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Integrated Effect of Seeding Rate, Herbicide Rate and Application Timing on Durum Wheat *(Triticum turgidum* L. *Var durum)* Yield, Yield Components and Wild Oat (*Avena fatua* L.) Control, in South Eastern Ethiopia

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Abstract: Knowledge of optimal combinations of crop densities, herbicide rate and time of application could improve the effectiveness and net benefit of commonly used herbicides. A study was conducted at two locations in SARC on-station and farmer's field, South Eastern Ethiopia for two years from 2007 to 2008. The experimental design was randomized complete block (RCB) design with split-plot arrangement. Durum wheat (*Triticum turgidum* L. var durum) seeding rates (recommended, 25% and 50% plus recommended rate) were arranged in the main plot. Four wild oat (*Avena fatua* L.) herbicide, Topik, doses (0, 25, 50 and 100 % of the recommended dose) and three timing of applications (14 DA, 32 DAE and 50 DAE) were used as sub-plot treatments. The treatments were compared to determine their effect on durum wheat yield, yield components wild oat densities and control efficacies. Durum wheat seeding rates significantly influenced grain and biomass yield, spike per unit area and kernel weight. Seeding rate of 225 kg ha^{-1} produced highest grain yield (3810.4 kg ha^{-1}) while 150 kg ha^{-1} recorded the lowest. Mean wild oat density count before herbicide application timings varied over the two locations averaging 37 and 87 seedlings m^{-2}. Increasing seed rate by 25 and 50% increased wild oat control efficacy by 16.9 and 21.5% respectively. Spraying the herbicide at later growth stages caused greater wild oat seedling density and reduced wheat yield at both locations. The highest efficacy (94.04%) was obtained in the second time of application (30 DAE) of 1 l lit ha^{-1}. The highest reduction in population density was occurred in 100% herbicide rate. There was a general decline in wild oat density in the early application and as the herbicide rate increased, but the effect of seeding rate varied very slightly. In contrast to the wild oat control efficacy the highest grain yield ha^{-1} was obtained in the first application date (14 DAE). Durum wheat yield losses in the absence of herbicide application were increased by about 16%. Maximum yield (3870.73 kg ha^{-1}) was obtained at 100% of the herbicide rate very closely followed by 50 and 25% of the recommended rate reducing durum wheat yield only by about 1.6 and 2% respectively. Durum wheat seeding rate, herbicide rate and application timing had statistically no significant interaction effect

Key words: Durum wheat · Wild oat · Herbicide · Rate · Seeding · Topik · Application · Timing

INTRODUCTION

Wild oat (*Avena fatua* L.) is one of the most widespread and harmful grass weeds in wheat (*Triticum estivum* L.) worldwide. It infests more than fifty countries and is considered one of the most important weeds in the world [1, 2]. Wild oat is also one of the most troublesome weeds which constrain wheat production in Ethiopia because of the continuous monocropping of wheat and barley in the large and small scale farming systems of the high lands [3]. Wild oat is one of the most dominant and frequently observed weed species in wheat fields and is becoming an increasingly serious constraint of wheat production in Bale highlands [4]. *Avena species* are highly competitive, resulting in greater reduction of wheat grain yield, i.e., 85% at 320 seedlings /m^2 [5]. Tanner *et al.* [6] reported grain yield reductions of 26 to 63% across four bread wheat cultivars at 90 weed seedlings m^{-2} in Ethiopia.

Before herbicides were widely available, farmers employed cultural measures to manage weed population. Wild oat management systems have evolved to the point

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that producers rely on herbicides to the virtual exclusion of all other strategies [7]. Although herbicides are generally effective, wild oat is widely spreading and continues to reduce yields. Herbicide choice and timing are critical for wild oat control in many fields. Quality losses, due to contamination of cereal samples by wild oats, can be substantial, resulting in rejection for seed and milling.

Herbicide control is now the merely option in many situations because of the high level of infestation and the scarcity and cost of labour for hand rouging. Fortunately, the wild oat herbicide range is now very effective, particularly in the case of wheat. Topik is one of the products of choice on all varieties of durum and bread wheat for wild oat control and may be applied up to flag leaf stage. There is considerable scope for reducing rates of wild oat herbicides when applied at the early stages [8].

However, herbicides are generally over used and the rather indiscriminant use of herbicides has led to health and environmental concerns. Using management practices that increase crop competitiveness may reduce the negative effects associated with the use of herbicides [9]. Restricting weed seed production gives producers greater opportunities and latitude to practice integrated weed management. Because it has not yet possible to obtain sufficient control of wild oat with one control measure under current cropping system, it is important to explore the potential for an integrated management system [10].

Increasing the crop seeding rate improve weed control in an integrated weed management system [11]. The effects of wheat seeding rate on grain yield have been inconsistent in different studies. Some times, seeding rate does not affect grain yield [12]. However in other experiments, higher seeding rates increased yields [13]. The combination of high sowing densities of crops and low rates of herbicides is an effective weed management strategy for grasses [8]. Therefore, the aim of this study was to develop integrated weed management systems that reduce reliance on herbicide and also investigate whether wild oats can be controlled effectively in wheat using higher crop densities and lower herbicide rates.

MATERIALS AND METHODS

Experimental Sites: The experiment was conducted for two years (2007-2008 main cropping seasons) at two proxy sites; Sinana Agricultural Research Center (SARC) on-station and farmer's field (Selka area) in Bala, South Eastern Ethiopia. SARC is located at 7°7'N latitude, 40° 10' E longitude and 2400 m.a.s.l altitude in Bale Zone of Oromia Region. The soil at the experimental sites was sandy loam in nature with pH 7.5, organic carbon 0.34%, low in total nitrogen (0.041%), medium in phosphorus (50.88 kg ha^{-1}) and high in potassium (315.90 kg ha^{-1}). The area is characterized by bimodal rainfall pattern. Average annual rain fall, minimum and maximum temperatures during the experimental years were 1369.3 mm, 9.7°Cand 20.0°C, respectively. The amount of average rain fall in main cropping season of the experiment (August-December) was 610 mm. The pattern, onset and distribution of rain fall were good in both Ganna and bona seasons.

Experimental Design and Treatments: The experimental design was RCBD arranged in a split plot design with three replications. Three durum wheat seeding rates adjusted at a series of increasing (SR_1= recommended rate, SR_2= recommended rate +25% and SR_3= recommended rate + 50%) i.e. 150 kg/ha, 187.5 kg/ha and 225 kg/ha were arranged as the main plot treatment. Factorial combinations of four grass weed herbicide, Topik, rates ($HR_{0=}$weedy check, $HR_{0.25}$=25% of recommended dose, $HR_{0.5}$=50% of recommended dose and HR_1=100% of recommended dose, 1 lit/ha) and three timing of applications, according to decimal code for the growth stages of cereals [14], i.e. two-three leaves unfolded seedling stage (14 DAE), two tillers or 4.5 leaves stage (32 DAE) and jointing stage when flag leaf is visible (50 DAE), were arranged as sub-plots. Plots of 3 by 4 m^2 spacing were sown at the same time. Topik was applied using knapsack sprayer.

Data Collection and Statistical Analysis: Wild oat density count was taken randomly from each treated and untreated plots before herbicide application and five weeks after each application by clipping all plants from two $0.25m^2$ quadrates and the density from treated plots compared with the untreated plots. The weed control efficiency (WCE) by number of weeds was calculated by using formula suggested by [15].

$$WCE = \frac{NWC\text{-}NWT}{NWC} * 100\%$$

Where:

WCE = Weed (Wild Oat) Control Efficiency;
NWC = Number of Weeds m^{-2} from Control plots (weedy check) and
NW T = Number Weeds m^{-2} in plots Treated with TopiK

Plant height was recorded as the average height of main tillers. Fertile spike count was taken randomly from each plot by clipping all fertile spikes from two $0.25m^2$ quadrates. Number of kernels per spike was counted as the average number of grains on single spike of main culm. Biomass yield, 100 kernel weight, Grain yield were also measured using a sensitive balance. Harvest index was calculated as the percent ratio of grain yield to the total above ground biomass. All data were analyzed using SAS GLM procedure [16]. Comparisons among treatments with significant differences for measured and scored characters were computed based on LSD test.

RESULTS AND DISCUSSION

Effect of Seeding Rates on Durum Wheat Grain Yield, Yield Components and Wild oat Control: The result of the data combined over the two years and two locations indicated that *durum wheat* seeding rates significantly influenced grain and biomass yield, spike per unit area and kernel weight. Seeding rate of *225* kg ha^{-1} produced higher grain yield (3810.4 kg ha^{-1}) and biomass yield (9185.0 kg ha^{-1}) (Table 1). Higher grain yield with higher seed rate was also reported by Olsen *et al.* [17]. This implies that increased crop density had strong and consistent negative effects on weed and positive effects on grain and biomass yield. It was found out that the highest number of spikes m^{-2} was recorded in the 225 kg ha^{-1}, while the lowest was recorded in 150 kg ha^{-1}. On the other hand maximum number of seeds $spike^{-1}$ was recorded in 150 kg ha^{-1} (Table 1). Weed competition in wheat reduces through decreases in spike numbers [18, 19] and number of grains per spike [20].

Durum Wheat seeding rates had a significant impact on the 1000-grain weight. The highest 1000 grain weight was recorded in the lowest seed rate of 150 kg ha^{-1}. These findings are in agreement with the work of Justes *et al.,* [21], Taye *et al.,* [22, 23] and Barton *et al.,* [10], who concluded the strong impact of crop seeding rates in wild oats management.

Increasing seed rate over recommended (150 kg ha^{-1}) by 25 and 50% to 187.5 and 225 kg ha^{-1} increased wild oat control efficacy by 16.9 and 21.5% respectively (Table 1). Decrease in weed population or efficacy with higher seed rate might be due to competition from crop plants for space, nutrients, moisture and solar radiation. The highest weed count recorded in low seed rate treatment. In their wild oat and wheat competition study Carlson and Hill [24] suggested that at relatively low seed rate, crop density would be naturally less, leaving a large amount of resources available for weeds and enabling them to establish quickly.

Effect of Herbicide, Topik, on Wild Oat (*Avena fatua*) Population Density: Since the experiment was sown in fields naturally well infested with the target weed, mean wild oat density count before each application timing was varied over the two years, averaging 37 and 87 seedlings m^{-2} at sinana on-station and Selka area respectively. However population density count five weeks after spray varied considerably among the herbicide rates and application timing (Fig. 1 and 2). Wild oat density count generally declined as herbicide rate increased. Conversely, density count was linearly increased with the application timing with minimum count at 14 DAE. On average over 59% of the declines in population density count occurred when the herbicide was applied in the early crop seedling stage at 14 DAE. The highest reduction in population density was occurred in 100% rate. There was a general decline in wild oat population density in the early application and as the herbicide rate increased, but the effect of seeding rate varied very

Table 1: Effect of seed rate, herbicide timing and dosage on different agronomic parameters of durum wheat and wild oat control

Seed rate	*Grain Yield (kg/ha)*	*Spike/0.25m² (No.)*	*Thousand Kernel Weight (gm)*	*Seeds/spike (No.)*	*Plant height (cm)*	*Spike length (cm)*	*Harvest Index (%)*	*Biomass (kg/ha)*	WCE(%)
SR_1	3718.6	249.1	47.1	45.3	89.9	6.2	41.8	8935.5	-5.4
SR_2	3595.9	263.9	46.3	42.5	88.7	6.1	40.9	8802.4	16.9
SR_3	3810.4	273.2	46.5	42.6	90.2	6.2	40.9	9185.0	21.5
Mean	*3708.30*	*262.07*	*46.63*	*43.47*	*89.60*	*6.17*	*41.20*	*8974.30*	-
LSD (P<0.05)	***	***	*	*ns*	***	*ns*	*ns*	*	-
CV (%)	*23.06*	*23.50*	*5.38*	*21.54*	*3.36*	*6.04*	*9.26*	*24.25*	-

- *SR_1= Recommended (150 kg/ha), SR_2= Recommended + 25% (187.5 kg/ha) and SR_3= Recommended + 50% (225 kg/ha)*
- *WCE = Weed (Wild Oat) Control Efficiency*
- *ns= statistically non-significant*
- **= Significant at 5% level o significance*
- ***= Significant at 1% level o significance*
- ****=. Significant at 0.1% level o significance*

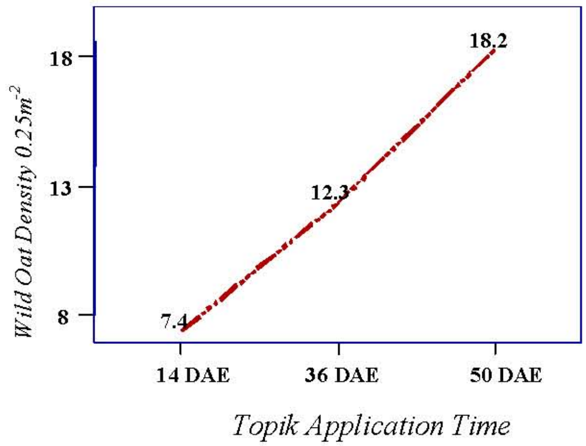

Fig. 1: Effect of Topik Application Timing on Wild Oat population Density Combined over Locations and

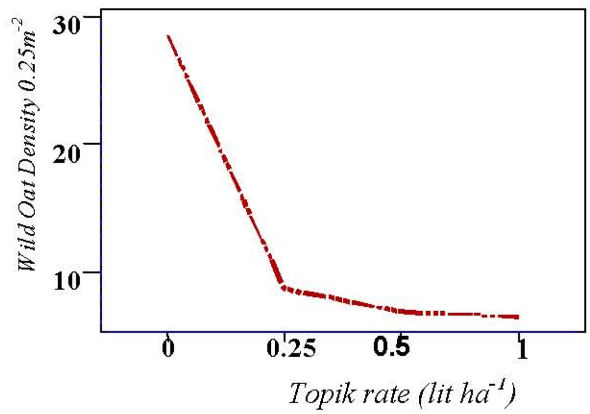

Fig. 2: Effect of Topik Rate on Wild Oat Population Density Combined Over Locations and Years

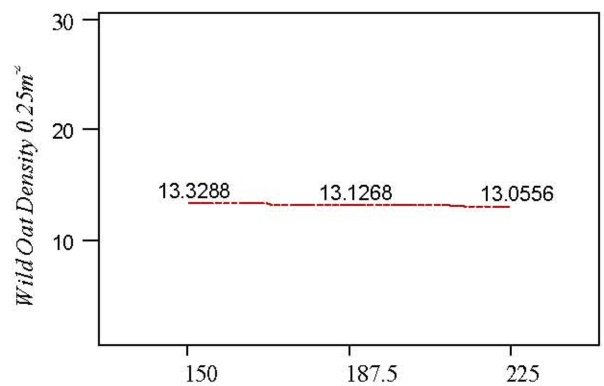

Fig. 3: Effect of Durum Wheat Seeding Rate on Wild Oat population Density Combined over Locations and Years

slightly (Fig. 3). Although herbicide rate, application timing and seeding rate interaction effect on wild oat survival was statistically not significant population density at each herbicide rate tended to decrease as seeding rate increased. A decline in the amount of wild oat population density in response to increased durum wheat seeding rate was more pronounced at the highest herbicide rate application in the tillering stage (30 days after emergence). Similar findings by O'Donovan *et al.* [25] indicated that at the lowest barley seeding rate, more wild oat density counted when the herbicide rate was reduced to 25 or 50% of the recommended rate. They concluded that at the highest seeding rate, there was little difference between applying wild oat herbicide at 50 or 100% of the recommended rate in terms of the amount of wild oat population density.

Herbicide Rate and Application Timing Effect on Durum Wheat Yield and Yield Components: The result indicated that herbicide had the most consistent and significant effect on durum wheat seed yield at both locations. The effect of the herbicide on durum wheat yield was not influenced by crop seeding rate, as indicated by the lack of significant interactions with these factors. The greatest reduction in yield occurred when no herbicide was applied (Table 2). When compared to the recommended rate of 1 lit/ha, yield losses in the absence of herbicide application increased by about 16%. Maximum durum wheat yield (*3870.73* kg/ha) was obtained when Topik was applied at 100% of the recommended rate very closely followed by 50 and 25% of the recommended rate reducing durum wheat yield only by about 1.6 and 2% respectively. In other study, Belles *et al.* [26], it was found out that maximum wheat yields were obtained when wild oat herbicide, tralkoxydim, was applied at 70 to 85% of the recommended rate. In contrast, reducing the herbicide rate below the recommended rate decreased bread wheat (*Triticum aestivum* L.) yield by 7% [27].

Table 2: *Effect of herbicide timing and dosage on wild oat control and some important agronomic parameters of durum wheat*

	Herbicide application timing (T)															
Herbicide application	*Efficacy of wild oat control*				*Grain Yield (kg/ha)*				*Fertile Spike/0.25m² (No.)*				*Thousand Kernel weight (gm)*			
Rate (HR)	*HT₁*	*HT₂*	*HT₃*	*Mean*	*HT₁*	*HT₂*	*HT₃*	*Mean*	*HT₁*	*HT₂*	*HT₃*	*Mean*	*HT₁*	*HT₂*	*HT₃*	*Mean*
HR_0	-1.32	-1.32	-1.32	*-1.32*	3339.93	3339.93	3339.93	*3339.93*	241.57	241.57	241.57	*241.57*	46.29	46.29	46.29	*46.29*
$HR_{0.25}$	76.36	88.16	28.99	*64.50*	4108.11	3803.86	3457.65	*3789.87*	269.89	261.17	240.6	*257.22*	46.59	46.62	46.64	*46.62*
$HR_{0.5}$	90.74	95.69	21.71	*69.38*	4108.68	3900.07	3425.10	*3811.28*	269.30	275.40	271.34	*272.01*	47.22	46.73	46.53	*46.83*
HR_1	93.45	99.58	33.28	*75.44*	4066.81	3913.05	3632.32	*3870.73*	285.00	285.72	258.89	*276.54*	46.45	45.98	47.44	*46.62*
Mean	*86.41*	*94.04*	*27.55*		*3905.88*	*3739.23*	*3463.75*		*266.44*	*265.97*	*253.10*		*46.64*	*46.41*	*46.73*	
LSD																
HR		***				***				***				*ns*		
T		***				***				*				*ns*		
RxT		*ns*				***				*ns*				*ns*		
CV (%)		-				*13.06*				*13.50*				*5.38*		

- *HR_0= control; $HR_{0.25}$= 25% of recommended rate; $HR_{0.5}$= 50% of recommended rate; HR_1= 100% of recommended rate (1 lit ha⁻¹)*
- *HT_1=application at 14 DAE; HT_2= application at 30 DAE; HT_3= application at 50 DAE*
- *ns= statistically non-significant*
- **= Significant at 5% level o significance*
- ***= Significant at 1% level o significance*
- ****=. Significant at 0.1% level o significance*

Table 3: *Effect of Durum wheat seeding rate and herbicide application timing on wild oat control and some important agronomic parameters of durum wheat*

	Herbicide application timing (HT)															
Durum Wheat	*Efficacy of wild oat control*				*Grain Yield (kg/ha)*				*Fertile Spike/0.25m² (No.)*				*Thousand Kernel weight (gm)*			
Seeding Rate	HT₁	HT₂	HT₃	Mean	HT₁	HT₂	HT₃	Mean	HT₁	HT₂	HT₃	Mean	HT₁	HT₂	HT₃	Mean
SR_1	63.30	68.31	2.23	*44.61*	3897.78	3778.18	3496.37	*3724.11*	258.31	250.98	238.56	*249.28*	47.16	46.86	47.19	*47.07*
SR_2	73.63	66.12	28.49	*56.08*	3791.86	3583.68	3429.04	*3601.53*	255.83	265.77	248.27	*256.62*	46.21	46.57	46.65	*46.48*
SR_3	65.33	60.38	26.39	*50.70*	4068.94	3871.22	3492.50	*3810.89*	290.91	283.36	271.41	*281.89*	46.64	45.79	46.22	*46.22*
Mean	*67.42*	*64.94*	*19.04*		*3919.53*	*3744.36*	*3472.64*		*268.35*	*266.70*	*252.75*		*46.67*	*46.41*	*46.69*	
LSD																
SR		*ns*				***				***				*		
HT		***				***				*				*ns*		
SrxHT		*ns*				*ns*				*ns*				*ns*		
CV (%)		-				*13.06*				*13.5*				*5.38*		

- *R_0= control; $R_{0.25}$= 25% of recommended rate; $R_{0.5}$= 50% of recommended rate; R_1= 100% of recommended rate (1 lit ha⁻¹)*
- *HT_1=application at 14 DAE; HT_2= application at 30 DAE; HT_3= application at 50 DAE*
- *ns= statistically non-significant*
- **= Significant at 5% level o significance*
- ***= Significant at 1% level o significance*
- ****=. Significant at 0.1% level o significance*

Table 4: *Effect of Durum wheat seeding rate and herbicide application rate on wild oat control and some important agronomic parameters of durum wheat*

	Herbicide application Rate (HR)																			
Durum Wheat	*Efficacy of wild oat control*					*Grain Yield (kg/ha)*					*Fertile Spike/0.25m² (No.)*					*Thousand Kernel weight (gm)*				
Seeding Rate (SR)	HR₀	HR₀.₂₅	HR₀.₅	HR₁	*Mean*	HR₀	HR₀.₂₅	HR₀.₅	HR₁	*Mean*	HR₀	HR₀.₂₅	HR₀.₅	HR₁	*Mean*	HR₀	HR₀.₂₅	HR₀.₅	HR₁	*Mean*
SR_1	-26.51	68.33	64.76	71.87	*44.61*	3380.28	3759.10	3872.81	3870.56	*3720.69*	234.28	239.00	249.70	273.72	*249.18*	46.48	47.12	47.77	46.87	*47.06*
SR_2	9.86	63.81	71.38	79.28	*56.08*	3236.65	3684.85	3721.31	3758.36	*3600.29*	238.68	258.33	268.61	260.61	*256.56*	46.26	46.53	46.47	46.63	*46.47*
SR_3	-2.55	60.24	70.72	74.38	*50.70*	3418.82	3967.28	3872.86	3990.53	*3812.37*	252.67	276.67	300.32	297.64	*281.83*	46.11	46.17	46.23	46.38	*46.22*
Mean	*-6.40*	*64.13*	*68.95*	*75.18*		*3345.25*	*3803.74*	*3822.33*	*3873.15*		*241.88*	*258.00*	*272.88*	*277.32*		*46.28*	*46.61*	*46.82*	*46.63*	*46.28*
LSD																				
SR			*ns*					***					***					*		
HR			***					***					***					*ns*		
SrxHR			*ns*					*ns*					*ns*					*ns*		
CV (%)			-					*7.3*					*1.97*					*6.29*		

- *SR_1= Recommended (150 kg/ha), SR_2= Recommended + 25% (187.5 kg/ha) and SR_3= Recommended + 50% (225 kg/ha)*
- *HR_0= control; $HR_{0.25}$= 25% of recommended rate; $HR_{0.5}$= 50% of recommended rate; HR_1= 100% of recommended rate (1 lit ha⁻¹)*
- *ns= statistically non-significant*
- **= Significant at 5% level o significance*
- ***= Significant at 1% level o significance*
- ****=. Significant at 0.1% level o significance*

On the other hand, neither grain yield nor net return was affected when relatively low rates of several graminicides were applied to either barley or wheat [28].

The highest spike per unit area was obtained from the highest application rate (1 l/ha) while kernel weight was not affected by herbicide application rate (Table 2).

Similarly, significant differences observed in grain yield, plant height, spike per unit area and biomass with respect to herbicide application timing. These all parameters were found to be more influenced by the first application date (14 days after emergence). It indicates that controlling weeds in the early tiller initiation seedling stage has a yield advantage (about 4-12%) than late applications.

Effect of Herbicide Rate and Application Timing on Wild oat (*Avena fatua* L.) Control Efficacy: There was also significant variation among the herbicide rates in controlling the target and most prevalent weed in the area, *Avena fatua*. Wild oat control efficacy was varied highly among the herbicide rates and application timings. It was found that application of 1 l ha^{-1} is more effective in controlling the target weed species. The highest efficacy (94.04%) was obtained in the second time of application (30 days after emergence) of 1 lit ha^{-1} Topik application. This could be because of the weed plants become woody in the late stage and are not likely to be killed easily by herbicide application. Efficacy of application in the early tiller initiation stage (14 days after emergence) was slightly lower than when the crop was in the tillering stage because late emerged weeds could not be killed in the first application.

However, Topik rate of 0.5 lit ha^{-1} applied at 14 days after emergence recorded the highest grain yield (4108.68 kg ha^{-1}), followed by rate 0.25 lit ha^{-1} (4108.11 kg ha^{-1}) applied at same timing of application. This indicates although Topik application in the early tiller initiation stage (14 days after emergence) is not effective in controlling wild oats as application in the tillering stage (30 days after emergence) it has considerable effect in increasing grain yield.

Interaction Effects of Durum Wheat Seeding Rate, Herbicide Rate and Application Timing: Various durum wheat seeding rates interactions with herbicide dosage and application timing had no significant effect on yield and yield component parameters. Yet statistically it is not significant maximum yield of durum wheat was obtained under the maximum seed rate of 225 kg ha^{-1}along with early application of Topik (14 days after emergence) at the rate of 1 liter ha^{-1}. Moreover, efficacy of lower Topik dose when applied in the early stages in combination with higher seed rate was efficient than when applied with higher seed rates in the latter stages. This might be because the lower dose of Topik might not be enough for controlling wild oats. Contrary to this, the lowest value of grain yield of wheat was recorded under seed rate of 187.5 kg ha^{-1} when there was no any attempt made for controlling weeds.

It can be recommended that 50% recommended rate (0.5 lit ha^{-1}) of the herbicide at these wild oat densities (37-87 seedlings m^{-2}) in the early application used for better yield. Yet, care should be taken for the effective control of the weed too, especially at relatively higher infestations for unlikelihood of producing herbicide-resistant biotypes. The relative success of 50% recommended rate of Topik in our study could be due to the initial wild oat population densities counted to 30 37-87 seedlings m^{-2}.

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