeding twice, Top Harvest 80 EC and Atlantis OD 37.5 significantly repressed grass weeds. Plots treated with Top Harvest 80 EC and Atlantis OD 37.5 gave higher grain yield compared to weedy check. Economic analysis also indicated that the maximum net benefit was obtained on plots treated with Top Harvest 80 EC (87,828.8 ETB ha^{-1}) and Atlantis OD 37.5 (87,812 ETB ha^{-1}). Hence, a single foliar application of Top Harvest 80 EC and Atlantis OD 37.5 as post emergence herbicides at twenty days after emergence could be recommended for the management of weeds in irrigated bread wheat fields in the study area and similar agro-ecologies.

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The authors have provided their consent for publication.

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The authors declare that they have no competing interests.

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