ECONOMIC THRESHOLD OF WILD MUSTARD (SINAPIS ARVENSIS L.) IN SAFFLOWER (*CARTHAMUS TINCTORIUS* L.)

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ABSTRACT

The use of intensive agricultural practices to obtain higher grain yield over several years in traditional oil-seed crops such as sunflower, canola, and maize eventually results in increased levels of some weeds in these crops. At this point, replacing these crops with different oil-seed crops such as safflower is a rational approach. However, weeds can also reduce safflower yield if they are not controlled before reach to economic threshold. A 3-year field experiment was conducted to determine the economic losses from wild mustard (*Sinapis arvensis* L.), which is the main weed species, and the economic threshold level of wild mustard in safflower fields of Turkey in 2017-2019. Safflower yield decreased from 5% to 63% as the density of wild mustard increased from 0.5 to 16 plant m^{-2}. The economic threshold of wild mustard in safflower was calculated based on a rectangular non-linear hyperbolic regression model. The economic threshold was recorded 1.26, 1.06, and 1.32 plants m^{-2} in 2017, 2018, and 2019, respectively, at a 91.25% control level by chlorsulfuron.

KEYWORDS:
Safflower, wild mustard, economic threshold, chlorsulfuron

INTRODUCTION

Safflower is one of the most promising oil-seed crops for reducing the vegetable oil gap in Turkey, which currently needs to import cooking oil [1,2]. This gap has grown so much that the currency paid for crude vegetable oil by Turkey are annually near 1.5 billion US Dollar [3]. In addition to its oil potential, safflower is also used in folk medicine, cooking, and the textile industry and as a biofuel and an ingredient in animal feed [4–6]. As a rich source of essential fatty acids, safflower oil is a high-nutrient product [5]. Moreover, safflower is a favourable crop to fill fallow fields in arid and semi-arid regions of Turkey. Owing to its strong root system, safflower can easily reach to deep soil layers and the water they contain, enabling it to withstand drought conditions [7]. The crop has been widely adopted in many semi-arid agricultural regions of Turkey, especially in the Central Anatolian Region [8]. Ankara has the largest safflower production area (2.767 ha) in Turkey and contributes 16% of the country's total safflower seed yield [9].

Safflower often replaces fallow in a wheat-fallow crop rotation system, and therefore, the safflower fields can be infested with wheat weeds [1]. Safflower fields near Ankara were found to host 35 weed species belonging to 16 plant families, including wild mustard (*Sinapis arvensis* L.), wild oat (*Avena fatua* L.), field bindweed (*Convolvulus arvensis* L.), common cocklebur (*Xanthium strumarium* L.), wheat (*Triticum aestivum* L.), and redroot pigweed (*Amaranthus retroflexus* L.). Among these weeds, wild mustard is the most common weed species in safflower fields and exists in more than half of them due to its competitive annual growth habit [1]. The weed can produce approximately 1.200-3.000 seeds in a season, and its seeds can survive in the soil for more than 10 years, creating a persistent seed bank [10]. Moreover, in the early stage of its growth, the weed's leaf area and height increase rapidly, allowing it to easily outpace competitors to reach the light [10]. Yield loss caused by wild mustard varies depending on its abundance and the specific crop and variety, and in some cases, it has reached 91% [11–14]. Despite safflower having a strong allelopathic effect on the wild mustard seed germination and seedling growth [15], crops such as canola, sunflower, wheat, and safflower that grow slowly during the seedling stages are generally vulnerable to wild mustard competition [11,16,17].

Many weed control practices such as cultivation, mulching, hand weeding, and flaming can help prevent yield losses caused by weed competition, but these practices are generally restricted to crops sown with large rows spacing. For crops such as wheat, barley and safflower that have narrow row spacing, such treatments have limited applications because they are too costly. In addition, the head and leaves of safflower have strong thorns, making weed control treatments such as hand weeding or hoeing painful and impractical. Chemical weed control is a popular approach compared with other techniques because it reduces the cost of production and has longlasting suppressive effects on weeds [18]. However, while herbicides provide effective weed control for a limited period after their application, they can have adverse effects on human and animal health, as well as the environment [19]. Providing a balance between the benefits of herbicides and the potential harm to non-target organisms is the key issue in terms sustainable crop production. Many models have been used to depict this balance, but the economic threshold (ET) model appears to be one of the more applicable ones [20]. Actually, weed-crop interactions constitute one of the most complicated phenomena in agricultural ecosystems [21], and ET can represent this interaction in terms of the economics of crop production and the closely related crop yield loss caused by weed [20]. Moreover, use of the ET model not only provides key information to the grower for determining the extent of weed control by weed management practices that is necessary, but also guides decisions on the cost of the herbicide use that is needed [22]. ET depends on the herbicide application cost, the price of yield, and average yield amount per land unit [23]. Employing ET may be a useful tool in many times to evaluate economic impacts of a specific weed like wild mustard. The weed can cause a significant degree of yield loss, even at low levels in some row crops such as wheat, sunflower, and canola [11,16,17,24]. Safflower growers in Turkey need information about the population density of wild mustard that is critically important in terms of economical weed control, but that information is lacking. However, no data was found in the available literature regarding economic impact of wild mustard on safflower seed yield.

The objective of this study was to determine the ET level of wild mustard in safflower and the effects of wild mustard on safflower yield and yield components in spring safflower grown Central Anatolian Region of Turkey.

MATERIALS AND METHODS

Site description and experimental design The field trial was conducted in dryland farming system during the 2016-2017, 2017-2018, and 2018-2019 safflower growing seasons at the İkizce Agricultural Farm Station (İAFS) of the Field Crop Central Research Institute (39.611917, 32.675258). The soil at the experimental sites was a clay loam soil, with 0.7% organic matter and a pH of 7.77. The weather data were taken from the meteorological station in the experimental field during the study and presented in Figure 1. According to köppen climate classification, the experimental field is classified as Csa [25].

Agronomic practices conducted by the farmers who cultivated safflower in the region were followed. The soil was ploughed to a depth of 30 cm with a mouldboard plough, and the seedbed are then prepared using a rotary tiller. The crop (var. Hasankendi) was seeded using a conventional driller on April 25, 2017 in the first year, April 04, 2018 in the second year, and on June, 2016 in the third year. The row spaces were adjusted to 15-17 cm apart at a density of 175-200 plants m^{-2}. The fertilization was done at once with 150 kg N and 60 P ha^{-1} during sowing.

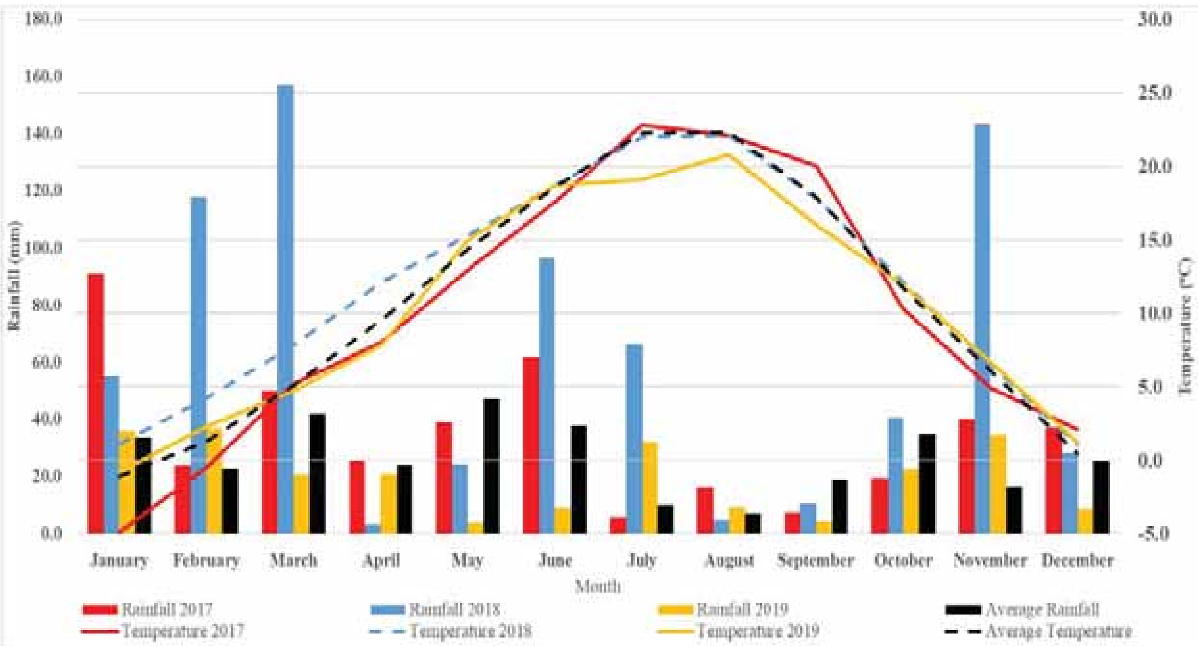

FIGURE 1
Meteorological data for the experimental fields in 2017, 2018, and 2019

The experimental design was a randomized block design with three replications, and each experimental plot was 1 m × 4 m. The field was naturally infested by wild mustard at densities of 5.13, 7.5, and 9.75 plants m^{-2} in 2017, 2018, and 2019, respectively. Six wild mustard densities (0, 1, 2, 4, 8, and 16 plants m^{-2} in the first growing season and 0, 0.5, 1, 2, 4 and 8 plants m^{-2} in the second and third growing seasons) were used in the experimental fields, and natural weed-infested plots including wild mustard and weed-free parcels were used for comparison to assess the impact of wild mustard. To obtain the experimental densities, weeds were transplanted from various part of the field or thinned by hand-pulling weekly. Following trial initiation, coloured string was tied to the wild mustard plants to discriminate them from newly emerging wild mustard plants. All weeds were periodically removed manually during growing season to maintain a fixed weed density, except for wild mustard.

Crop plants in the middle of rows are then evaluated to avoid the field edge effects, and their yield, and yield components such as head number per plants, plant height, and 1000-seed weight were recorded. As the safflower plants reached maturity, all plants in four 0.25 m^{-2} quadrats placed in the centre of each plot were manually cut off at the soil surface on September 7, 2017, September 21, 2018, and August 29, 2019, respectively, and the numbers of heads per plant were counted and recorded. The grain was manually stripped from the straw in the laboratory, and the safflower yield was recorded. Safflower grain moisture was adjusted to 13%, and the 1000-seed weight was calculated based on 1000 randomly selected safflower seeds from each plot. Ten plants in the middle rows from each plot were measured from the soil surface to the top of the plant, and the average plant height was then calculated.

Statistical analysis Data were analysed with nonlinear regression analysis using SPSS statistical software to determine the safflower yield loss (SPSS, 2004). The relationship between the percentage of safflower yield loss and weed density was calculated with a non-linear regression model according to Cousens [23], who described this relationship with a rectangular hyperbolic model using Equation 2:

$$Yield = Yieldwf \times \frac{(1-(i\times d))}{100\times\left(\frac{1+(i\times d)}{A}\right)} \quad (2)$$

where i, d, and A are percentage yield loss per unit at d level of wild mustard, wild mustard density, and maximum asymptote, respectively.

ET of wild mustard (plants m^{-2}) was calculated according to Lindquist and Kropff [26] using Equation 3:

$$Economic\ Threshold = \frac{(HAC)}{Yo\times PS\times YL\times HEL} \quad (3)$$

where HAC (herbicide application cost), Yo, PS, YL, and HEL indicate the herbicide application cost to control wild mustard (the cost of herbicide, Chlorsulfuron DF 75%, and its application in dollars (US$) ha^{-1}), safflower grain yield of the weed-free plots (kg ha^{-1}), the price of safflower (in dollar (US$) kg^{-1}), yield loss percentage caused by wild mustard (%), and herbicide efficacy level (%), respectively.

The effect of wild mustard density on safflower grain and grain yield components was determined in comparison with plots with natural weed infestation and weed-free plots. All data were subjected to analysis of variance to evaluate the effects of the main factors and their interactions. Data were analysed separately according to year and main effects because interactions between them were significant. Plant height, head number per plant, and 1000-seed weight data were transformed to the arcsine square root before statistical analysis. However, original data are presented in the related figures for clarity. Plant height, head number per plant, and 1000-seed weight data were also subjected to analysis of variance, and Fisher's protected LSD test ($P< 0.05$) was used to separate treatment means.

RESULTS

The experimental fields naturally contained wild mustard and other weed species such as redroot pigweed, wild oat, and fat hen (Table 1). Wild mustard density and safflower yield was strongly related in all years (Table 2). An increase in wild mustard density from 1 to 16 resulted in a decrease in safflower yields from 11.30% to 56.07% in the first year (Table 2). Yield reduction caused by wild mustard at a density of 1 plant m^{-2} was more than 10%. Therefore, for the subsequent seasons, wild mustard densities were reduced from 16 to 8 plants m^{-2} at the highest level and from 1 to 0.5 plant m^{-2} at the lowest level.

The trial results showed that plant height, head number per plant, 1000-seed weight, and grain yield changed significantly depending on the wild mustard density. Among the yield components, the head number per plant was more sensitive to weed competition than plant height and 1000-seed weight in 2018 and 2019, but not 2017. In terms of all yield components, safflower yield was dramatically affected by weed competition depending on the year, weed composition, and other environmental conditions.

The head number per plant was significantly reduced as wild mustard density increased from 0 to 8 plants m^{-2} or from 0 to 16 plants m^{-2} for all years (Figure 2). The decline in the head number per plant varied depending on the year; in the first year, it was higher than other years due to heavy redroot pigweed infestation in the experimental fields (Table 1). The most dramatic decline in the head number per plant occurred in the third year, when severe drought affected the experimental field (Figure 2). Although safflower has a strong root system to reach subsoil water supply [27], it has more rigorous plant growth and grain yields when grown under irrigated conditions or rain-fed conditions [28].

TABLE 1
Density and average coverage area of weed species in the experimental fields (plant m^{-2} (%)).

Weeds	2017	2018	2019
Fat hen (*Chenopodium album* L.)	0.38 (1.63)	0.28 (1.25)	0.66 (1.25)
Field bindweed (*Convolvulus arvensis* L.)	0.5 (4.63)	1.25 (3.95)	0.75 (2.50)
Wild buck weed (*Fallopia convolvulus* (L.) Á. Löve)	0.13 (0.63)	-	0.25 (1.25)
Wild mustard (*Sinapis arvensis* L.)	5.13 (12.88)	7.5 (14.50)	9.75 (15.75)
Redroot pigweed (*Amaranthus retroflexus* L.)	13.13 (6.88)	2.15 (2.50)	1.25 (0.66)
Bristly foxtail (*Setaria verticillata* (L.) P. Beauv.)	0.5 (2.5)	-	-
Wild oat (*Avena fatua* L.)	2.8 (4.50)	1.5 (0.25)	1.66 (0.85)
Common fumitory (*Fumaria officinalis* L.)	0.25 (0.38)	-	0,25 (0.40)
Groundsel (*Senecio vulgaris* L.)	0.13 (0.63)	-	-
False carrot (*Turgenia latifolia* (L.) Hoffm.)	0.63 (0.63)	-	-
Couch grass (*Elymus repens* (L.) Gould)	0.38 (0.50)	-	-
Shepherd-purse (*Capsella bursa-pastoris* (L.) Medik.)	-	2.5 (3.25)	0.85 (1.15)
Field milk thistle (*Sonchus arvensis* L.)	-	0.88 (1.25)	0.75 (0.98)
Canada thistle (*Cirsium arvense* (L.) Scop.)	-	1.25 (1.75	0.5 (0.66)

Increasing the density of wild mustard from 0 to 16 plants m^{-2} in 2017 and from 0 to 8 plants m^{-2} in 2018 and 2019 significantly decreased safflower plant height from 115.2, 96.5, and 84.6 cm to 70.3, 82.6, and 68.7 cm, respectively (Figure 3). The effect of wild mustard density on safflower height was also closely related to rainfall or irrigation, and weed flora of safflower like head number per plant. But, the growth of safflower under high weed competition in the drought year (2019) did not vary more than in the rainy year (2018) (Table 1). Under drought conditions, the average height of safflower plants was shorter than under rainy or irrigated conditions, regardless of the safflower genotype and year [27]. A decrease in safflower plant height depended on the wild mustard density and climatic conditions, similar to the findings of previous studies [28,29]. Allelopathy has an important role in crop-weed interaction [30]. Previous studies showed that safflower extracts decreased wild mustard seed germination and reduced weed seedling fresh weight and length [15]. In addition, safflower's strong root system and ability to survive under drought conditions may help suppress wild mustard seed germination and seedling growth. At this point, our results support those of Farhoudi and Lee [15].

The 1000-seed weight was affected by wild mustard competition; however, the impact was minimal at lower weed densities, whereas it was clearer at high weed densities (Figure 4). The effect of years on the relation between 1000-seed weight and weeds was not statistically significant, in contrast to the results for the head number per plant and the plant height (P>0.05). Jalali et al. [28] reported that the 1000-seed weight was not significantly affected by weed interference or by irrigation treatment applied at various intervals to six-leaf stage safflower in a field heavily covered by field bindweed, common lambsquarters, camel thorn (*Alhagi camelorum* L.), and common cocklebur. However, Blackshaw [31]

TABLE 2
Efficacy of wild mustard density on the safflower and safflower yield from 2017 to 2019.

Treatment	Yield (kg ha^{-1})		
	2017	2018	2019
0.5 WM m^{-2}	-	1752.7±68.2 B	1686.8±67.7 A
1 WM m^{-2}	2124.8±47.0 B*	1660.2±54.9 C	1523.1±60.3 B
2 WM m^{-2}	2024.0±50.6 B	1479.2±33.4 D	1285.7±42.5 C
4 WM m^{-2}	1544.3±74.8 C	1092.3±66.0 E	977.5±56.3 D
8 WM m^{-2}	1273.3±68.6 D	742.4±57.4 G	660.6±41.9 F
16 WM m^{-2}	1048.1±89.4 E	-	-
Weed-Free	2385.8±44.5 A	1863.3±31.0 A	1723.8±56.1 A
Weedy	1155.7±77.5 DE	884.9±24.1 F	756.1±29.0 E

WM: Wild mustard; * Means ± SE within columns followed by the same letter are not significantly different between treatments at the 0.05 probability level as determined by Fisher's Protected LSD test.

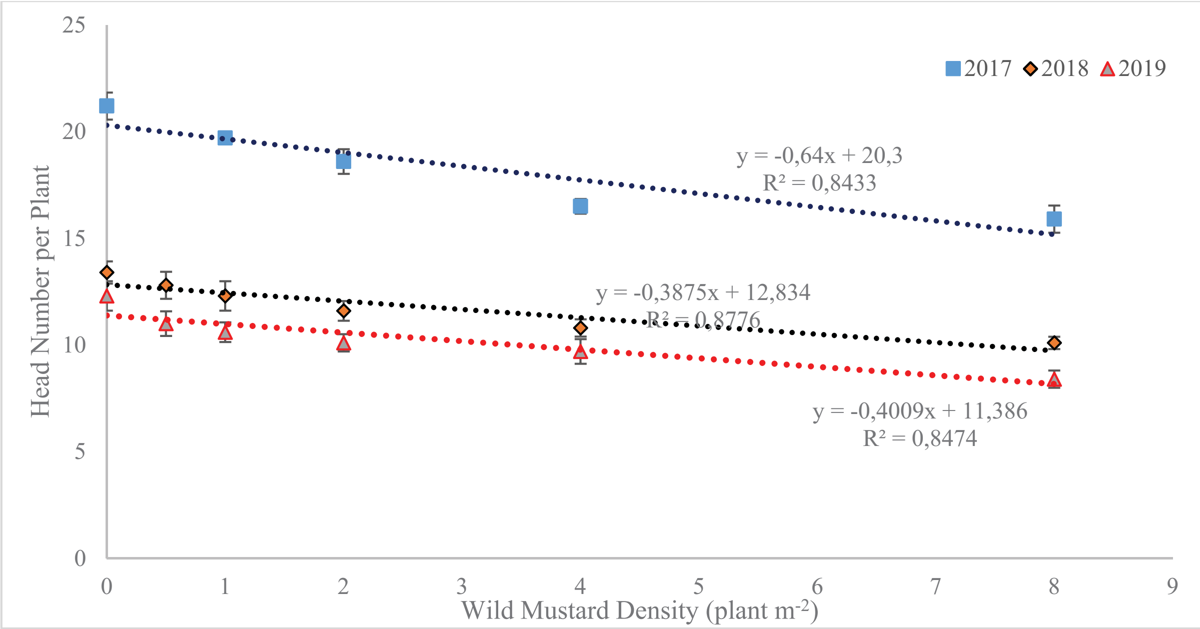

FIGURE 2
Relationship between wild mustard densities and head number per plant

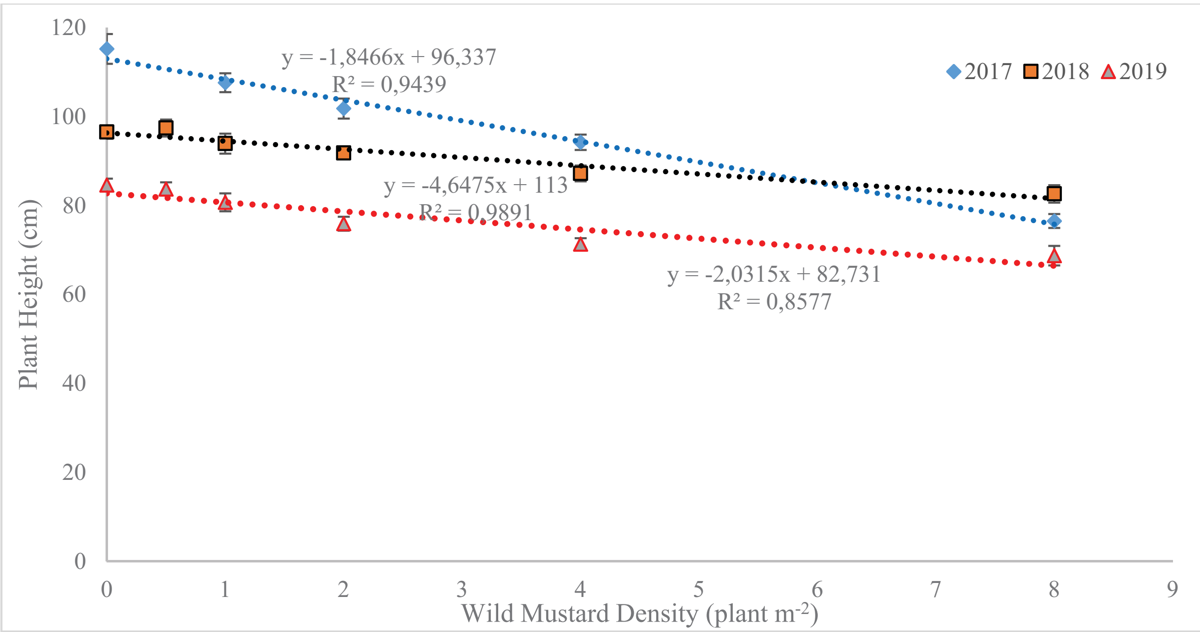

FIGURE 3
Relationship between wild mustard densities and plant height (cm)

indicated that the 1000-seed weight of safflower declined significantly due to green foxtail (*Setaria viridis* (L.) P. Beauv.). Behdarvand et al. [32] found a slight relation between wild mustard density and 1000-grain weight of wheat compared with other yield components of wheat such as spike number per square meter and grain number per spike. In their study, 1000-grain weight of wheat decreased by 6.96% at a density of 15 wild mustard plants m^{-2}. Similar findings in field pea were reported by Wall et al. [34], who showed that competition of wild mustard affected the 1000-seed weight. Our results accorded with those of Behdarvand et al. [32] and Wall et al. [34] in terms of 1000-seed weight.

Wild mustard is such a strong competitor that the impact of total weeds and that of wild mustard at a density of 8 plant m^{-2} (or lower) had similar effects on the safflower yield (Figure 2). Competition between wild mustard and other weeds for space, water, nutrients, and sunlight attenuated the impact of wild mustard. This phenomenon, interspecies competition between weeds, has been described by many researchers West et al. [35].

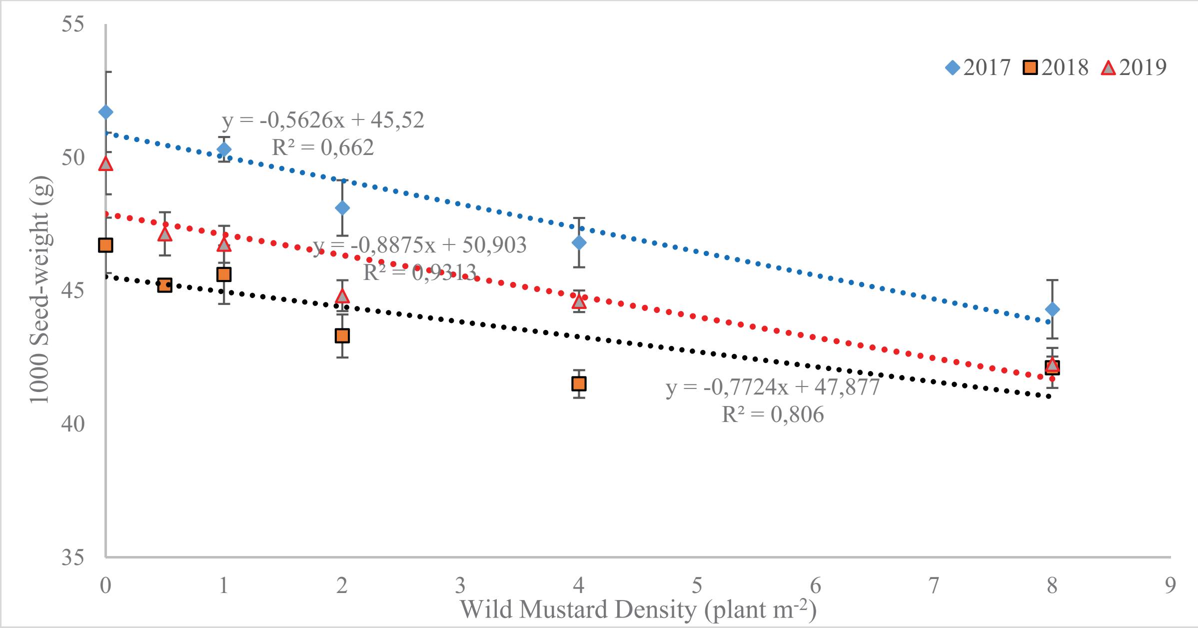

FIGURE 4
Relationship between wild mustard densities and 1000 seed weight (g)

Safflower yield reduction owing to wild mustard density steadily increased up to 4 plants m^{-2}, but at higher densities, the yield reduction caused by per wild mustard was less than at lower densities (Figure 2). This difference was attributed to intra-species competition between wild mustard plants instead of other plants. Intra-species competition involving wild mustard plants has also been studied in other crops such as wheat and soybean. Mennan [16] investigated the influence wild mustard density on wheat grain yields and reported that wheat grain loss at 1, 4, 6, and 32 wild mustard plants m^{-2} was 2.02-3.79%, 7.70-9.77%, 14.50-16.85%, and 36.00-37.83%, respectively. Yield loss caused by wild mustard steadily increased up to a density of 4 plants m^{-2}, but beyond that each incremental increase in weed density had less of an impact on yield loss. Our results accorded with the findings of previous studies were obtained in field trials with canola [17], sunflower [11], pea [33], and navy bean [36].

The crop yield-weed density model described by Cousens [23] is a useful tool to evaluate the economic cost for the farmers due to weed-related yield loss (Figure 5).. An advantage of this model is its inclusion of intra-species competition between wild mustard plants. In Table 3, the parameter i represents the yield loss due to 1 wild mustard plant m^{-2} in safflower; the losses were 13.50%, 13.09%, and 14.87% in 2017, 2018, and 2019, respectively. These reductions translated to safflower grain yield reductions of 260.66, 203.1, and 200.8 kg ha^{-1} in 2017, 2018, and 2019, respectively. These values represent the highest yield losses on an incremental basis, but the amount of loss per each incremental increase declined as weed density rose (Figure 3).

The parameter A indicated the yield loss when the wild mustard population reached the highest weed population level. The first year had the lowest asymptote value, and the values in the second and third years were higher: 76.59%, 145.42%, and 132.47% in 2017, 2018, and 2019, respectively (Table 3). Theoretically, these values should not exceed 100%, yet the values in our study were higher than the maximum theoretical value described by Cousens [23]. In some previous studies, this theoretical value was also exceeded, similar to our findings. This outcome shows that a specific weed species' highest impact on the crop in a specific environment has a limit even if the weed number is above the carrying capacity of that area [34,37,38] . Wall [36] indicated that the parameter A was 73.9% and 96.2% for wild mustard species in navy bean. These values were in line with our first-year value of 76.59% for wild mustard in safflower.

According to ET model, the parameters HAC and PS were US$0.69, US$0.48, and US$0.61 ha^{-1}, and US$0.186, US$0.203, and US$0.197 kg^{-1} in 2017, 2018, and 2019, respectively. The herbicide efficacy level was 91.25% for all years [39]. The economic thresholds were calculated to be 1.26, 1.06, and 1.32 plants m^{-2} in the years 2017, 2018, and 2019, respectively. These values varied by year, depending on the parameters mentioned above because production costs and safflower prices were not stable. Our calculated ETs were very similar to those of Mennan [16], who stated that the ET level of wild mustard in wheat with chlorsulfuron (75%) was 1.14 plant m^{-2}, as well as those of Başaran and Kadıoğlu [24], who reported that the threshold values with tribenuron-methyl 37.5% and mesosulfuron methyl 3% + iodosulfuron methyl sodium 0.6% were 0.67–1.37 and 1.14 plants m^{-2}.

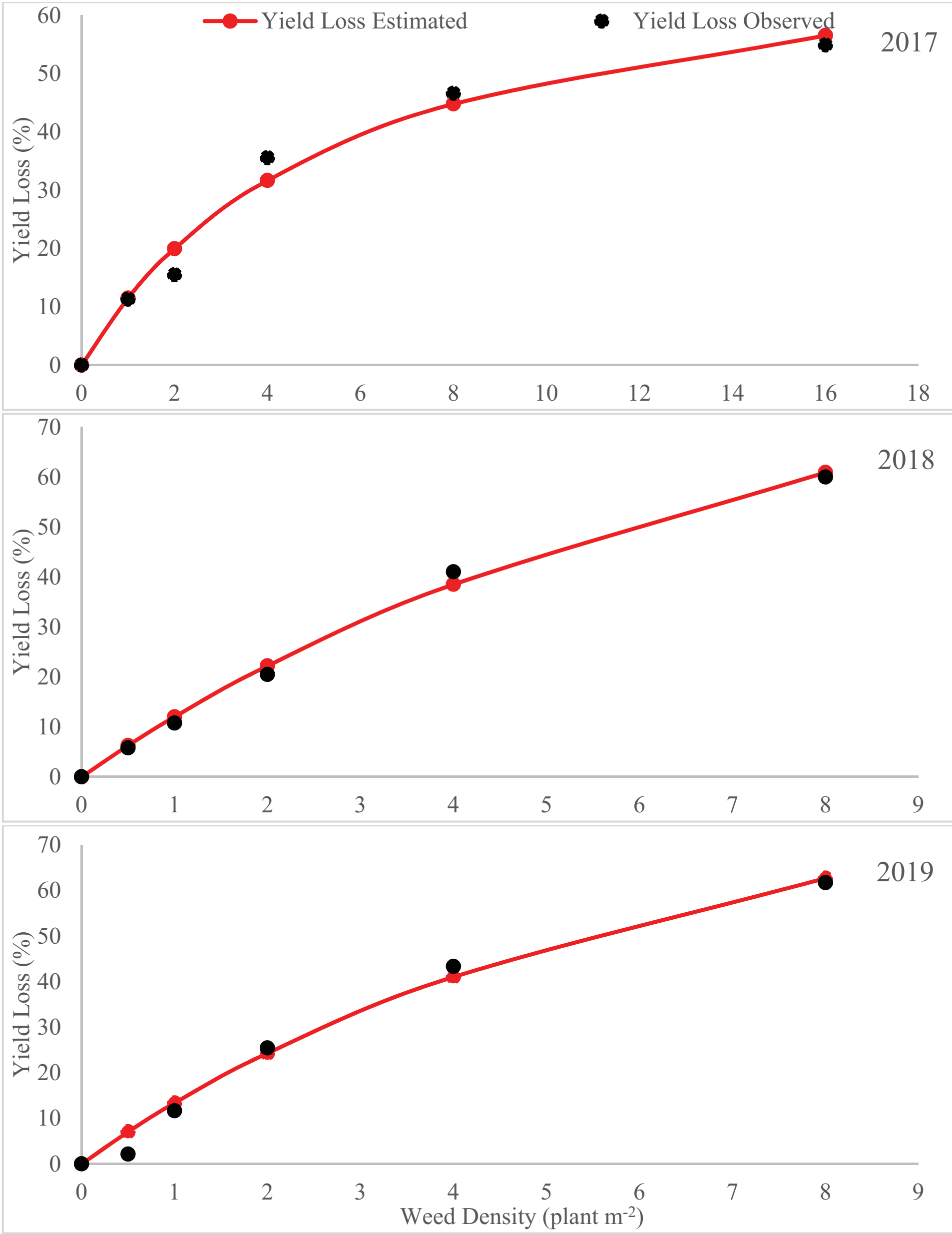

FIGURE 5
Estimated and observed yield losses (%) of safflower for various wild mustard densities in 2017- 2019.

TABLE 3
The parameters and standard errors calculated from the rectangular hyperbolic model of safflower yield loss by SPSS in 2017-2019

Parameters	2017	2018	2019
I	13.50 ± 1.40	13.09 ± 1.03	14.87 ± 1.43
A	76.59 ± 5.42	145.64 ± 21.01	132.47 ± 19.43
R^2	96.9	98.3	97.5

i, percent yield loss per unit of weed density, followed by the standard error; A, asymptotic value of the maximum yield loss (%), followed by the standard error; R^2 = 1−(residual sum of squares)/(corrected sum of squares).

CONCLUSIONS

In this study, wild mustard caused significant losses in safflower grain yield and important yield components of safflower, even at the low density of 0.5 plant m^{-2}. The data showed that the ET varied from 1.06 to 1.32 plants m^{-2} depending upon parameters such as weed control efficiency, herbicide cost, cost of herbicide application, safflower price, and grain yield. The results also showed that wild mustard at a density of 8 plants m^{-2} or higher may reduce safflower yield as much as all other weeds combined in safflower fields. The results indicated that the effect of weed flora in safflower and the effect of climatic conditions on the results were statistically important ($P<0.05$). Controlling wild mustard in safflower fields based on the ET would reduce the cost of production and minimize the adverse effects of excessive herbicide use on the environment. The effect of variety on the ET appears to be a very important component, similar to the aforementioned factors. This effect should be taken into account in future ET studies carried out in safflower.

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REFERENCES

[1] Serim, A.T., Asav, U. and Türkseven, S.G. (2015) Determination of weeds in safflower (*Carthamus tinctorius* L .) cultivations in Ankara province. Turkish Journal of Weed Science. 18, 19–23.

[2] Ekin, Z. (2020) Field evaluation of rhizobacterial inoculants in combination with humic substances to improve seed and oil yields of safflower (*Carthamus tinctorius* L.) under irrigated and rainfed conditions. Applied Ecology And Environmental Research. 18, 6377–403.

[3] Kıllı, F. and Beycioğlu, T. (2019) Oilseeds and crude oil production in the world and turkey, problems of oilseeds production in Turkey. IJAAES International Journal of Anatolia Agricultural Engineering. 17–33.

[4] Ekin, Z. (2005) Resurgence of safflower (*Carthamus tinctorius* L.) utilization: A global view. J. Agron. 83–7.

[5] Khalid, N., Khan, R.S., Hussain, M.I., Farooq, M., Ahmad, A. and Ahmed, I. (2017) A comprehensive characterisation of safflower oil for its potential applications as a bioactive food ingredient - A review. Trends in Food Science & Technology. 66, 176–86.

[6] Kose, A. (2019) Inheritance of oil yield and its components in safflower (*Carthamus tinctorius* L.). Turkish Journal of Field Crops 24, 65–9.

[7] Hussain, M.I., Lyra, D.A., Farooq, M., Nikoloudakis, N. and Khalid, N. (2016) Salt and drought stresses in safflower: a review. Agronomy for Sustainable Development. 36, 1–31.

[8] Baydar, H. and Erbaş, S. (2020) Our native and national safflower varieties: Olein, Zirkon and Safir. Ziraat Fakültesi Dergisi. 233–7.

[9] TUIK. (2020) Agricultural statistic in Turkey https://www.mgm.gov.tr/FILES/iklim/iklim_siniflandirmalari/koppen.pdf Last access: November. 28,

[10] Warwick, S.I., Beckie, H.J., Thomas, A.G. and McDonald, T. (2000) The biology of Canadian weeds. 8. *Sinapis arvensis*. L. Canadian Journal of Plant Science. 80, 939–61.

[11] Onofri, A. and Tei, F. (1994) Competitive ability and threshold levels of three broadleaf weed species in sunflower. Weed Research 34, 471–9.

[12] Mosavi, K., Rahimian, H. and Mahdi, N.M. (2004) Economic threshold of wild mustard (*Sinapis arvensis* L.) competition in winter wheat (*Triticum aestivum* L.). Applied Entomology and Phytopathology. 72, 113–28.

[13] Anafjeh, Z., Fathi, G., Alami-Said, K., Zand, E. and Choab, A. (2009) Response of canola (*Brasica napus* L.) to plant densities of mustard (*Sinapis arvensis* L.) with emphasis on agronomic control. Iranian Journal of Crop Sciences. 11, 109–22.

[14] Bilalis, D., Karkanis, A., Travlos, I., Antoniadis, A., Ntatsi, G., Bebeli, P. and Savvas, D. (2015) Wild mustard (*Sinapis arvensis* L.) and corn poppy (*Papaver rhoeas* L.) competition with four pea varieties cultivated following conventional or organic farming practices. Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca Horticulture. 72, 4–6.

[15] Farhoudi, R. and Lee, D.J. (2012) Evaluation of safflower (*Carthamus tinctorius* cv. Koseh) extract on germination and induction of cc-amylase activity of wild mustard (*Sinapis arvensis*) seeds. Seed Science and Technology. 40, 134–8.

[16] Mennan, H. (2003) Economic thresholds of *Sinapis arvensis* (Wild mustard) in winter wheat fields. Journal of Agronomy. 2, 34–9.

[17] Safahani Langeroudi, A.R. and Kamkar, B. (2009) Field screening of canola (*Brassica napus*) cultivars against wild mustard (*Sinapis arvensis*) using competition indices and some empirical yield loss models in Golestan Province, Iran. Crop Protection. 28, 577–82.

[18] Kraehmer, H., Laber, B., Rosinger, C. and Schulz, A. (2014) Herbicides as weed control agents: State of the Art: I. weed control research and safener technology: The path to modern agriculture. Plant Physiology 166, 1119–31.

[19] Abouziena, H.F. and Haggag, W.M. (2016) Weed control in clean agriculture: A review. Planta Daninha. 34, 377–92.

[20] Coble, H.D. and Mortensen, D.A. (1992) The threshold concept and its application to weed science. Weed Technology. 6, 191–5.

[21] Maxwell, B.D. and Luschei, E. (2008) The ecology of Crop-Weed Interactions: Towards a more complete model of weed communities in agroecosystems. Journal of Crop Improvement. 7528, 20–43.
[22] Thomas, A.G., Légère, A., Leeson, J.Y., Stevenson, F.C., Holm, F.A. and Gradin, B. (2011) Weed community response to contrasting integrated weed management systems for cool dryland annual crops. Weed Research. 51, 41–50.
[23] Cousens, R. (1985) An empirical model relating crop yield to weed and crop density and a statistical comparison with other models. The Journal of Agricultural Science. 105, 513–21.
[24] Başaran, B. and Kadioğlu, İ. (2016) Determination of the economic threshold level of wild mustard (*Sinapis arvensis* L.) in wheat fields of Tokat province. Turkish Journal of Weed Science. 19, 1–5.
[25] MGM. (2016) Climate of Turkey, according to Köppen Climate Classification. https://www.mgm.gov.tr. Last access: November. 28, 2020
[26] Lindquist, J.L. and Kropff, M.J. (1996) Applications of an ecophysiological model for irrigated rice (*Oryza sativa*)- Echinochloa competition. Weed Science. 44, 52–6.
[27] Öztürk, E., Özer, H. and Polat, T. (2008) Growth and yield of safflower genotypes grown under irrigated and non-irrigated conditions in a highland environment. Plant Soil and Environment. 54, 453–60.
[28] Jalali, A.H., Salehi, F. and Bahrani, M.J. (2012) Effects of different irrigation intervals and weed control on yield and yield components of safflower (*Carthamus tinctorius* L.). Archives of Agronomy and Soil Science. 58, 1261–9.
[29] Omidi, A.H., Khazaei, H., Monneveux, P. and Stoddard, F. (2012) Effect of cultivar and water regime on yield and yield components in safflower (*Carthamus tinctorius* L.). Turkish Journal of Field Crops. 17, 10–5.
[30] Belz, R.G. (2007) Allelopathy in crop/weed interactions an update. Pest Management Science. 63, 308–26.
[31] Blackshaw, R.E. (1993) Safflower (*Carthamus tinctorius*) density and row spacing effects on competition with green foxtail (*Setaria viridis*). Weed Science. 41, 403–8.
[32] Behdarvand, P., Chinchanikar, G.S., Dhumal, K.N. and Baghestani, M.A. (2013) Effects of wild mustard (*Sinapis arvensis* L.) and wild oat (*Avena ludoviciana* L.) densities on grain yield and yield components of wheat in response to various levels of nitrogen. Advances in Environmental Biology. 7, 1082–7.
[33] Wall, D.A., Friesen, G.H. and Bhati, T.K. (1991) Wild mustard interference in traditional and semi-leafless field peas. Can J. Plant Sci. 71, 473–80.
[34] Friesen, G.H. and Wall, D.A. (1991) Control of *Sinapis arvensis* in safflower with post-emergence herbicides. Crop Protection. 10, 74–7.
[35] West, A.M., Richardson, R.J., Arellano, C. and Burton, M.G. (2010) Bushkiller (*Cayratia japonica*) growth in interspecific and intraspecific competition. Weed Science. 58, 195–8.
[36] Wall, D.A. (1993) Wild mustard (*Sinapis arvensis* L .) competition with navy beans bean. Canadian Journal of Plant Science. 73, 1309–13.
[37] Trezzi, M.M., Vidal, R.A., Patel, F., Miotto Jr, E., Debastiani, F., Balbinot Jr, A.A. and Mosguen, R. (2015) Impact of *Conyza bonariensis* density and establishment period on soyabean grain yield, yield components and economic threshold. Weed Research. 55, 34–41.
[38] Galon, L., Basso, F.J.M., Chechi, L., Pilla, T.P., Santin, C.O., Bagnara, M.A.M., Franceschetti, M.B., Castoldi C.T., Perin, G.F. and Forte, C.T. (2019) Weed interference period and economic threshold level of ryegrass in wheat. Bragantia. 78, 409–22.
[39] Budak, İ., Serim, A.T. and Asav, Ü. (2020) Determination of the efficacy of some herbicides on the weeds in safflower. Plant Protection Bulletin. 60, 81–7.

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