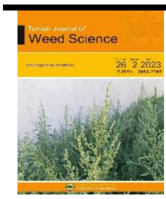

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Araştırma Makalesi/Research Article

Weed Management Through Herbicide Application to Increase Flax (*Linum usitatissimum* L.) Straw Yield

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ABSTRACT

Flax (*Linum usitatissimum* L.) is cultivated in many countries for its fibre and seeds. The production of flax is limited by weeds, which causes damage to the crops with a reduction of quality and quantity. The aim of this study was to determine effectiveness of combinations of pre and post emergence herbicides on weeds and flax straw yield. On-farm chemical weed control trial with seven applications were conducted from 2017-2018 in Black Sea region of Turkey. Pendimethalin and a tank mixture of linuron and lenacil were used as pre-emergence herbicides. As post emergence herbicides for broadleaf weeds bentazone+MCPA, tribenuronmethyl, clopyralid; for grass weeds pre mixture of fenoxaprop-P-ethyl+cloquintocet- mexyl were used. Each broadleaf herbicide was mixed with fenoxaprop-P-ethyl+cloquintocet- mexyl as a grass weeds herbicide. The efficacy of herbicides were evaluated in terms of the number of weeds at 7th, 14th, 28th and 56th days following the applications. The straw yield of flax in the experimental fields was measured as well. A total of 15 weed species, 13 dicotyledons and 2 monocotyledons, were found in the trials. The analysis of the collected data has shown significant differences between the weedy-check (no herbicide) and the pre-emergence and post emergence herbicide combinations in number of weeds and straw yield. Herbicide applications on all weed species except for *Convolvulus arvensis* exhibited a statistical difference compared to the control plots. Although herbicide treatments showed significant difference in yield compared to control, there was no difference in yield between treatments. Overall, the result of this study demonstrated that the use of combinations of pre and post emergence herbicides effectively reduced weed populations and improved competitive ability of flax and finally increased flax straw yield.

Key Words: Weed, Pre emergence, Post emergence, Flax yield, Herbicides, Effectiveness

1. INTRODUCTION

Flax (*Linum usitatissimum* L.) is an annual and self-pollinated species belonging to the Linaceae family. It is one of the oldest crops (Allaby et al., 2005) and the origin has been reported either from the Indo-Afghan region or from the Fertile Crescent (Duk et al., 2021). It is grown for seed and fiber. Flax seeds known as linseed are used as functional food thanks to α-linolenic acid, omega-3 fatty acid content (Fahad et al., 2015), high-quality of protein, soluble fibre and antioxidants (Oomah, 2001; Zou et al., 2017). Fibre flax is known as linen in Western countries and used for the manufacturing of clothes, table linen, rag-based bags, linoleum and printing inks and bio-based composite materials (Goudenhooft et al., 2019; Möhl et al., 2022; Ramesh, 2019; Turner et al., 2014).

The production of flax for fibre and seed was important during the Ottoman Empire and the beginning of the Turkish Republic. In the Black Sea Region of Türkiye, in particular, the Sinop city had important areas for the production of flax fibres (Uğurlu & Dönmez, 2012). Since all stages from cultivation to fibre processing were carried out in rural areas based on manpower, because of the migration towards the cities, the production of flax decreased dramatically by years (Arslanoglu et al., 2022). In recent years, there are efforts from some public institutions and private companies to produce raw materials for industry. The main biotic stress factor weeds reduce significantly the yield as they compete for nutrients and water and also transmit pest and disease (Heller et al., 2015). It is inevitable to control weeds and to keep flax field weed free until certain period during the cultivation.

Various studies have shown that the competitive ability of flax versus weeds is lower than some other crops. This poor competitive ability is also due to the morphological structure of flax such as single, non-branched stem, small leaves and poorly developed roots, especially during the first development stage (Fahad et al., 2015; Liu et al., 2009). Plants with a large leaf surface can benefit from sunlight more effectively than plants with narrow leaves. Since the leaf surface of flax is narrow, the rate of benefiting from sunlight significantly decreases. The root development of flax is slow, and these roots show little resistance to environmental stresses such as flood and drought (Liu et al., 2011). As a result, the ability to compete with weeds decreases to the same extent. The time until flowering and early capsule formation to create a shade gives the weeds time to germinate (Zhang et al., 2014). Friesen et al., (Friesen et al., 1992) reported that while 237 round-leaved mallow (*Malva pusilla* Sm.) per m^2 can decrease up to 15% yield in wheat, only 20 mallow plants per m^2 cause flax yield losses of 10 to 33.9%.

Weed competition decreases not only yield, but also quality of fibre with the mixing of weeds in flax straw (Marshall et al., 1995). Therefore, it is important to keep field weed-free during the early stages of flax growth to maximize yield. In the flax fields, there are a wide variety of dicotyledon and monocotyledon weeds such as lambsquarters (*Chenopodium album* L.), Canada thistle (*Cirsium arvense* (L.) Scop.), redroot amaranth (*Amaranthus retroflexus* L.), as well as green foxtail (*Setaria viridis* (L.) P. Beauv.) and wild oats (*Avena fatua* L.). Wild oat (*Avena fatua* L.) is the most troublesome weed in flax as well as many other crops due to its competitiveness (Kurtenbach, 2017). Another study determined that in flax field the most dominant weeds were yellow sweetclover (*Melilotus alba* Medik.) (28.9%), lambsquarters (*Chenopodium album* L.) (19.8%), garden vetch (*Vicia sativa* L.) (9.8%), scarlet pimpernel (*Anagallis arvensis* L.) (8.3%), field bindweed (*Convolvulus arvensis* L.) (7.8%), Mexican fireplant (*Euphorbia heterophylla* (L.)) (7.4%) and the remaining other weeds (18%) in flax fields in India (Pali et al., 1997). According to Weed Science Society of America (WSSA), considering eight most troublesome weeds in Canada, six of these species are also the most problematic weeds in flax production. These include wild oat (*Avena fatua* L.), wild buckwheat (*Fallopia convolvulus* (L.) A. Löve), redroot pigweed (*Amaranthus retroflexus* L.), Canada thistle (*Cirsium arvense* L. Scop.,) green foxtail (*Setaria viridis* L. P. Beauv.), and common lambsquarters (*Chenopodium album* L.) (Anonymus, 2022; Leeson et al., 2005).

Herbicides with a wide variety of mode of action are used for controlling weeds in flax fields in the world. For example, in Canada, which is the leader of linseed cultivation, 15 different pre-emergence and post-emergence herbicides with six different modes of action (Group 1, 3, 4, 6, 8,14) are used. Group 1, 4 and 6 mode of action for in crop use and Group 3, 8, 14 and 9 registered for pre emergence soil-incorporated herbicide (Anonymus, 2022). However, there are not registered herbicides for weed control in the flax in Turkey, yet.

The aim of the study was to investigate the effects of different mode of action pre-emergence and post-emergenceherbicides on weeds and flax straw yield. Herbicides pendimethalin (HRAC Groups 3), linuron and lenacil ((HRAC Groups 5), as pre-emergence and bentazone+MCPA (HRAC Groups 2),, tribenuronmethyl (HRAC Groups 4),, clopyralid (HRAC Groups 6), and fenoxaprop-P-ethyl + cloquintocet-mexyl as post emergence were applied to weeds.

2. MATERIAL AND METHODS

Field experiments were conducted in 2017-2018 growing season in Sinop, Türkiye. The altitude of the site is 200 m (geographical coordinates 41º52'24.8" N 34º31'50.1" E). The climate data including monthly accumulated precipitation and mean temperature are shown in Table 1. Also, soil characteristics of the trial field are shown in Table 2.

Table 1. Temperatures (°C) and rainfall in 2017-2018 growing season*

Month	Temperature (°C)	Rainfall (mm)
October	14.0	7.4
November	10.3	68.8
December	9.4	0.2
January	5.1	1.2
February	6.4	1.8
March	9.2	2.4
April	13.5	0.8
May	16.1	37.6
June	18.7	14.5

*Source: Sinop Meteorology Station Directorate

Table 2. Physico-chemical properties of the soil of experimental areas in depth of 0-30 cm.

Organic matter (%)	pH (1/2.5)	EC (%)	$CaCO_3$ (%)	P_2O_5 (%)	K_2O (%)	Soil type
2.02	6.56	0.0039	4	2.8	3	Clay

Previous crops on the experimental field were wheat and oat. Experiment was arranged as a randomized complete block design (RCBD) with seven different treatments in four replications. The size of each plot was 4 m x 5 m. In the trial, the intermediate safety strip was left as 0.5 meters between the plots. Pendimethalin and a tank mixture of linuron and lenacil were used as pre-emergence herbicides. As post emergence herbicides for broadleaf weeds bentazone+MCPA, tribenuronmethyl, clopyralid; for grass weeds pre mixture of fenoxaprop-P-ethyl+ cloquintocet- mexyl were used. Different combinations of pre- and post-emergence herbicide mixtures were applied to the plots. (Table 3). Flax was seeded immediately after the pre-emergence applications, and post-emergence applications were made after the weeds emerged and in the 2-4 leaf period.For the application of herbicides, backpack pulveriser was used.

Flax cultivar Rolin was used. Seeding rate was 80 kg Ha^{-1}. Experimental site was fertilised according to soil test recommendations. Weed species and density was counted 7 14, 28, 56 days after treatment. Flax plants were harvested by hand 240 days after planting on June 13, 2018.

Table 3. Herbicide treatments applied to flax.

Treatments	Herbicides	Doses ml ha⁻¹
T1	Control	0
T2	Pendimethalin+bentazon+MCPA+fenoxaprop-P-ethyl+cloquintocet-mexyl	3000 + 2000 + 800+
T3	Pendimethalin + tribenuronmethyl* + fenoxaprop-P-ethyl+cloquintocet-mexyl	3000 + 10 + 800
T4	Pendimethalin + clopyralid + fenoxaprop-P-ethyl+cloquintocet-mexyl	3000 + 1000 + 800
T5	Linuron + lenacil + bentazon + MCPA + fenoxaprop-P-ethyl+cloquintocet-mexyl	2000 + 1000 + 2000 + 800
T6	Linuron + lenacil + tribenuronmethyl* + fenoxaprop-P-ethyl+cloquintocet-mexyl	2000 + 1000 + 10 + 800
T7	Linuron + lenacil + clopyralid + fenoxaprop-P-ethyl+cloquintocet-mexyl	2000 + 1000 + 1000 + 80

*g ha⁻¹

Weed species were counted and identified on 7th,14th, 28th and 56th day after herbicide application in every 20m² plot. ‘Flora of Turkey’ by Davis (1965) was used for weed species identification. The density of the weed species in all plots were estimated as plant/m². In all plots flax was harvested by hand at physiological maturity on june 13, 2018, flax straws were weighed.

All data were subjected to ANOVA using SAS statistical package (SAS institute, Cary, NC, USA). Weed species number were square root transformed before analysis. Because of zero values in the data, the value of 1 was added to each data before transformation. No transformation was applied to flax yield values. Where the ANOVA indicated the treatment effects were significant, means were separated at P<0.05 with LSD test.

3. RESULT

3.1. Effect of herbicide treatments on weed density

Various weed species belonging to the Poaceae, Asteraceae, Rosaceae, Ranunculaceae, Equisateceae, Lamiaceae, Convolvulaceae families were found in the field. Under these plant families many of the monocotyledon and dicotyledon annual and perennial species were found. As a dicotyledon weeds, *Convolvulus arvensis* L., *Lactuca serriola* L., *Potentilla reptans* L., *Taraxacum officinale* Weber., *Ranunculus arvensis* L., *Achillea millefolium* L., *Trifolium repens* L., *Mentha arvensis* L., *Equisetum arvense* L., *Anthemis arvensis* L., *Briza media* L., *Euphorbia helioscopia* L., *Cardaria draba* (L.) Desv., *Anagallis arvensis* L., and as a monocotyledon weeds; *Agropyron repens* (L.) P. Beauv., *Briza media* L. were found. In the experimental field the predominant weed species was *A. repens* (L.) P. Beauv. with almost 44% of all other species. *R. arvensis* L. was 27% with share of 5.7% to *B. media* L. and 5.3% to *A. arvensis* L. These four species constituted 82% of all weed species. The other 11 species (*C. arvensis* L., *L. serriola* L., *P. reptans* L., *T. officinale* Weber, *R. arvensis* L., *A. millefolium* L., *T. repens* L., *M. arvensis* L., *E. arvense* L., *B. media* L., *C. arvensis* L., *E. helioscopia* L., *C. draba* (L.) Desv., *A. arvensis* L.) are sporadically occured in the experimental field.

All pre and post emergence combinations of herbicides reduced the number of weeds (Fig. 1). The greatest suppression of weeds was obtained after T6 treatment in all observation days. Weedy check (Control) showed a significantly higher weed density per square meter after 56th day of application than herbicide treatments. Weed density was 45.7 m^2/plant for control, while it was 2.6 for T6, 4.9 for T4, 5.2 for T5, 6.02 for T3 and 6.8 for T7.

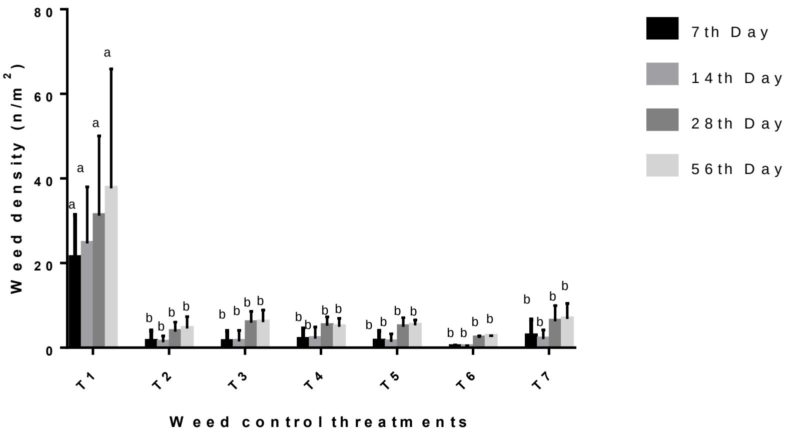

Figure 1. Weed population (number per square meter) after 7, 14, 28, 56 days.

The cumulative effects of the herbicides on the weed species after 56th days of application were evaluated. Each weed species effect of the treatments can be seen in Table 4. Efficacy of herbicides on weed species was significant except to the *C. arvensis*. The effect of treatments against *R. arvensis* L., *A. arvensis* L., *A. repens* (L.) P. Beauv., *B. media* L., which constitute 82% of all weed species in the trial, was significant.

Table 4. Effect of treatments on number of plants of weeds per plot and flax straw yield

Weed Species	T1	T2	T3	T4	T5	T6	T7	CV (%)	LSD (%5)
A. repens (L.) P. Beauv.	19.30 a*	6.16 b	7.10 b	8.53 b	5.37 b	7.42 b	8.60 b	34.3	4,55
L. serriola L.	3.28 a	1.00 b	1.00 b	1.00 b	1.00 b	1.00 b	1.00 b	51.8	1.02
P. reptans L.	4.18 a	1.00 b	1.58 b	1.00 b	1.00 b	2.08 b	2.49 b	62.5	1.76
T. officinale Weber.	3.97 a	1.50 b	1.25 b	1.36 b	2.09 b	1.10 b	1.36 b	49.62	1.33
R. arvensis L.	14.53 a	2.02 b	1.36 b	1.31 b	1.36 b	2.08 b	2.49 b	82.07	4.38
A. millefolium L.	3.20 a	1.89 b	2.12 b	1.70 bc	1.00 c	1.00 c	1.00 c	38.66	0.97
T.repens L.	4.51 a	1.00 b	1.00 b	1.00 b	1.00 b	1.00 b	1.00 b	60.51	1.35
M.arvensis L.	2.35 a	1.25 ab	2.02 ab	1.25 ab	1.00 b	1.00 b	1.36 ab	61.92	1.34
E. arvense L.	2.49 a	1.41 b	1.18 b	1.46 b	1.58 ab	1.28 b	1.00 b	40.26	0.89
A.arvensis L.	6.95 a	2.92 b	1.75 b	3.01 b	1.00 b	1.87 b	1.91 b	48.96	2.01
B. media L.	7.30 a	2.35 b	2.25 b	1.89 b	1.67 b	3.00 b	3.63 b	55.67	2.61
C. arvensis L.	4.14 a	2.97 a	3.83 a	3.62 a	3.18 a	3.36 a	3.59 a	47.39	2.45
E. helioscopia L.	3.65 a	1.75 b	1.36 b	2.87 ab	1.50 b	2.27 ab	1.72 b	49.58	1.59
C. draba (L.) Desv.	2.30 a	1.00 b	1.00 b	1.00 b	1.00 b	1.00 b	1.00 b	54.23	0.95
A. arvensis L.	4.91 a	2.83 ab	3.35 ab	2.26 b	2.04 b	1.58 b	2.91 ab	62.12	2.62
Yield (kg Ha^{-1})	386 b	923 a	786 a	861 a	951 a	864 a	675 ab	26.06	30.14

*Means with the same letter within the same line are not significantly different according to LSD test at $\alpha < 0.05$

Plots treated with herbicide had a significantly lower number of weeds than that of untreated control plots. However, no differences were statistically found between the herbicide applications for weed species excluding *A. millefolium*. T5, T6 and T7 applications were more effective on this weed species compared to other applications (Table 4).

3.2.Effect of herbicides on flax straw yield

Flax was harvested at the time of early yellow ripeness for high fibre quality (Nilsson, 2006). The untreated and treated plots were pulled out and weighed separately for each plot. The effects of the herbicides on the flax straw yield were as the follows: the yield of the control plot was the lowest yield with 386 kg Ha^{-1}, whereas the herbicide treatment yields with T5 (951 kg Ha^{-1}), T2 (923 kg Ha^{-1}), T6 (864 kg Ha^{-1}), T4 (861 kg Ha^{-1}), T3 (786 kg Ha^{-1}) and T7 (675 kg Ha^{-1}) realized significantly higher (Table 4).

T2, T3, T4, T5 and T6 applications were found to be more effective than T7 applications. However, there was no statistically significant difference between these applications.

4. DISCUSSION

4.1 Effect of herbicide treatments on weed density

In the experimental field of this study various weed species belonging to different families were found. In the studies reported so far, weed flora in flax cultivation shows similarities with the weed species detected in our study, but there are also differences.

In this study the predominant weed species were *A. repens* (L.) P. Beauv. with 44% of all other species, *R. arvensis* L (27%), *B. media* L. (5.7%) and *A. arvensis* L. (5.3%). These four species constituted 82% of all weed species. In the other studies, it was determined that the dominant weed species of flax were *Chenopodium album* L., *Sinapis arvensis* L., *Cirsium arvense* (L.) Scop., *Polygonum nodosum* Pers. and *Polygonum convolvulus* L. (Heller, 1992; Nalewaja, 1996), *Echinochloa crus-galli* L., *Viola arvensis* Murr., *Geranium pusillum* L., and *C. album* L. (Heller & Adamczewski, 2010; Mańkowski et al., 2013). In Lithuania, most common weeds of organic linseed and flax crop were *Sonchus arvensis* (59%), *Poa annua* (10%), *Convolvulus arvensis* (9%) in the experimental field (Gruzdeviene & Jankauskiene, 2011). According to Beckie et al. (2013) it is the only *Avena fatua* that is constantly found among all the problematic weed species described and has resistant populations to herbicides in flax field .

The weed flora is related not only to crop but also to the soil characteristics, climatic conditions and to the previous crops. As Zimdahl (Zimdahl, 2018) described climate, soil and biota (living organisms) are the three important component of weed-environmental interactions. Agricultural managements such as soil tillage, irrigation, fertilization, date of planting, growing period of crop, seed dispersal at harvest and weed control methods can also affect the species composition and weed density.

The existence of weed species can be explained also through the crop-weed interaction approach. *Lactuca serriola* is an invasive weed in many countries. This species is distributed on ruderal areas, roadsides but also in many agricultural areas such as wheat, cereals and pulses (Barroso et al., 2021; Chadha & Florentine, 2021). This species is a strong competitor thanks to the deep tap root system. It aggressively consumes soil moisture and nutrients. Even with low densities of plant (0.2-1.2 plant/m^2) yield loss can be 10% and reached up 80% with 50 plant/m^2. In our study the density of *L. serriola* was between 0.3-2 plant/m^2. This means that due to this plant yield of linen can decrease.

Another perennial dicotyledon weed species *Potentilla reptans* L. has long stolons. It has determined that this species can germinate in any month of the growing season when there are no limiting factors such as moisture and salinity in the soil (Kołodziejek et al., 2019). In our study the density of this species was low but after using post emergence herbicide density increased. This is a high probability of occurring new ramets from nodes of stolons after some disturbance.

C. arvensis is a problematic weed in a wide range of crops such as wheat. Studies have reported the effects of different herbicide combinations on the control of *C. arvensis* (Boydston & Williams, 2004; Stone et al., 2005). However, herbicide combinations used in our study did not show a significant effect on the *C. arvensis*.

Mankovski et al. (2015) indicated that bentazone and chlorsulfuron used as post-emergence were more effective in reducing the number and weight of weeds in flax compared to linuron used as pre-emergence.

In general, the effectiveness of herbicide with time decreased depend of the new generation of the weeds which were coming from new seeds or brunches.

4.2. Effect of herbicides on flax straw yield

All tested herbicides positively affected flax straw yield compared to the weedy check plots in the experimental field. Although the flax yield was the highest in T5 treatment and the lowest in T7 treatment compared to control, there was no statistical difference between the treatments (Table 4). Weed control efficacy and flax yield with treatment of herbicide were also obtained by other authors (Christopher et al., 1991; Ghalwash & Soliman, 2008). Herbicides for weed control in flax affect not only straw yield but also content, length, thinness and divisibility of fiber (Mańkowski et al., 2015). Safi et al., 2020 reports that Quizalofop-p-Tefuryl treatment significantly increased flax seed yield.

5. CONCLUSION

This study demonstrated that the application of pre-emergence and post-emergence herbicides targeting both monocotyledon and dicotyledon weeds led to an increase in flax straw yield through the reduction of weed density. Additionally, it is recommended to conduct detailed studies on the effects of herbicides with different modes of action (MoA) and to investigate the phytotoxic effects of herbicide combinations on flax.

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