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Research Article

Effect of Integrated Weed Management on Yield and Yield Component of Bread Wheat in Guji Zone, Southern Oromia

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Abstract: Bread wheat (*Triticum aestivum* L.) is one of the most important food crops in the world, providing a staple food for over 35% of the global population; in Ethiopia, however, production in highland regions like the Guji zone is severely constrained by heavy weed infestation, causing significant yield gaps. While Integrated Weed Management (IWM) is a promising solution, locally validated and economically feasible strategies for this specific agroecology are lacking. Therefore, this study was conducted to evaluate the agronomic performance and economic viability of different weed management practices in bread wheat. A field experiment was conducted over the 2021 and 2022 main growing seasons at two locations in the Guji zone using a Randomized Complete Block Design. Ten treatments, including herbicides (Salon 5 OD, Zura 2, 4-D), manual weeding, and their integrated combinations, were evaluated. Results revealed that all weed management treatments significantly outperformed the weedy check. The integrated treatment of Salon 5 OD followed by one hand weeding was most effective, reducing final weed density to 3.37 plants m^{-2} compared to 12.34 plants m^{-2} in the weedy check. This superior weed control translated directly into yield, with the same integrated treatment producing a grain yield of 3,623.7 kg ha^{-1}, a 145% increase over the weedy check (1,480.7 kg ha^{-1}). Economically, this strategy also yielded the highest net benefit (85,446.55 ETB ha^{-1}) and the highest marginal rate of return (3,656.90%). It is concluded that an integrated approach is essential for managing the mixed weed flora in the Guji zone. Based on its high efficacy, excellent grain yield, and superior profitability, the application of Salon 5 OD supplemented with one timely hand weeding is recommended as the most economically viable and sustainable weed management strategy for wheat farmers in the study area and similar agroecologies.

Keywords: Bread Wheat, Grain Yield, Herbicide, Integrated Weed Management, Economic Viability

Introduction

Bread wheat (*Triticum aestivum* L.) is one of the world's most significant food crops, feeding more than 35% of the world's population and producing 772.6 million tons per year (Nigus et al., 2022). Ethiopia and South Africa are the top producers in sub-Saharan Africa, while China, India, and Russia are the biggest producers worldwide (Hungerford et al., 2019). Ethiopia produces around 5.8 million tons annually with an average productivity of 3 tons per hectare (CSA, 2022), which is lower than the achievable crop yields of up to 5 tons per hectare (Zegeye et al., 2020). Ethiopia's average yield is still low by international standards, despite an increase in wheat production area and productivity (Anteneh & Asrat, 2020). Wheat production is best suited to highlands with elevations ranging from 1900 to 2700 meters above sea level (Abrahim et al., 2019). With elevations between 2200 and 2900 meters, the Guji zone is a crucial prospective location for wheat intensification. However, biotic factors weeds being the most important as well as socioeconomic difficulties severely limit productivity in these highlands.

Weeds compete with crops for space, light, nutrients, and water, which results in large production losses. Heavy rainfall encourages aggressive weed growth in Southern Oromia's highlands, resulting in serious infestations. Uncontrolled weed pressure is a major cause of low wheat yields, with losses estimated at 10-80%

(Atnafu, 2019). The difficulty in identifying grass weeds from wheat seedlings in the early vegetative phases makes timely hand weeding impossible (Gorfu et al., 1992). Furthermore, persistent labor shortages during peak agricultural seasons result in weeding being done too late or not at all, leaving farmers with significant yield penalties. Ethiopian farmers employ a variety of techniques to counteract this, such as hand weeding and the growing use of post-emergence herbicides to compensate for labor shortages. Both strategies, meanwhile, have significant drawbacks. Herbicide-resistant weed biotypes and a shift in the weed community toward more tolerant species can result from an over-reliance on a single technique, such as the repeated application of a single herbicide. The most efficient, environmentally friendly, and sustainable method for addressing these drawbacks is Integrated Weed Management (IWM) (Harker & O'Donovan, 2013). IWM uses a variety of strategies, including mechanical, cultural, and chemical approaches, to maintain weed populations below a certain economic threshold.

While research in other Ethiopian highlands has proved the potential of IWM, these findings are not universally applicable. According to Tadesse et al. (2021), research has demonstrated that in the central highlands, a combination of herbicides and one additional hand weeding can be successful. Nonetheless, the Guji zone has a unique range of weeds, with broadleaf weeds like Galinsoga parviflora and grasses like wild oat (Avena fatua) posing the greatest threat (Bekele, 2018). Although broad-spectrum herbicides are frequently used by local farmers, there is no guarantee that they will be effective against this particular plant complex throughout the growing season. Regarding whether particular combination of weed control techniques is both economically viable for smallholder farmers in the Guji zone and agronomically effective against the indigenous weed flora, there is a crucial information vacuum. A technically good but costly solution is not a workable one. Thus, the purpose of this study was to determine and assess the economic feasibility and agronomic performance of various integrated weed management strategies for bread wheat in the Guji zone of Southern Oromia.

Materials and Methods

Description of the Study Area

The experiment was conducted during the 2021 and 2022 main growing seasons at two locations in the Guji zone of Southern Oromia, Ethiopia. The first site was on-station at the Bore Agricultural Research Center (06°24'02.4"N, 38°35'07.8"E; 2747 m.a.s.l.), and the second was on a representative farmer's field in the Ana Sora district (06°10'54.7"N, 38°42'63.5"E; 2452 m.a.s.l.). Both locations represent the highland agro-ecology of the region, which is a key wheat-producing area. The predominant soil types are Nitosols and Orthic Acrisols. The soil of the experimental sites revealed a clay loam texture with a pH of approximately 5.1, indicating Moderate acidic soil conditions. The long-term meteorological data for the area indicates a bimodal rainfall pattern with an average annual rainfall of 1200 mm and a mean annual temperature of 16°C, conditions which are conducive for wheat cultivation but also for aggressive weed growth.

Treatments and Experimental Design

The experiment consisted of ten weed management treatments laid out in a Randomized Complete Block Design (RCBD) with three replications at both locations. The treatments were designed to evaluate the efficacy of two common herbicides, applied alone and in combination with manual weeding. The details of the treatments are presented in Table 1. The gross plot size was 3 m x 4 m (12 m²). The experiment was designed to compare the efficacy of different weed management strategies. The treatments included two herbicides (Salon 5 OD and Zura 2, 4-D) and manual hand weeding, which were applied alone, in combination, or as part of an integrated program. In total, ten treatments were evaluated: Salon 5 OD alone; Salon 5 OD tank-mixed with Zura 2,4-D; Salon 5 OD followed by one hand weeding; Zura 2,4-D alone; Zura 2,4-D followed by one hand weeding; a three-way combination of Salon 5 OD, Zura 2,4-D, and one hand weeding; one hand weeding only; two hand weeding; a season-long weed-free control; and a weedy check control. The bread wheat variety ‘Huluka’, which is well-adapted to the Guji highlands, was used for the experiment. Seeds were sown by drilling in rows at a rate of 150 kg ha^{-1}. All plots received a basal application of NPSB fertilizer at a rate of 150 kg ha^{-1} and a top-dressing of Urea at 100 kg ha^{-1} at the mid-tillering stage to ensure crop nutrient requirements were met.

Herbicides were applied using a calibrated knapsack sprayer with a spray volume of 200 L ha^{-1}. All other agronomic practices, such as pest and disease control, were carried out uniformly for all treatments as per the regional recommendations. Weed density (plants m^{-2}) and weed dry biomass (g m^{-2}) were recorded from two randomly placed 0.5 m × 0.5 m quadrats within each plot. Data was collected at two key timings: 30 days after sowing (DAS) just before the application of post-emergence herbicides, and at physiological maturity (just before crop harvest). Weeds within each quadrat were identified by species, counted, and then harvested by cutting at the soil surface. The harvested weed samples were oven-dried at 72°C for 48 hours to a constant weight to determine the dry biomass. Weed Control Efficiency (WCE): WCE for each treatment was calculated based on weed dry biomass using the following formula:

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

Where WDC is Weed Dry Matter in weedy Check and WDT is Weed Dry Matter in a Treatment.

Harvest Index (%) was calculated by:

$$HI = \left(\frac{\text{Grain yield}}{\text{Total above ground dry biomass}} * 100\right)$$

At maturity, the crop from a net plot area was manually harvested to determine grain yield, which was adjusted to 12.5% moisture content and converted to kg per hectare (kg ha^{-1}).

Results and Discussion

Weed Species Composition at the Experimental Sites

The experimental fields were infested with a diverse population of weed species. A total of fifteen weed species belonging to nine weed families were identified across both years and locations. The weed flora was composed of both grasses and broadleaf species, with the latter being more numerous in species count. The dominant and most problematic weeds identified were the grass species *Snowdenia polystachya*, *Avena fatua* (wild oat), and *Phalaris paradoxa*, and the broadleaf species *Galium spurium*, *Galinsoga parviflora*, *Guizotia scabra*, and *Polygonum nepalense*. The co-existence of competitive grass and broadleaf weeds highlights the challenge faced by farmers in the Guji highlands and underscores the need for a broad-spectrum weed management strategy. A detailed list of all weeds species and their relative abundance is presented in Table 1.

Table 1: Weed Species Identified in the Experimental Fields

Scientific Name	Family	Life Forms	Categories
Snowdenia polystachya L,	Graminaea	Annual	Grass
Galium spurium	Rubiaceae	Annual	Broadleaved
Andropogon abyssinicus	Poaceae	Annual	Grass
Cynodon dactylon	Poaceae	Perennial	Grass
Commelina benghalensis L	Commelinacea	Annual/Perennial	Broadleaved
Plantaqo lanceolata	Plantaginaceae	perennial	Broadleaved
Rumex abyssinicus	Polygonaceae	Perennial herb	Broadleaved
Phalaris paradox	Graminaea	Annual	Grass
Avena fatua,	Graminaea	Annual	Grass
Eragrostis cillianensis	Poaceae	Annual	Grass
Guzotia scabra	Asteraceae	Annual	Broadleaved
Galansoga palviflor	Asteraceae	Annual	Broadleaved
Poligonium nepalense	Polygnonaceae	Annual	Broadleaved
Erucastrum arabicum	Brassicaceae	Annual	Broadleaved
Trifolium rueppellianum	Fabaceae	Annual	Broadleaved

Effect of Weed Management Treatments on Weed Density

Analysis of variance revealed that weed management treatments had a highly significant effect ($P < 0.01$) on weed density at both 30 days after emergence (DAE) and at the pre-harvest stage (Table 2; Fig. 1). As expected, the highest weed density at harvest was recorded in the untreated weedy check plots (12.34 plants m^{-2}). All weed control treatments significantly reduced weed density compared to this check. The most effective treatment was the integrated application of Salon 5 OD followed by one hand weeding, which resulted in the lowest final weed density (3.37 plants m^{-2}). This was statistically similar to the weed-free plots (3.73 plants m^{-2}), demonstrating the high efficacy of this integrated approach. The superior performance of combining an herbicide with manual weeding can be attributed to the complementary action of the two methods. The post-emergence herbicide (Salon 5 OD, containing Pinoxaden) effectively controlled the early flush of grass weeds, while the subsequent hand weeding at a later stage removed weeds that escaped the chemical application as well as late-emerging broadleaf species. These results are in agreement with (Fikru et al., 2021), who reported that integrating chemical and cultural practices provides more consistent and broader-spectrum weed control than either method used alone. Similarly, (Amare & Raghavaiah 2016) found that supplementing herbicide application with one hand weeding significantly enhanced weed control efficiency and crop yield in wheat.

Interestingly, no significant difference in final weed density was observed between the 'one hand weeding' and 'Zura 2, 4-D + one hand weeding' treatments. This suggests that for the weed spectrum present, the single hand weeding at 30 DAE was effective enough at removing the major flush of weeds that the addition of the 2, 4-D herbicide for broadleaf control did not provide an additional, statistically significant reduction in weed numbers by harvest. This observation is similar to that of (Mosisa et al., 2013), who also noted situations where the mechanical weeding component was the primary driver of weed reduction in an integrated system.

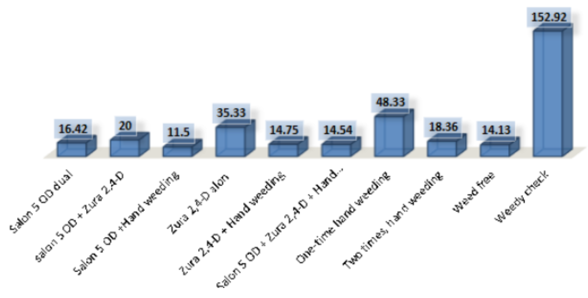

Fig. 1: Bar chart showing the impact of different treatments on weed density in wheat crop

Table 2: Effect of weed management treatments on weed density, dry biomass, and control efficiency (combined data, 2021-2022)

Treatment	Weed dry biomass	Weed density pre	Weed density post	Weed control efficiency
Salon 5 OD dual	27.36^{cd}(759.80)	10.07^{a}(104.2)	4.02^{dc}(16.42)	8.16^{a}(72.46)
salon 5 OD + Zura 2, 4-D	31.45^{cd}(1,120.0)	9.40b^{a}(89.04)	4.49^{c}(20.0)	7.58^{ba}(58.51)
Salon 5 OD +hand weeding	25.23^{cd}(693.30)	10.19^{a}(105.38)	3.37^{d}(11.50)	8.56^{a}(74.13)
Zura 2, 4-D alone	40.01^{b}(1,693.30)	10.24^{a}(103.50)	5.97^{b}(35.33)	6.21^{b}(42.85)
Zura 2, 4-D + hand weeding	26.193^{cd}(755.00)	9.35b^{a}(91.25)	3.74^{dc}(14.75)	7.95^{a}(68.59)
Salon 5 OD + Zura 2, 4-D + Hand weeding	25.16c^{d}(680.00)	9.09^{ba}(84.29)	3.76^{dc}(14.54)	8.84^{a}(77.87)
One-time hand weeding	40.03^{a}(1,707.70)	10.14^{a}(103.54)	6.81^{b}(48.33)	6.16^{b}(41.98)
Two times, hand weeding	28.87^{cd}(908.30)	8.42^{b}(71.75)	4.21^{dc}(18.36)	8.17^{a}(67.20)
Weed free	19.83^{d}(418.30)	9.41^{ba}(88.29)	3.73^{dc}(14.13)	9.05^{a}(82.05)
Weedy check	55.29^{a}(3,150.30)	9.48^{ba}(89.79)	12.34^{a}(152.92)	0.71^{c}(0.00)
LSD(0.05)	9.45	1.21	1.04	1.58
CV	25.27	10.75	16.95	18.91

Means followed by the same letter within the column are not significantly different at a 5% level of significance; CV = coefficient variation; LSD = least significant difference.

Table 3: Combined analysis of weed management effects on key agronomic traits in Southern Oromia (2021-2022)

Treatment	Plant height (cm)	Spike length (cm)	Productive tiller	Spike per spikelet	Kernel per spike
Salon 5 OD Dual	81.01^{bdc}	7.96^{dc}	2.62^{c}	7.60^{dc}	35.58^{de}
salon 5 OD + Zura 2, 4-D	81.56^{bc}	7.88^{d}	2.44^{c}	7.69^{dc}	37.51^{d}
Salon 5 OD + hand weeding	85.17^{ba}	8.35^{bac}	3.81^{ba}	8.21^{ba}	41.70^{bc}
Zura 2, 4-D	76.28^{ed}	7.12^{e}	1.83^{d}	7.26^{de}	31.83^{fe}
Zura 2, 4-D + hand weeding	81.99^{bac}	8.14^{bdc}	2.82^{c}	7.81^{bc}	39.50^{dc}
Salon 5 OD + Zura 2, 4-D + hand weeding	85.29^{ba}	8.67^{a}	3.71^{b}	8.27^{ba}	44.08^{ba}
One-time hand-weeding	79.06^{edc}	7.84^{d}	2.74^{c}	7.68^{dc}	38.64^{dc}
Two times, hand weeding	84.41^{ba}	8.46^{ba}	3.83^{ba}	8.26b^{a}	45.26^{ba}
Weed free	86.79^{a}	8.75^{a}	4.21^{a}	8.39^{a}	47.57^{a}
Weed check	74.89^{e}	6.65^{f}	1.37^{e}	6.81^{e}	29.61^{f}
LSD(0.05)	5.05	0.45	0.42	0.49	4.13
CV	7.65	7.01	17.52	7.88	13.05

Means followed by the same letter within the column are not significantly different at a 5% level of significance; CV = coefficient variation; LSD = least significant difference.

Weed Dry Biomass and Weed Control Efficiency

Weed dry biomass, a critical indicator of weed competition with the crop, was significantly influenced (< 0.01) by the different weed management treatments (Table 3). The lowest weed dry biomass (19.83 g m^{-2}) was, as expected, recorded in the season-long weed-free plots. Critically, the integrated treatments performed nearly as well, with the three-way combination of Salon 5 OD + Zura 2, 4-D + one hand weeding (25.17 g m^{-2}) and Salon 5 OD + one hand weeding (25.23 g m^{-2}) showing no statistical difference from each other. Conversely, the highest accumulation of weed biomass (55.29 g m^{-2}) occurred in the untreated weedy check plots, underscoring the severe level of weed pressure at the experimental sites. These biomass reductions are directly reflected in the Weed Control Efficiency (WCE) values. The highest WCE among the practical treatments was achieved by the three-way combination of herbicides and hand weeding (77.9%), followed very closely by Salon 5 OD + one hand weeding (74.1%). The weed-free plot, serving as the practical benchmark for maximum control, achieved a WCE of 82.1%. By definition, the weedy check plot, against which all others are compared, had a WCE of 0%.

The superior performance of the integrated strategies is due to the complementary action of the different control tactics. The initial application of herbicides effectively suppressed the early and highly competitive flush of both grass and broadleaf weeds. The subsequent manual weeding then eliminated weeds that either escaped the chemical application or germinated later in the season, preventing them from establishing and accumulating significant biomass. This two-pronged approach provides broader-spectrum and longer-lasting control than any single method can achieve alone. This finding is well-supported by (Mekonnen and Gebre, 2022) also concluded that supplementing herbicide use with one timely hand weeding provided a synergistic effect, maximizing weed biomass reduction and subsequent grain yield in highland wheat systems. The results thus clearly demonstrate that an integrated approach is essential for minimizing weed competition.

Effect of Weed Management on Wheat Yield and Yield Components

Analysis of variance indicated that all weed management treatments had a highly significant effect (< 0.01) on the final grain yield and all measured yieldattributing parameters. The degree of weed control directly correlated with improvements in crop performance, with the most effective weed management strategies consistently producing the best results, while the weedy check plots consistently performed the poorest.

Plant Height

Weed management practices had a statistically significant effect on plant height ($p<0.05$). The greatest plant height (86.79 cm) was observed in the weed-free control plots. This was closely followed by integrated approaches using Salon 5 OD + Zura 2, 4-D + Hand weeding (85.29 cm) and Salon 5 OD + Hand weeding (85.17 cm). Conversely, the minimum plant height (74.90 cm) was recorded in the weedy check plot. The superior plant height in effectively managed plots can be attributed to the reduction of interspecific competition. With weeds suppressed, crop plants have greater access to essential growth resources such as sunlight, water, and nutrients, allowing them to achieve their full genetic potential for vegetative growth. In contrast, the significant stunting observed in the weedy check is a direct result of intense competition from weeds, which limits resource availability and can induce stress. These findings are consistent with recent research by (Anum et al., 2024), who both documented significant increases in crop height in response to effective chemical and integrated weed control. This general trend, however, contrasts with the findings of Belete et al. (2018), who reported the largest plant height in weedy check plots. Such an anomaly can sometimes be explained by the phenomenon of etiolation, where plants under canopy shade (from taller weeds) stretch upwards in search of light, resulting in taller but weaker, less productive stems.

Spike Length

The length of the spike, a critical yield component, was also significantly influenced by the weed management methods ($p<0.05$). The longest spikes (8.75 cm) were recorded in the weed-free plots, followed by the integrated treatment of Salon 5 OD + Zura 2, 4-D + manual weeding (8.67 cm). The shortest spike length (6.65 cm) was observed in the weedy check plot where no weed control was applied. This outcome is directly linked to plant health and resource allocation. In a low-competition environment, plants can develop robustly during the vegetative stage, leading to a greater partitioning of photo-assimilates to reproductive structures during the flowering and grain-filling stages. This supports the development of larger, more developed spikes. This principle aligns with the findings of (Upadhyay et al., 2018), who demonstrated that reduced weed pressure allows for improved source-sink dynamics, benefiting the development of reproductive organs like the spike. Similarly, (Keller et al., 2015) reported a direct correlation between weed biomass and reduced spike length in wheat, corroborating the present results.

Productive Tillers

The number of productive tillers per plant, a primary determinant of grain yield, was significantly impacted by the weed management treatments. The highest count of productive tillers (3.58) was recorded in the completely weed-free plots, with the Salon 5 OD + manual weeding treatment following closely (3.46). A drastically lower number of productive tillers (1.15) were recorded in the weedy check plot. This disparity is due to the high sensitivity of the tillering stage to environmental stress. Weed infestation creates intense competition for resources, which suppresses the plant's ability to initiate and sustain viable, grain-bearing tillers. The effective control of weeds by the top-performing treatments mitigated this stress, enabling the plants to produce more tillers. This supports the conclusions of (Yawale et al., 2019), who found that early-season weed control is crucial for maximizing tiller production in cereals. These results are also in agreement with Ayana et al. (2021), who previously reported a sharp decline in productive tiller numbers with increasing weed density.

Spikelets per Spike

The number of spikelets per spike, which sets the potential for the number of grains, was significantly dependent on the weed management method. The highest number of spikelets (8.39) was recorded in the weed-free plot. This was statistically similar to plots treated with Salon 5 OD + Zura 2, 4-D + hand weeding (8.27) and two hand weeding (8.26). The lowest number of spikelets per spike (6.81) was predictably found in the weedy check plot. The increased number of spikelets in weed-free plots is a result of enhanced nutrient and water uptake during the critical phase of spike differentiation. When weeds are controlled, the crop can efficiently utilize available resources to develop a more robust reproductive structure with a higher number of spikelets. These findings are consistent with recent studies by Singh and Kumar (2022), who observed that integrated weed management significantly increased the number of spikelets per spike compared to a weedy control. Furthermore, (Ramesh et al., 2017) concluded that competition for nitrogen during the stem elongation phase directly limits the formation of spikelets, which explains the poor performance of the crop in the weedy check plots.

Kernels per Spike

The number of kernels per spike was significantly influenced by the different weed control methods. The highest number of kernels (47.57) was achieved in the weed-free plot, followed by the treatment involving two hand weeding (45.27). In stark contrast, the lowest number of kernels per spike (29.61) was recorded in the weedy check. This outcome is a cumulative result of the benefits of a weed-free environment. The significantly higher kernel count is due to superior access to growth factors like nutrients, moisture, and light. This leads to a higher net assimilation rate and improved photosynthetic efficiency from more vigorous leaf development. Consequently, plants in weed-free plots can support better pollination, reduce flower abortion, and effectively partition assimilates to fill the developing grains. These results are substantiated by recent findings from (Garkhal et al., 2024), who reported that effective weed control enhances "source-sink" strength, leading to improved grain set and filling. Similarly, (Şin et al., 2024), demonstrated that a reduction in weed-induced stress during the post-anthesis period is critical for maximizing the final number of kernels per spike.

Thousand-Grain Weight

Thousand-grain weight, a key indicator of grain filling and quality, was significantly influenced by the weed management methods ($p<0.05$). The highest thousand-grain weight was recorded in the integrated treatment of Salon 5 OD + hand weeding (45.32 g), which was statistically similar to the weed-free, plots (44.56 g). In stark contrast, the minimum thousand-grain weight was observed in the weedy check plot (31.09 g). This result highlights the critical importance of weed control during the reproductive and grain-filling stages of the crop. The effective suppression of weeds by the top-performing treatments reduced competition for water, light, and nutrients, allowing the crop to efficiently translocate photo-assimilates to the developing grains. This superior resource partitioning results in plumper, heavier grains. This is consistent with recent findings by (Girma and Bekele, 2022), who demonstrated that effective post-emergence weed control in the Arsi highlands led to a significant increase in the thousand-grain weight of bread wheat. The findings also align with previous work by (Amare & Raghavaiah 2016), who reported that test weight in wheat decreased proportionally with increasing weed density in the central highlands of Ethiopia.

Aboveground Biomass

The weed management treatments had a significant effect on the total aboveground biomass of bread wheat. The highest biomass yield was recorded in the weed-free plots (9,911 kg ha^{-1}), followed closely by two manual weeding (9674.7 kg ha^{-1}) and the integrated Salon 5 OD + manual weeding treatment (9483.5 kg ha^{-1}). The lowest aboveground biomass was produced in the weedy check plot (5922.8 kg ha^{-1}), which was significantly lower than all other treatments. The substantial reduction in biomass in the unweeded plots is a direct consequence of intense weed-crop competition. Weeds limit the crop's access to essential growth resources, thereby suppressing vegetative growth and reducing overall dry matter accumulation. Conversely, the high biomass in the effectively managed plots is due to the efficient capture and utilization of resources in a low-competition environment. As reported by (Tesfaye, 2023), unchecked weed growth can severely limit the photosynthetic capacity and resource uptake of cereal crops, leading to dramatic reductions in dry matter. This principle supports the findings of (Kebede et al., 2017), who noted that robust weed control allows plants to utilize all available resources, resulting in a significant increase in total biomass production.

Grain Yield

Grain yield was significantly influenced by the different weed management practices across both the 2021 and 2022 growing seasons (Fig. 2). The highest grain yield was obtained from the season-long weed-free plots (3780.8 kg ha^{-1}), followed by the integrated treatment of Salon 5 OD + hand weeding (3623.7 kg ha^{-1}). The lowest grain yield was recorded in the unmanaged weedy check plot (1480.7 kg ha^{-1}). The superior grain yield in the best-performing treatments is the cumulative result of improved yield components, including greater plant height, more productive tillers, longer spikes, and heavier grains, all stemming from reduced weed competition. The dramatic yield reduction in the weedy check plot representing a yield loss of approximately 61% compared to the weed-free treatment underscores the severe economic impact of uncontrolled weed infestation. This is attributable to the high weed biomass that directly competes with the crop for growth-limiting resources throughout the season. These results are in agreement with a recent meta-analysis by (Haile and Negussie, 2024), which confirmed that season-long weed competition is a primary cause of significant yield gaps in wheat production across the Ethiopian highlands. The findings also corroborate earlier work by (Dalga et al., 2015), who similarly reported the highest grain yields under weed-free conditions and the lowest from weedy check plots in southern Ethiopia.

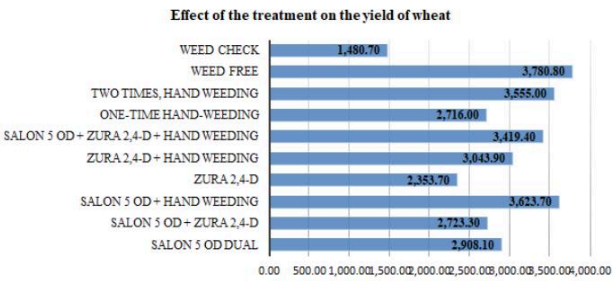

Fig. 2: Bar chart showing the impact of different treatments on wheat production

Harvest Index

The harvest index (HI), a crucial measure of the efficiency with which a crop partitions total biomass into economic grain yield, was statistically significant among the different weed management practices ($p<0.05$). The highest harvest index was recorded in the integrated treatment of Salon 5 OD + Zura 2, 4-D + hand weeding (38.80%), which was statistically comparable to the Salon 5 OD + hand weeding treatment (38.69%). Conversely, a drastically lower harvest index (25.13%) was obtained from the weedy check plot. This significant disparity highlights that uncontrolled weed competition disproportionately penalizes grain production more severely than overall biomass accumulation. In the weedy check plot, intense competition for nutrients, water, and light, especially during the critical grain-filling period, severely impairs the plant's ability to translocate photo-assimilates from the vegetative parts (source) to the developing grains (sink). This leads to poor grain filling and a lower grain yield relative to the total vegetative mass produced, resulting in poor partitioning efficiency and a low harvest index (Table 4).

Table 4: Effect of weed management treatments on thousand kernel weight, above ground biomass, Grain yield, and harvesting Index (combined data, 2021-2022)

Treatment	Thousand kernel Weight (g)	Above ground biomass (kg-ha)	Grain yield (kg-ha)	Harvesting index
Salon 5 OD dual	39.39	8,177.70	2,908.10	35.91
salon 5 OD + Zura 2, 4-D	38.78	7,986.80	2,723.30	34.61
Salon 5 OD + hand weeding	45.32	9,483.50	3,623.70	38.69
Zura 2, 4-D	36.08	7,392.80	2,353.70	32.24
Zura 2, 4-D + hand weeding	40.66	8,222.30	3,043.90	37.27
Salon 5 OD + Zura 2, 4-D + hand weeding	43.69	8,890.90	3,419.40	38.81
One-time hand-weeding	40.74	7,495.80	2,716.00	36.67
Two times, hand weeding	42.66	9,674.70	3,555.00	36.97
Weed free	44.56	9,911.00	3,780.80	38.38
Weed check	31.09	5,922.80	1,480.70	25.13
LSD (0.05)	4.14	591.53	279.97	4.59
CV	12.69	10.04	11.68	16.02

Means followed by the same letter within the column are not significantly different at a 5% level of significance; CV = coefficient variation; LSD = least significant difference.

Table 5: Economic analysis of weed management practices in the 2021 and 2022 main cropping seasons at Southern Oromia

Treatment	Grain yield (kg ha-1)	Adjusted yield(kg ha-1)	Total cost (birr)	Total benefit (birr)	Net benefit (birr)	MRR(%)
Weedy check	1,480.70	1,332.63	22,500	46,642.05	24,142.05	_
Zura 2, 4-D	2,353.70	2,118.33	23,450	74,141.55	50,691.55	2,794.68
Salon 5OD + Zura 2, 4-D	2,723.30	2,450.97	26,000	85,783.95	59,783.95	356.56
One time, hand weeding	2,908.10	2,617.29	26,250	85,554.00	59,304.00	D
Zura 2, 4-D + hand weeding	2,716	2,444.40	27,200	95,882.85	68,682.85	987.25
Salon 5 OD dual	3,623.70	3,261.33	28,100	91,605.15	63,505.15	D
Salon 5 OD + hand weeding	3,043.90	2,739.51	28,700	114,146.55	85,446.55	3,656.9
Salon 5 OD + Zura 2, 4-D + hand weeding	3,419.40	3,077.46	30,000	107,711.10	77,711.10	D
Two times, hand weeding	3,555.00	3,199.50	34,500	111,982.50	77,482.50	D
Weed free	3,780.80	3,402.72	43,500	119,095.20	75,595.20	D

MRR = maximum rate of return

In contrast, the effective weed suppression in the integrated treatments ensured sustained resource availability for the crop. This not only promoted healthy vegetative growth but, more importantly, supported efficient physiological processes during the reproductive stage. As a result, a larger proportion of the total dry matter produced was successfully converted into grain, leading to a high harvest index. This principle is supported by recent research from Teshome and Gebre (2023), who found that season-long weed competition in the Oromia region severely disrupted source-sink relationships in wheat, leading to a marked decrease in the harvest index compared to plots where weeds were controlled effectively.

Partial Budget Analysis

To evaluate the economic viability and profitability of the different weed management strategies for local farmers, a partial budget analysis was conducted. This analysis meticulously accounted for the costs that varied among treatments specifically, the market price of herbicides (Salon 5 OD, Zura 2, 4-D), the operational cost of herbicide application, and the local labor cost for manual weeding. These "total variable costs" were then compared against the gross field benefits, calculated from the grain yield of each treatment valued at the current market price. The complete breakdown of costs and benefits is presented in Table 5. The analysis revealed substantial differences in economic returns across the treatments. The highest net benefit was achieved with the integrated treatment of Salon 5 OD followed by one hand weeding, which generated a remarkable 85,446.55 Ethiopian Birr (ETB) ha^{-1}. This treatment represents an optimal balance between achieving a high grain yield due to excellent weed control and maintaining a moderate investment cost. The next most profitable strategy was Salon 5 OD + Zura 2, 4-D + hand weeding, yielding a net benefit of 77,711.10 Ethiopian Birr (ETB) ha^{-1}. As expected, the weedy check plot resulted in the lowest economic return, confirming that the catastrophic yield loss far outweighs the savings from forgoing any investment in weed control.

To further assess the financial efficiency of each additional investment, a marginal analysis was performed. The marginal rate of return (MRR) indicates the financial return gained from each additional unit of capital invested in a more intensive weed management strategy compared to the next cheapest option. The highest MRR was obtained from the Salon 5 OD + hand weeding treatment, at an exceptional 3,656.90%. This outstanding figure signifies that for every 1.00 ETB invested in this specific strategy over a less intensive one, a farmer could expect a return of approximately 36.57 ETB. Such a high MRR signifies an extremely profitable and financially sound investment. The application of Zura 2, 4-D alone also showed a strong, albeit lower, return with an MRR of 2,794.68%.

Conclusion

Uncontrolled weed infestation severely undermines the yield, agronomic performance, and economic viability of wheat production in the Guji Zone. This study confirms that active weed management is essential, with all tested practices significantly outperforming the weedy check. An Integrated Weed Management (IWM) strategy combining a targeted herbicide application with supplementary manual weeding emerged as the most effective and sustainable solution. This approach maximizes yield, reduces sole reliance on chemicals, and mitigates the long-term risks of herbicide resistance and environmental harm. Based on superior agronomic results and compelling economic analysis, the integrated use of Salon 5 OD followed by one timely hand weeding is unequivocally recommended. This strategy is the most advantageous for farmers, delivering the highest net benefit (85,446.55 ETB ha^{-1}) and an exceptional marginal rate of return (3,656.90%). It represents the optimal balance of productivity, profitability, and sustainability for wheat producers in the Guji Zone and regions with similar agroecological conditions. To broaden the impact of these findings, further adaptive research is necessary. Future studies should focus on validating and tailoring this IWM package for other major wheat-producing regions of Ethiopia, exploring optimal herbicide combinations, timings, and cultural practices for diverse agroecologies.

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Ethics

This article presents original work from a field experiment and has been approved by the corresponding author and all co-authors. They confirm that no ethical issues were involved in the preparation of this manuscript. All sources have been properly acknowledged and cited in the references.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

References

Abrahim, A., Hussein, T., & Badebo, A. (2018). Pathogenic Variability of Wheat Stem Rust Pathogen (*Puccinia graminis* f. sp. *tritici*) in Hararghe Highlands, Ethiopia. *Advances in Agriculture*, *2018*, 1–7. https://doi.org/10.1155/2018/8612135

Amare, T., & V. Raghavaiah, C. (2015). 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. *Advances in Crop Science and Technology*, *04*(01). https://doi.org/10.4172/2329-8863.1000206

Anteneh, A., & Asrat, D. (2020). Wheat production and marketing in Ethiopia: Review study. *Cogent Food & Agriculture*, *6*(1), 1778893. https://doi.org/10.1080/23311932.2020.1778893

Anum, W., Javeed, Z., Hussain, F., Ahmad, A., Khan, A.-M., Hassan, W., & Shahzad, K. (2024). Weed Control Practices in Wheat (Triticum Aestivum L.) with Special Emphasis on Line Spacing and Seed Rate. *Pak-Euro Journal of Medical and Life Sciences*, *7*(Special 2), 309–316. https://doi.org/10.31580/pjmls.v7iSp2.3187

Atnafu, D. (2019). Weed Management Methods on Yield and Yield Components of Bread Wheat (Triticum Aestivum L.) *International Journal of Research and Innovations in Earth Science*, *6*(5), 63–78.

Ayana, D., Ashagre, H., & Hamza, I. (2021). Effect of Weeding Frequency on Yield an Yield Components of Food Barley (*Horduem vulgare L.)* Varieties at Amuru District, Horo Guduru Wollega Zone of Oromia, Ethiopia. *Journal of Plant Sciences*, *9*(2), 32–37. https://doi.org/10.11648/j.jps.20210902.11

Bekele, S. (2018). *Weed Flora Survey and their Relative Importance in Wheat Fields of Guji Zone, Southern Ethiopia*.

CSA. (2022). *Agricultural sample survey: Report on area and production of major crops (private peasant holdings, Meher Season)*.

Dalga, D., Tana, T., Sharma, J. J (2016). Weed Dynamics and Yield of Bread Wheat (Triticum aestivum L.) in Response to Weed Management and Nitrogen Fertilizer Rates in Southern Ethiopia. *Scientia Agriculturae*, *16*(1), 8–19. https://doi.org/10.15192/pscp.sa.2016.16.1.819

Fikru, A., Tadesse, B., & Eshetu, M. (2021). Efficacy and economics of integrated weed management in bread wheat (Triticum aestivum L.) in the southeastern highlands of Ethiopia. *Journal of Plant Protection Research*, *61*(2), 195–203.

Garkhal, K., Nath, S., & Singh, R. (2024). Weed dynamics and maize productivity as influenced by sole and tank mix application of herbicides. *Indian Journal of Weed Science*, *56*(1), 80–83. https://doi.org/10.5958/0974-8164.2024.00013.3

Girma, F., & Bekele, S. (2022). Impact of Post-Emergence Herbicides on Yield Components of Bread Wheat in the Arsi Highlands. *Ethiopian Journal of Agricultural Sciences*, *32*(2), 89–104.

Gorfu, A., Tanner, D. G., & Taa, A. (1992). On-farm evaluation of pre- and postemergence grass herbicides on bread wheat in the Arsi Region of Ethiopia. *Proceedings of the Seventh Regional Wheat Workshop for Eastern, Central, and South Africa, Addis Ababa*, 330–337.

Haile, M., & Negussie, A. (2024). Yield Losses in Bread Wheat Due to Uncontrolled Weed Growth: A Meta-Analysis of Studies in the Ethiopian Highlands. *Journal of Agronomy and Crop Science*, *210*(1), 45–58.

Harker, K. N., & O'Donovan, J. T. (2013). Recent Weed Control, Weed Management, and Integrated Weed Management. *Weed Technology*, *27*(1), 1–11. https://doi.org/10.1614/wt-d-12-00109.1

Kebede, M., Gerama, G., Bidira, T., & Birhanu, C. (2017). Influence of post-emergence herbicides on major grass weeds and wheat (Triticum aestivum L.) at Gedo and Shambo, Western Oromia. *Communications in Plant Sciences*, *7*(3–4), 55–61. https://doi.org/10.26814/cps2017009

Keller, M., Böhringer, N., Möhring, J., Rueda-Ayala, V., Gutjahr, C., & Gerhards, R. (2015). Changes in Weed Communities, Herbicides, Yield Levels and Effect of Weeds on Yield in Winter Cereals Based on Three Decades of Field Experiments in South-Western Germany. *Gesunde Pflanzen*, *67*(1), 11–20. https://doi.org/10.1007/s10343-014-0335-8

Mekonnen, T., & Gebre, S. (2022). Synergistic effects of herbicide combinations and supplementary weeding on weed dynamics and productivity of bread wheat (Triticum aestivum L.) in Arsi Highlands, Ethiopia. *Ethiopian Journal of Agricultural Sciences*, *32*(1), 45–60.

Mosisa, W., Sharma, J. J., & Dechassa, N. (2013). Integrated Weed Management and its Effect on Weeds and Yield of Common bean at Haramaya, Ethiopia. *Ethiopian Journal of Weed Management*, *6*, 1–14.

Nigus, M., Shimelis, H., Mathew, IsacK., & Abady, S. (2022). Wheat production in the highlands of Eastern Ethiopia: opportunities, challenges and coping strategies of rust diseases. *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science*, *72*(1), 563–575. https://doi.org/10.1080/09064710.2021.2022186

Ramesh, K., Rao, A. N., & Chauhan, B. S. (2017). Role of crop competition in managing weeds in rice, wheat, and maize in India: A review. *Crop Protection*, *95*, 14–21. https://doi.org/10.1016/j.cropro.2016.07.008

Şin, B., Köse, M., & Yılmaz, M. (2024). The Effect of Weed Control at Different Periods on Antioxidant Content of Faba Bean (Vicia faba L.). *Turkish Journal of Agriculture - Food Science and Technology*, *12*(s3), 2699–2703. https://doi.org/10.24925/turjaf.v12is3.2699-2703.7174

Tadesse, B., Fikre, A., & Gebre, E. (2021). Efficacy of integrated weed management on weed dynamics and yield of bread wheat in the central highlands of Ethiopia. *Journal of Crop Improvement*, *35*(4), 520–535.

Tesfaye, K. (2023). Weed Competition and its Effect on Dry Matter Accumulation in Teff (Eragrostis tef.) *Varieties. Journal of the Drylands*, *15*(1), 72–85.

Teshome, D., & Gebre, M. (2023). Influence of Weed Competition Duration on Biomass Partitioning and Harvest Index in Bread Wheat (Triticum aestivum L.) in the Oromia Region. *Ethiopian Journal of Agricultural Sciences*, *33*(1), 55–68.

DOI: 10.3844/ajabssp.2025.35.44

Upadhyay, P. K., Rajanna, G. A., Sepat, S., Bana, R. S., Choudhary, A. K., Singh, T., Shiva Dhar, G. P. K., & Yadav, R. L. (2018). Doubling farmers' income through agronomic interventions under changing scenario. *Extended Summaries of XXI Biennial National Symposium. Indian Society of Agronomy, IARI, New Delhi*, 652.

Yawale, M. A., Garko, M. S., Dawaki, K. D., & Hussaini, M. A. (2020). Weed Control Efficiency of Some Herbicides in Upland Rice Ecology of Kano State Nigeria. *The International Journal of Science & Technoledge*, *8*(5). https://doi.org/10.24940/theijst/2020/v8/i5/st2005-016

Zegeye, F., Alamirew, B., & Tolossa, D. (2020). Analysis of Wheat Yield Gap and Variability in Ethiopia. *International Journal of Agricultural Economics*, *5*(4), 89–98. https://doi.org/10.11648/j.ijae.20200504.11