Int. J. Biosci. 2020

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 17, No. 1, p. 106-118, 2020

INNSPUB

RESEARCH PAPER OPEN ACCESS

Weed control in non-glyphosate resistant cotton with glyphosate using a hooded band sprayer

Ahmet Tansel Serim[1*], Ünal Asav[2], Süleyman Gürdal Türkseven[3], Bariş Özgür Koçtürk[4], Mehmet Demirci[5]

[1]*Bilecik Şeyh Edebali University, Faculty of Agriculture and Natural Science, Department of Plant Protection, Bilecik, Turkey*

[2]*Gaziosmanpaşa University, Faculty of Agriculture, Department of Plant Protection, Tokat, Turkey*

[3]*Ege University, Agricultural Faculty, Department of Plant Protection, İzmir, Turkey*

[4]*Directorate of Agricultural Equipment and Machinery Test Centre, Ankara, Turkey*

[5]*Agrobest Group, İzmir, Turkey*

Key words: Clethodim, cotton, hooded field sprayer, glyphosate, tepraloxydim, weed.

http://dx.doi.org/10.12692/ijb/17.1.106-118 Article published on July 17, 2020

Abstract

Conventional crop production systems are employed in cotton fields in Turkey, and weeds have a significant importance in this system because they cause severe yield and quality losses. Because there is no new wide spectrum herbicide in cotton, the researcher has been compelled to find new application techniques to use available herbicides. Glyphosate is one of the most effective herbicides available due to its broad spectrum, ability to reduce the demand for soil herbicides, and potency in the production of genetically modified crops. The use of glyphosate to control broadleaf and grass weeds in non-genetically modified crops is only possible with a hooded field sprayer. This study was conducted across two sites in Aydın and İzmir, Turkey, in 2015 and 2016 to determine the efficacy and safety of the combined hooded field sprayer (CHFS) designed to simultaneously apply selective and total herbicides to different areas of cotton. Glyphosate was applied with clethodim at 1.44 + 0.145 and 1.44 + 0.116 kg ai ha^{-1}, respectively, or with tepraloxydim at 1.44 + 0.05 and 1.44 + 0.04 kg ai ha^{-1}, respectively, over between-row areas + intra row areas simultaneously using the CHFS. Clethodim at 0.145 kg ai ha^{-1} and tepraloxydim at 0.05 kg ai ha^{-1} were also applied using the third boom of the CHFS, conventional system. All the weeds in the experimental fields were perfectly controlled by CHFS, except purple nutsedge, which was controlled with glyphosate (62.5% to 88.75%), but not with clethodim or tepraloxydim (≤35%). Shikimate levels in the cotton leaves showed that the seedlings were exposed to the glyphosate at various rates, but these exposures did not cause any significant injury in cotton.

* **Corresponding Author:** Ahmet Tansel Serim ✉ a_serim@hotmail.com

Introduction

The cotton industry generates income and creates both direct and indirect employment opportunities in rural Turkey. In addition to basic production, it also includes 'added value' manufacturing processes, such as cotton ginning, and sells cotton fibre to the textile industry, cotton seed to the oil and fodder industries, cotton linter to the paper industry, and crude cotton oil to the energy industry. Globally, Turkey is ranked an impressive seventh out of the 45 cotton-producing countries, with an annual production of 871 million tonnes, and it is the fourth biggest importer, with an annual domestic consumption of 1.459 million tonnes (Statista, 2019; USDA, 2019).

Cotton growers operate in challenging environmental conditions that cause reduced yield and lower crop quality if not properly addressed. Weeds in the cotton fields not only adversely affect yield and lint quality, but they also hinder the cotton harvest (Doğan and Boz, 2004). In addition, the allelopathic effects of some weeds, such as bermudagrass [*Cynodon dactylon* (L.) Pers.] and johnsongrass [*Sorghum halepense* (L.) Pers.], on cotton plants negatively affect cotton seed germination and total fresh weight and inhibit root growth resulting in a reduced root length (Vasilakoglu *et al.*, 2005). Some weed species affect cotton yield more than others. For example, redroot pigweed (*Amaranthus retroflexus* L.), when present at a density range of 0.20–0.33 weed plants m^{-1}, reduces cotton seed yield to 50% of the maximum (Ma *et al.*, 2015). Common cocklebur (*Xanthium strumarium* L.) and johnsongrass are considered to place the greatest competitive pressure on cotton plants, causing an almost 31% loss in yield when present at a density of one common cocklebur plant per 2.1 m and a 70% yield reduction at 32 johnsongrass plants per 9.8 m (Bridges and Chandler, 1987). Agronomic treatments and weed control practices, especially herbicide usage, should be closely coordinated so that weeds are removed as they are sprouting, which is when cotton plants are the most vulnerable to weed competition, to minimize yield loss (Buchanan and Burns, 1970). Further, cotton should be weed free not only during the critical early growth stage but also at harvest time if clean cotton fibres are to be obtained (Wilcut *et al.*, 1970). Therefore, effective weed control using a broad-spectrum herbicide, such as glyphosate or glufosinate, potentially gives a higher crop yield and quality.

Weed control programs in cotton offer several options that include soil-applied herbicides and post-emergence herbicides in Turkey. Many selective pre- and post-herbicides are available to control grassy weeds in cotton; however, for broadleaf weeds, few pre-herbicides are available and there is only one post-herbicide, fluometuron SC (500 g L^{-1}), which has been registered in cotton after finished the study, in Turkey (PPP, 2019). Pala and Mennan (Pala and Mennan, 2018) reported that pendimethalin, fluometuron, benfluralin, and metolachlor-S + benoxacor were commonly used pre-sowing herbicides to control broadleaf weeds in Diyarbakır, Turkey, while clethodim, haloxyfop methylester, quizalofop-P-ethyl, tepraloxydim, tepraloxydim, fluazifop-P-butyl, and propaquizafop were preferred by growers to control narrow weeds at post-emergence, and cotton growers used pre-plant glyphosate was 41%. However, there is a need for wide spectrum post herbicides in cotton such as glyphosate, glufosinate and diquat, because broadleaves weeds controlled with fluometuron are far more limited than uncontrolled.

Glyphosate has been used to control annual and perennial weeds- in orchard fields, vineyard, non-agricultural fields for more than 40 years in USA and 30 years in Turkey (Benbrook, 2016; PPP, 2019). It is registered in the cotton fields for only pre-sowing or pre-emergence application when the weeds were 2-4 true leaf stage (PPP, 2019). The herbicide was launched in glyphosate-resistant cotton varieties in 1996 in the USA and spread to the other countries (Benbrook, 2016). It provides an effective solution to control annual and perennial weeds in cotton when it is applied as post-emergence (Doğan *et al.*, 2007), but glyphosate-resistant cotton varieties have not been registered in Turkey. Using glyphosate at post-emergence in conventional cotton with a traditional field sprayer, therefore, is not possible because these types of sprayers treat herbicide over the whole area (Hanks and Beck, 1998). To overcome this obstacle, hooded field sprayers are a good option when using glyphosate in conventional crop production (Dill *et al.*, 2008).

Band spraying is generally made with a sprayer contained a shield or hooded unit which has produced plastic or metal layers to protect sensitive crop from herbicide contact and limit herbicide spray in a specific area, generally between the rows. Limiting of the amount of field where has been applied with herbicide may alleviate not only adverse effects of herbicide on agricultural environmental (Hanks and Beck, 1998) but also increased public concerns about herbicide use (Ivany, 2002). This herbicide application technique has also reduced the amount of herbicide which has moved from the application site to undesired environments such as streams, rivers and canals (Oliver *et al.*, 2014) and given to control opportunity for farmers to weeds with unregistered herbicides (Serim *et al.*, 2017). Hooded sprayers have been used to protect the sensitive crop plant from the destructive effects of non-selective herbicide when it applied into the row middles (Dill *et al.*, 2008; Doğan *et al.*, 2007).

Hooded sprayers have been successfully used in many row crops, such as sugarcane (Griffin *et al.*, 2012), sugar beet (Carballido *et al.*, 2013), sunflower (Serim *et al.*, 2018), maize (Serim *et al.*, 2017), and cotton (Peterson, 2003) to control weeds in these crops. Griffin *et al*l (2012) has stated that bermudagrass control in sugarcane with glyphosate applied at 1.12, 2.24 and 3.36 kg ai ha^{-1} using a hooded sprayer was 68, 80 and 91% 42 DAT, and the suppressive effects of glyphosate on the weed continued even next year. Hooded field sprayers have also been reduced herbicide injury and drift risk applying herbicide to inter-row weeds (Foster *et al.*, 2018; Osuch *et al.*, 2020). Although it is generally considered that banding herbicide application with a hooded sprayer is more convenient to non-selective post herbicides, the studies indicated that this application technique is also pertinent to selective pre herbicides and post organic herbicides (Main *et al.*, 2013). Aside from its effectiveness as much broadcast herbicide application as (Main *et al.*, 2013), this technique is cost effective in terms of herbicide price because total herbicides are cheaper than selective herbicides (Carballido *et al.*, 2013).

In this study, we aimed to determine the efficacy and safety of the combined type hooded field sprayer designed for total and selective herbicides used at the same time to kill the weed species were not controlled by registered selective herbicides in Turkey.

Materials and methods

Study area

The field experiments were carried out in İzmir and Aydın provinces, Turkey, in 2015 and 2016. The soil type at İzmir was clay loam, with 1.32% organic matter and pH 7.95, and at Aydın, it was clay, with 1.39% organic matter and pH 8.11. Precipitation during the cotton-growing season in 2015 was 670 mm (14% higher than average) and 945 mm (5% higher than average) in İzmir and Aydın, respectively, while in the next year, rainfall for the season was 88% of average (Figure 1).

Experimental procedure and bio-efficacy evaluation

The experiments were established in a complete randomized block design with four replicates. Experimental plots consisted of five rows of cotton and were 3 × 10 m. Inter-row, a 55 cm band of each row, was sprayed by glyphosate while intra-row, a 15 cm band per row, was treated by clethodim or tepraloxydim. Alleys of 1 and 2 m were left between plots and blocks, respectively. Weed species and their densities at application time are presented in Table 1.

Control of individual weed species in all treatments was visually evaluated at 28 days after treatment (DAT) and at the harvest, using a rating scale of 0% to 100% (Anonymous, 2019), with 0% equal to no plant response and 100% equal to complete plant death. Herbicide application and evaluation times are presented in Table 2.

Analytical method

The visible cotton injury was also rated by grading 100 cotton plants in the middle rows of the plots in the experimental fields at 15 and 30 DAT. In addition, shikimic acid levels in cotton seedlings were measured 2 DAT to determine whether the crop plants were exposed to glyphosate, using the method of Henry *et al.* (2007) with some modifications. The leaf samples from the youngest leaves (approximately 0.03–0.04 mg) were collected and transported to the laboratory in a cooler. One millilitre of 0.25 N HCl was added to the vials containing the samples, which were stored in the freezer at −20 °C. Shikimate level in the sample was calculated using a calibration curve based on 0.01–1 µg of shikimate in 1 mL of HCl. The effect of herbicide treatments on cotton yield was determined at harvest time, and to avoid side effects, a 3-m section was randomly selected for evaluation from the middle two rows of each plot (Keeling *et al.*, 2011).

Sprayer design and herbicide application

A crop hooded sprayer designed for row applications was used in the experiments (Figure 2). It contained three sprayer booms in the following order: the first for controlling inter-row weeds, the second for eliminating intra-row weeds, and the third for conventional spraying (Serim *et al.*, 2018). The sprayer had two electrical sprayer pumps located under the tanks to deliver glyphosate and the selective herbicides tepraloxydim and clethodim. The hooded units (Figure 3) were mounted on the first boom parallel to each other, 700 mm apart to apply glyphosate (Figure 4). The tepraloxydim and clethodim were applied from the second boom through a 150-mm space between the hooded units (Figure 4). The even flat nozzles were placed on the hooded unit on the first and second booms, while the flat fun nozzles were held on the third boom. Spray pressure was 200 kPa in all trials, and spray volumes were 296.2 L ha^{-1} in 2015 and 285.6 L ha^{-1} in 2016. Commercial products of glyphosate isopropylamine salt (480 g L^{-1}), tepraloxadim (50 g L^{-1}), and clethodim (116.2 g L^{-1}) were used in the experiments at two- to four-leaf stages of cotton. Treatments consisted of glyphosate + tepraloxydim (1.44 kg ai ha^{-1} + 0.05 kg ai ha^{-1}), glyphosate + clethodim (1.44 kg ai ha^{-1} + 0.145 kg ai ha^{-1}), glyphosate + tepraloxydim (2.88 kg ai ha^{-1} + 0.05 kg ai ha^{-1}), glyphosate + clethodim (2.88 kg ai ha^{-1} + 0.145 kg ai ha^{-1}), tepraloxydim (0.05 kg ai ha^{-1}), and clethodim (0.145 g ai ha^{-1}). A weedy control was included in each year for comparisons of weed control efficacy.

Statistical analysis

Data for visual weed control, percent of control, were transformed by arcsine square root to normalize the variances within treatments before ANOVA. Data of weed control efficacy were pooled over location and year because there is no interaction between location, year and weed control efficacy whereas cotton lint yield and shikimic acid data were not combined over years and locations because of the significant interactions between them. However, non-transformed means are presented in Tables 4 and 5 for clarity. Means of individual treatments were separated with the use of Fisher's Protected LSD test using SPSS statistical software (SPSS, 2004).

Results and discussion

Crop injury and yield

Crop injury caused by tepraloxydim, clethodim, and glyphosate did not occur in 2015 or 2016. The shikimate levels of randomly selected seedling samples were determined as an indicator of glyphosate exposure (Table 3). Shikimate levels in the leaves showed that the cotton seedlings were exposed to the glyphosate at various rates (Tables 3 and 4), but they were not significantly injured.

The response of cotton seedlings to sub-lethal rates of glyphosate was augmentative contrary to expected adverse effects. Miller *et al.* (2009) found similar results in cotton plants, which tolerate glyphosate within a variable range, In that study, plant dry weight and height were generally unaffected by glyphosate rates below 70 g ha^{-1}. Further, seed cotton yield was not reduced when exposed to glyphosate at up to 140 g ha^{-1}; it even increased to a limited extent. Ellis and Griffin (2002) and Thomas *et al.* (2005)

similarly found that glyphosate applied at a rate lower than 70 g ha⁻¹ did not cause a detrimental effect on cotton seedling growth and yield and even slightly augmented the yield due to shikimate amount. This observation corroborates the results of Miller *et al.* (2009), who showed that glyphosate at rates below 140 g ai ha⁻¹ resulted in a higher amount of seed cotton yield.

Table 1. Density and coverage area of weed species in the experimental fields.

Location	Weed	Density (plant m⁻²)	Coverage (%)
İzmir 2015	Common cocklebur (*Xanthium strumarium* L.)	1.25	2
	Black nightshade (*Solanum nigrum* L.)	2	3
	Common purslane (*Portulaca oleracea* L.)	5	13
	Purple nutsedge (*Cyperus rotundus* L.)	5.5	1.5
	Redroot pigweed (*Amaranthus retroflexus* L.)	2	4
	Sorha (*Sorghum halepense* (L.) Pers.)	3	1.0
	Barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.)	5	1.25
	European heliotrope (*Heliotropium europaeum* L.)	1.5	2
	Dwarf spurge (*Euphorbia exigua* L.)	1	3
	Fat hen (*Chenopodium album* L.)	4	10
Aydın 2015	Purple nutsedge (*Cyperus rotundus* L.)	7	1.75
	Fat hen (*Chenopodium album* L.)	3	8
	Common purslane (*Portulaca oleraceae* L.)	6	11
	Purple nutsedge (*Cynodon dactylon* (L.) Pers)	3	0.8
	Sorha (*Sorghum halepense* (L.) Pers.)	3.5	1.2
	Barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.)	4.5	1.0
İzmir 2016	Black nightshade (*Solanum nigrum* L.)	7.5	13
	Common purslane (*Portulaca oleracea* L.)	3.5	7
	Purple nutsedge (*Cyperus rotundus* L.)	4	1.25
	Sorha (*Sorghum halepense* (L.) Pers.)	5	1.2
	Barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.)	2	5
	Dwarf spurge (*Euphorbia exiqua* L.)	0.5	0.2
	Fat hen (*Chenopodium album* L.)	2.5	4.5

Table 2. Herbicide treatment and harvest dates at experimental fields.

Site	Application	Date
İzmir-2015	Herbicide treatment	16.06.2015
	Harvest	03.10.2015
Aydın-2015	Herbicide treatment	18.06.2015
	Harvest	04.10.2015
İzmir-2016	Herbicide treatment	21.05.2016
	Harvest	22.10.2016

Yield loss caused by weeds was 48.87%–59.84% and 43.81%–50.76% depending upon the herbicides in 2015 and 2016 at İzmir, respectively (Table 3), and 43.88%-62.63% at Aydın.

The reduced rate of clethodim and tepraloxydim (80% of the recommended rates) with glyphosate provided a statistically similar amounts of yield compared to the recommended rates of them with glyphosate. Although glyphosate + clethodim and glyphosate + tepraloxydim treatments resulted in similar cotton yields in both years in İzmir, the yield loss in the first year was higher than in the second for the experimental fields in the first year, when weed coverage was higher. Another reason for the difference in yield losses between the 2 years was precipitation, with İzmir having more rainfall in the first year than in the second, especially at June. The cotton yield loss in Aydın, similar to İzmir in 2015, was noteworthy. Excessive rainfalls may trigger germination of annual weed seeds and increase yield losses. Cotton yield was lower in tepraloxydim and clethodim treatments that did not provide broadleaf weed and purple nutsedge control.

Table 3. The effect of glyphosate, glyphosate + selective herbicides, and selective herbicides applied on cotton at Aydın and İzmir in 2015 and 2016.

Treatment	Aydın-2015		İzmir-2015		İzmir-2016	
	SC	Yield	SC	Yield	SC	Yield
Glyphosate+Clethodim (1.44 + 0.145 kg ai ha⁻¹)	0.239	2765.3 A*	0.215	3106.3 A	0	2911.8 A
Glyphosate+Clethodim (1.44 + 0.116 kg ai ha⁻¹)	0.225	2692.8 A	0.084	2992.8 A	0.245	2970.3 A
Glyphosate + Tepraloxydim (1.44 + 0.05 kg ai ha⁻¹)	0.371	2662.0 A	0	2954.3 A	0.271	3071.8 A
Glyphosate + Tepraloxydim (1.44 + 0.04 kg ai ha⁻¹)	0.315	2556.5 A	0	2964.0 A	0.179	2984.3 A
Tepraloxydim (0.05 kg ai ha⁻¹)	0.493	1841.8 C	0.121	2440.0 C	0	2691.8 B
Clethodim (0.145 kg ai ha⁻¹)	0.110	2181.8 B	0	2626.0 B	0	2766.0 B
Control	0.239	1033.5 D	0.215	1247.5 D	0	1512.5 C

* Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD (P ≤ 0.05).

Broadleaves weed control

Predominant weeds in İzmir were common purslane and black nightshade in 2015 and 2016, respectively. Common purslane is a creeping weed and competes with cotton seedlings at early stages, while black nightshade is more competitive and its presence in the cotton fields has adverse effects not only on cotton yield but also lint quality.

Table 4. The effect of glyphosate, glyphosate + selective herbicides, and selective herbicides applied on broadleaves weeds at Aydın and İzmir in 2015 and 2016 (%) [a].

Treatment	CHEAL		POROL		SOLNI		EPHEX	
	IR	InR	IR	InR	IR	InR	IR	InR
Glyphosate+Clethodim (1.44 + 0.145 kg ai ha⁻¹)	95* A	-	100 A	-	97.50 A	-	96.38 A	-
Glyphosate+Clethodim (1.44 + 0.116 kg ai ha⁻¹)	96.25 A	-	100 A	-	98.75 A	-	95.00 A	-
Glyphosate + Tepraloxydim (1.44 + 0.05 kg ai ha⁻¹)	95 A	-	100 A	-	96.25 A	-	93.13 A	-
Glyphosate + Tepraloxydim (1.44 + 0.04 kg ai ha⁻¹)	100 A	-	100 A	-	100.00 A	-	96.88 A	-
Tepraloxydim (0.05 kg ai ha⁻¹)	-	-	-	-	-	-	-	-
Clethodim (0.145 kg ai ha⁻¹)	-	-	-	-	-	-	-	-

[a] Data pooled across locations and years; -, no efficacy; IR, inter row; InR, intra row; CHEAL, *Chenopodium album*; POROL, *Portulaca oleracea*; SOLNI, *Solanum nigrum*; EPHEX, *Euphorbia exiqua*.

*Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD (P ≤ 0.05).

The recommended rate of glyphosate applied within rows could efficiently control not only these weeds but also others, especially dwarf spurge and fat hen. Injury of black nightshade from glyphosate at 1.44 kg ai ha^{-1} ranged from 96.25 to 100% whereas common purslane control with the same rate of glyphosate was 100%. Glyphosate at 1.44 kg ai ha^{-1} controlled dwarf spurge and fat hen at least 93.13% and 95%, respectively. Fennimore and Umeda (2003) and Umeda and Hicks (2001) applied glyphosate at 1.12 and 1.2 kg ai ha^{-1}, respectively, to control common purslane at post-emergence and found that it provided nearly complete control. Many researchers have investigated the response of black nightshade to glyphosate and reported high rates. Even at half of the recommended rates (e.g., 450 g ai ha^{-1}), glyphosate controlled the weed as effectively as at the recommended rate (34). These results on the efficacy of glyphosate against black nightshade within cotton rows accord with our results (Table 4).

Table 5. The effect of glyphosate, glyphosate + selective herbicides, and selective herbicides applied on narrow-leaf weeds at Aydın and İzmir in 2015 and 2016 (%) [a].

Treatment	CYPRO		ECHCG		SORHA	
	IR	InR	IR	InR	IR	InR
Glyphosate+Clethodim (1.44 + 0.145 kg ai ha^{-1})	78.25 A*	26.50	94.58 A	95.00 A	95.00 A	95.17 A
Glyphosate+Clethodim (1.44 + 0.116 kg ai ha^{-1})	77.50 A	21.92	93.75 A	94.17 A	97.00 A	93.75 A
Glyphosate +Tepraloxydim (1.44 + 0.05 kg ai ha^{-1})	78.33 A	25.67	94.58 A	95.00 A	94.92 A	95.83 A
Glyphosate + Tepraloxydim (1.44 + 0.04 kg ai ha^{-1})	80.83 A	27.25	94.38 A	98.13 A	95.42 A	97.25 A
Clethodim (0.145 kg ai ha^{-1})	25.00 B	23.67	96.88 A	87.50 B	96.00 A	93.92 A
Tepraloxydim (0.05 kg ai ha^{-1})	28.58 B	27.50	96.88 A	96.33 A	88.92 B	90.75 A

[a] Data pooled across locations and years; -, no efficacy; LSD, least significant difference ($P < 0.05$); IR, inter row; InR, intra row; CYPRO, *Cyperus rotundus* L.; ECHCG, *Echinochloa crus-galli* (L.) P. Beauv.; SORHA, *Sorghum halepense* (L.) Pers..

*Means followed by the same letter within a column are not significantly different according to Fisher's Protected LSD ($P \leq 0.05$).

Fat hen was another glyphosate-sensitive weed in the current study, and previous reports indicated that it could be controlled by glyphosate at various rates, such as 1440 g ai ha^{-1}, 840 g ai ha^{-1} at the four-leaf stage, and 280.25 g ai ha^{-1} in various environments (Serim *et al.*, 2018; Umeda *et al.*, 2001; Hoss *et al.*, 2003). The response of fat hen to glyphosate is closely related to the herbicide rate, application volume, and application time (Hoss *et al.*, 2003; Krausz *et al.*, 1996). Fat hen was at the two- to four leaf stage when the herbicides were applied in the fields. The results were parallel to the findings of Krausz *et al.* (1996) and Schuster *et al.* (2007). Similar to other weeds, dwarf spurge was also susceptible to post-emergence glyphosate applied intra-row with the HBS (Table 4).

Grass weed control

In both 2015 and 2016, barnyardgrass and johnsongrass were perfectly controlled by glyphosate + clethodim and glyphosate + tepraloxydim even at lower rates of clethodim and tepraloxydim with glyphosate (Table 5).

There was no difference between inter-row barnyardgrass control with glyphosate 1.44 kg ai ha^{-1} (≥ 93.75%) and with clethodim 0.145 kg ai ha^{-1} (≥ 96.88%) or tepraloxydim at 0.05 kg ai ha^{-1} (≥ 96.88%). Good intra-row barnyardgrass control (≥ 87.50%) was obtained with reduced tepraloxydim and clethodim rates, 80% of labelled rate. Clethodim at 0.116 and 0.145 kg ai ha^{-1}, and tepraloxydim at 0.04

and 0.05 kg ai ha⁻¹ controlled intra-row johnsongrass 93.75 and 95.17, and 97.25 and 95.83%, respectively. Efficacy of tepraloxydim at 0.05 kg ai ha⁻¹ to inter-row johnsongrass and clethodim at 0.145 kg ai ha⁻¹ to intra-row barnyardgrass in Aydın in 2015 were lower than the other locations and years.

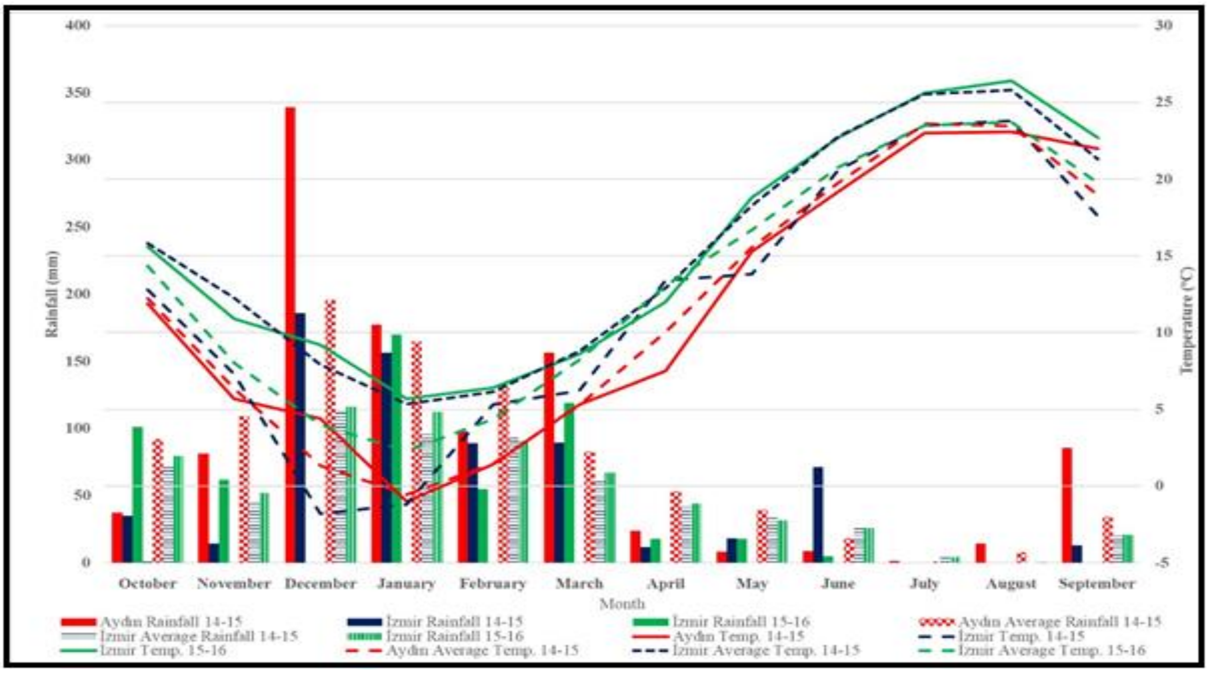

Fig. 1. Meteorological data of experimental fields in 2015 and 2016.

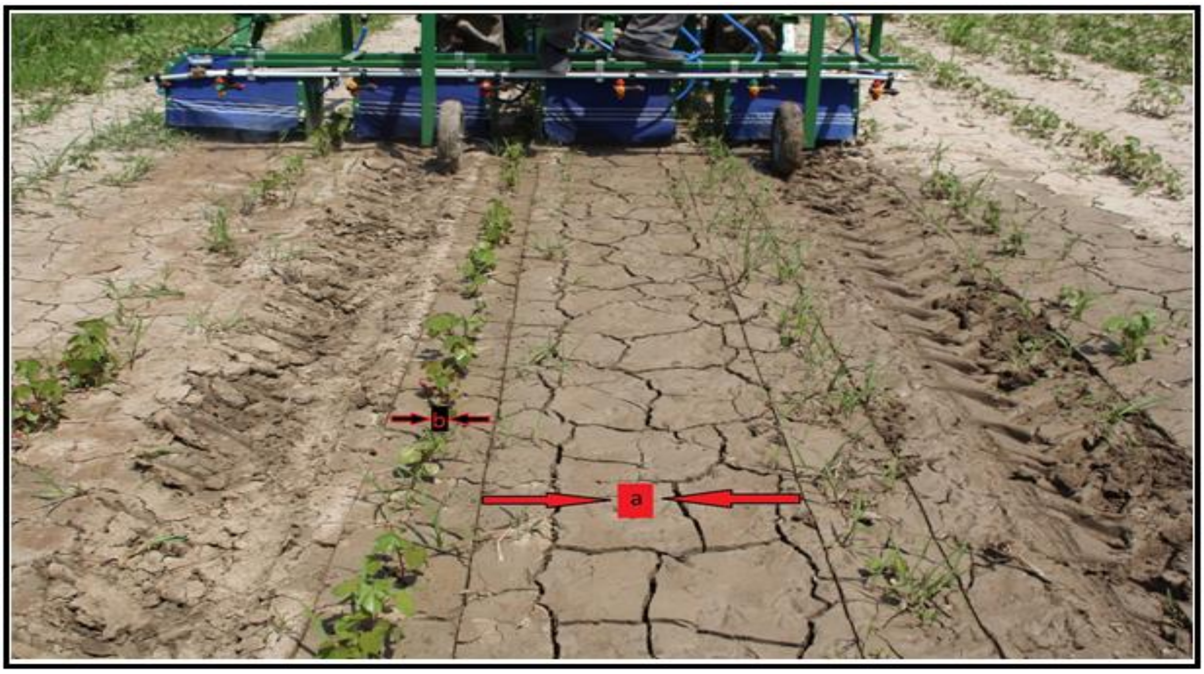

Fig. 2. Prototype of CHFS to simultaneously apply selective and total herbicides to different areas of cotton (**a**) to spray glyphosate inter-row weeds (**b**) to spray clethodim/tepraloxydim intra-row weeds.

This unexpected result may have been caused by the location of the parcels, with the nearby field border being fairly covered by grass weeds. Glyphosate at 1.44 kg ai ha⁻¹ resulted in 94.92% or greater inter-row johnsongrass control. Johnsongrass control with post herbicides may strictly depend on application time and the specific herbicides. Johnson and Norsworthy (2014) observed that glyphosate at 0.84 kg ai ha⁻¹

controlled Johnsongrass more than 87% when it was applied at four different growth stages from 15 cm to 60 cm, while clethodim was more effective than others when it was applied at 30 cm. Furthermore, clethodim at half the recommended rate provided johnsongrass control that was equal to that of the full rate. These findings on clethodim efficiency when it is applied at a reduced rate coincide with those of Rosales-Robles *et al.* (1999). The results in 2015 and 2016 johnsongrass control intra-row with clethodim parallel reports by Johnson and Norsworthy (2014) and Rosales-Robles *et al.* (1999). Koger *et al.* (2005) reported that an early application of glyphosate was more effective than a late application for shoot reduction of barnyardgrass 3 weeks after treatment. Barnyardgrass was 10–15 cm in Aydın and İzmir when glyphosate was applied, and it was controlled by glyphosate as reported by Koger *et al.* (2005).

Fig. 3. Hooded unit of CHFS Prototype.

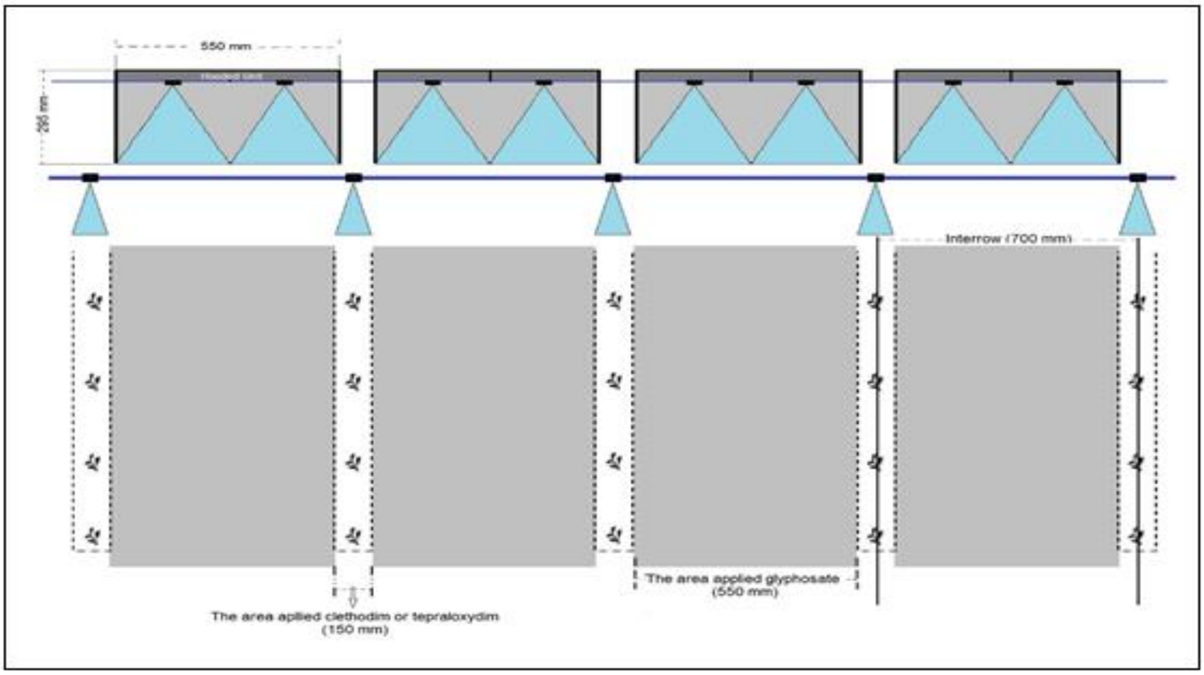

Fig. 4. Design of spraying locations in the experimental fields.

Purple nutsedge was moderately controlled (77.50 to 80.83%) by glyphosate applied inter-row; however, it was not suppressed by clethodim and tepraloxydim applied intra-row at the same period. Purple nutsedge control was less than 35% at 30 DAT when clethodim and tepraloxydim were applied, regardless of the rates. Many of herbicides, including glyphosate, have not been sufficient in purple nutsedge control because it is a perennial weed with numerous underground rhizomes and tubers.

The growth stage of the purple nutsedge at the application time has a notable effect on the ability of glyphosate to control the weed (Bariuan *et al.*, 1999), and this effect was clear in the results obtained in Aydın. Purple nutsedge control in intra-rows fell from 80.6% in 2015 to 71.44% in 2016 because the growing season in 2016 was drier than the previous one. Other reports have indicated that environmental factors such as high moisture stress and low humidity may reduce the efficacy of glyphosate on purple nutsedge (Thomas *et al*, 2005).

Conclusions

Overall, this study confirmed that a hooded field sprayer can increase the weed control spectrum through the use of a total herbicide, such as glyphosate, in row crops, such as cotton. The hooded field sprayer allowed control of important broad- and narrow-leaf weeds without any injury to the crop at the early stages. Additionally, glyphosate application gives the possibility of suppressing troublesome weeds like purple nutsedge infestation in a certain extent in the next season (Etheredge *et al.*, 2010). Choosing HFS may provide extra advantages to farmers, such as a delay in herbicide resistance due to the herbicides having different modes of action, using various plant protection products at the same time if they inhibit the effect of the others, and application can be repeated as necessary. Another advantage of CHFS is the ability to reduce herbicide spray drift. Herbicide drift during application is closely associated with the nozzle height (Nordby and Skuterud, 1975), and having the nozzle level closer to the ground may decrease potential herbicide risks. CHFS has two sprayer units; the first boom has a hooded unit that covers the spray area and prevents drift, and the second boom consists of even flat nozzles at 15- to 20-cm height.

Acknowledgements

This research was financially supported in part by The Scientific and Technological Research Council of Turkey, Project number: 114O709.

References

Anonymous. 2019. Standard herbicide test methods for weeds. [Accessed December 14, 2019]. https://www.tarimorman.gov.tr/TAGEM/Belgeler/yayin/Yabanc%C4%B1%20Ot%20Standart%20%C4%B0la%C3%A7%20Deneme%20Metotlar%C4%B1.pdf.

Bariuan JV, Reddy KN, Wills GD. 1999. Glyphosate injury, rainfastness, absorption, and translocation in purple nutsedge (*Cyperus rotundus*). Weed Technology **13,** 112-119. https://doi:10.1017/S0890037X00045000

Benbrook CM. 2016. Trends in glyphosate herbicide use in the United States and globally. Environmental Sciences Europe **28,** 3. https://doi:10.1186/s12302-016-0070-0

Bridges DC, Chandler JM. 1987. Influence of johnsongrass (*Sorghum halepense*) density and period of competition on cotton yield. Weed Science **35,** 63-67. https://doi:10.1017/S0043174500026795

Buchanan GA, Burns ER. 1970. Influence of weed competition on cotton. Weed Science **18**, 149-154.

Carballido J, Rodríguez-Lizana A, Agüera J, Pérez-Ruiz M. 2013. Field sprayer for inter- and intra-row weed control: Performance and labor savings. Spanish Journal of Agricultural Research **11,** 642-651. https://doi:10.5424/sjar/2013113-3812

Dill GM, Cajacob CA, Padgette SR. 2008.

Glyphosate-resistant crops: adoption, use and future considerations. Pest Management and Science **64,** 326–331.

Doğan MN, Boz Ö. 2004. The concept of reduced herbicide rates for the control of johnsongrass (*Sorghum halepense* (L.) Pers.) in cotton during the critical period for weed control. Journal of Plant Diseases and Protection **112,** 71-79.

Doğan MN, Boz OO, Unay A. 2008. The effect of glyphosate on weeds in cotton - Importance of glyphosate resistance under field conditions in Turkey. Journal of Plant Diseases and Protection **21,** 45-50.

Ellis J, Griffin J. 2002. Soybean (*Glycine max*) and cotton (*Gossypium hirsutum*) response to simulated drift of glyphosate and glufosinate. Weed Technology **16,** 580-586. https://doi:10.1614/0890-037X(2002)016[0580:SGMACG]2.0.CO;2

Etheredge LMJr, Griffin JL, Boudreaux JM. 2010. Nutsedge (*Cyperus* spp.) control programs in sugarcane. Journal of the American Society of Sugarcane Technology **30**, 67-80.

Fennimore SA, Umeda K. 2003. Weed control in glyphosate-tolerant lettuce (*Lactuca sativa*). Weed Technology **17**, 738-746. https://doi:10.1614/wt02-141

Foster HC, Sperry BP, Reynolds DB, Kruger GR, Claussen S. 2018. Reducing herbicide particle drift: Effect of hooded sprayer and spray quality. Weed Technology **32**, 1-8. https://doi:10.1017/wet.2018.84

Griffin JL, Clay PA, Miller DK, Grymes CF, Hanks JE. 2012. Bermudagrass control in sugarcane with glyphosate and a hooded sprayer. Journal American Society of Sugar Cane Technologists **32,** 38-50.

Hanks J, Beck J. 1998. Sensor-controlled hooded sprayer for row crops. Weed Technology **12**, 308-314. https://doi:10.1017/S0890037X00043864

Henry WB, Shaner DL, West MS. 2007. Shikimate accumulation in sunflower, wheat, and proso millet after glyphosate application. Weed Science **55**, 1-5. https://doi:10.1614/WS-06-065.1

Hoss N, Al-Khatib K, Peterson D, Loughin T. 2003. Efficacy of glyphosate, glufosinate, and imazethapyr on selected weed species. Weed Science **51,** 110-117. https://doi:10.1614/0043-1745(2003)051[0110:EOGGAI]2.0.CO;2

Ivany JA. 2002. Banded herbicides and cultivation for weed control in potatoes (*Solanum tuberosum* L.). Canadian Journal of Plant Science **82**, 617-620.

Johnson DB, Norsworthy JK. 2014. Johnsongrass (*Sorghum halepense*) management as influenced by herbicide selection and application timing. Weed Technology **28,** 142-150. https://doi:10.1614/WT-D-13-00100.1

Keeling JW, Verett KS, Ree JD, Dotray PA. 2011. Cotton (*Gossypium hirsutum*) tolerance to propazine applied pre and post emergence. Weed Technology **25**, 178-182. https://doi:10.1614/WT-D-10-00110.1

Koger CH, Price AJ, Reddy KN. 2005. Weed control and cotton response to combinations of glyphosate and trifloxysulfuron. Weed Technology **19**, 113-121. https://doi:10.1614/WT-03-273R

Krausz RF, Kapusta G, Matthews JI. 1996. Control of annual weeds with glyphosate. Weed Technology **10**, 957-962.

Ma X, Wu H, Jiang W, Ma Y, Ma Y. 2015. Interference between redroot pigweed (*Amaranthus* *retroflexus* L.) and cotton (*Gossypium hirsutum* L.): Growth analysis. PloS One **10**, e0130475. https://doi:10.1371/journal.pone.0130475

Main DC, Sanderson KR, Fillmore SAE, Ivany JA. 2013. Comparison of synthetic and organic herbicides applied banded for weed control in carrots (*Daucus carota* L.). Canadian Journal of Plant Science **93,** 857-861. https://doi.org/10.4141/cjps2013-052

Miller DK, Downer RG, Leonard BR, Holman EM, Kelly ST. 2009. Response of nonglyphosate-resistant cotton to reduced rates of glyphosate. Weed Science **52,** 178-182. https://doi:10.1614/P2002-089

Nordby A, Skuterud R. 1975. The effects of boom height, working pressure and wind speed on spray drift. Weed Research **14**, 385-395. https://doi:10.1111/j.1365-3180.1974.tb01080.x

Oliver DP, Anderson JS, Davis A, Lewis S, Brodie J, Kookana R. 2014. Banded applications are highly effective in minimising herbicide migration from furrow-irrigated sugar cane. Science of the Total Environment **466-467**, 841-848. https://doi.org/10.1016/j.scitotenv.2013.07.117

Osuch A, Przygodziński P, Rybacki P, Osuch E, Kowalik I, Piechnik L, Przygodziński A, Herkowiak M. 2020. Analysis of the effectiveness of shielded band spraying in weed control in field crops. Agronomy Journal **10,** 475. https://doi.org/10.3390/agronomy10040475

Pala F, Mennan H. 2018. Current state of weed management and problematic weeds in cotton fields of Diyarbakir. Ege Üniversitesi Ziraat Fakültesi Dergisi **55**, 111-117 (in Turkish with an abstract in English). https://doi: 10.20289/zfdergi.330081

Peterson DA. 2003. Evaluation of weed control and economic benefit of a light-activated sprayer in cotton. PhD thesis, Texas Tech University, USA, p. 21-54.

PPPT. 2019. Plant Protection Products in Turkey. [Accessed December 14, 2019]. https://bku.tarim.gov.tr/

Rosales-Robles E, Chandler JM, Senseman SA, Prostko EP. 1999. Integrated johnsongrass management in cotton with reduced rates of clethodim and cultivation. The Journal of Cotton Science **3,** 27-34.

Schuster CL, Shoup DE, Al-Khatib K. 2007. Response of common lambsquarters (*Chenopodium album*) to glyphosate as affected by growth stage. Weed Science **55,** 147-151. https://doi:10.1614/WS-06-130.1

Serim AT, Dursun E, Kocturk BO, Asav U. 2016. Weed control in maize fields using banded herbicide application. VII International Scientific Agriculture Symposium. Book of Abstracts p 690.

Serim AT, Asav Ü, Türkseven SG, Dursun E. 2018. Banded herbicide application in a conventional sunflower production system. Turkish Journal of Agriculture and Forestry **42,** 354-363. https://doi:10.3906/tar-1712-95

Sikkema PH, Shropshire C, Hamill AS, Weaver SE, Cavers PB. 2004. Response of common lambsquarters (*Chenopodium album*) to glyphosate application timing and rate in glyphosate-resistant corn. Weed Technology **18,** 908-916. https://doi:10.1614/WT-03-061R1

SPSS. 2004. SPSS for Windows. SPSS Inc., Chicago, Illinois, USA.

Statista. 2019. Cotton production by country worldwide. [Accessed December 14, 2019]. https://www.statista.com/statistics/2630.55/cotton-production-worldwide-by-top-countries/

Thomas W, Burke I, Robinson B, Pline-Srnić W, Edmisten KL, Wells R, Wilcut JW. 2005. Yield and physiological response of nontransgenic cotton to simulated glyphosate drift. Weed Technology **19,** 35-42. https://doi:10.1614/WT-03-194R

Umeda K, Hicks TV. 2001. Timing of glyphosate application for weed control in glyphosate tolerant lettuce. Vegetable Report. [Accessed December 14, 2019]. https://repository.arizona.edu/bitstream/handle/10150/214925/az1252-5h2001.pdf?sequence=1&isAllowed=y.

USDA. 2019. Cotton: World Markets and Trade. [Accessed December 14, 2019] https://apps.fas.usda.gov/psdonline/circulars/cotton.pdf.

Vasilakoglou I, Dhima K, Eleftherohorinos I. 2005. Allelopathic potential of bermudagrass and johnsongrass and their interference with cotton and corn. Agronomy Journal **97**, 303-313. https://doi:10.2134/agronj2005.0303

Wilcut JW, York AC, Jordan DL. 1995. Weed management systems for oil seed crops. Cap. 10. In: Handbook of Weed Management Systems. ISBN: 0-8247-9547-4. Marcel Dekker, Inc. New York, USA.