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Effects of some control methods on Johnson grass and yield components in tomato fields

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Abstract: Johnson grass is one of the most dangerous and difficult to control weeds. The aim of this study was to determine the effect of different control methods on Johnson grass in tomato fields and to investigate the effect of these methods on the phenological stages and yield indicators of tomatoes. The study was carried out during the 2019 and 2020 seasons. The experiment treatments were as follows: hand hoe, mulch, preemergence herbicide pendimethalin (5 L/ha), postemergence herbicide fluazifop-P-butyl (1 L/ha), and control parcels. The number of flowers, the number of branches, and the length of the plant were determined in tomato. The yield and characteristics of the fruit were calculated and the fruits were analyzed. For Johnson grass, the time for germination, flowering, and seed maturity were determined. Plant height, fresh and dry biomass weight of weed, and rhizomes were also calculated. The results of this experiment showed that the best yield was 64.943 kg/ha in the hand hoe and the fluazifop-P-butyl treatment. The lowest density and fresh biomass of Johnson grass were detected in the fluazifop-P-butyl (217.3 stem/m^2, 1009.4 g/m^2) and the mulch (251.7 stem/m^2, 1355.2 g/m^2) treatments, respectively. The highest density and fresh biomass were detected in control parcels (448.8 stem/m^2, 3239.2 g/m^2), and in the pendimethalin treatment (334.2 stem/m^2, 1956.4 g/m^2), respectively. The percentage of lost yield in the control parcels was 90.1%. Hand hoe was found to be the most effective control method against Johnson grass followed by fluazifop-P-butyl, mulch, and pendimethalin.

Key words: Johnson grass, tomato, control methods, phenological stages, loss of yield

1. Introduction

Johnson grass [*Sorghum halepense* (L.) Pers.] is a perennial weed that belongs to the family Poaceae, it is common in subtropical climates and causes problems in many cultivated plants (Grace et al., 2001). It can germinate from seed or rhizome. The seed can germinate within a year and remain viable for 6 years (Ceseski et al., 2017), but the germination rate of its seed is low; it can be as high as 3.3%. This percentage increases due to the influence of biotic and abiotic environmental conditions according to its effectiveness in removing the seed coat, which is the cause of dormancy (Al Sakran et al., 2020). Johnson grass can form a new rhizome approximately 1 month after the 5–6 leaf stage (Ceseski et al., 2017).

Johnson grass is ranked 6th in the world for importance and a problem for 50 different cultivated plants. It spreads over an area of millions of hectares worldwide (Peerzada et al., 2017). It has many features that contribute to its expansion. This species produces thousands of live, self-fertilizing seeds (Clements and DiTommaso, 2012). It has been reported that it causes heavy yield losses in economically important crops such as soybeans [*Glycine max* (L.) Meri.], maize (*Zea mays* L.), cotton (*Gossypium barbadense* L.), vegetables, and fruits (Uremis et al., 2009). The heavy competition resulted in yield losses of 70% in cotton, 88%–100% in corn, 69% in sugarcane, and 59%–88% in soybeans (Barroso et al., 2016). It was one of the weeds identified in the cotton growing areas in Kahramanmaraş Province and the plant density was determined as 2.65 plants/m^2 (Tursun et al., 2004). In a study conducted in the Marmara Region, it was determined that the density varied between 13.40 and 30.12 plants/m^2, and the frequency of occurrence varied between 34.20% and 100% (Yazlık, 2014). In Diyarbakir Province, the density of Johnson grass was 4.06 plants/m^2 and the frequency of occurrence was determined as 58% in tomato areas (Özaslan and Kendal, 2014). Because Johnson grass is a strong competitor to other weeds and due to its large biomass, it is used as a

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genetic source for the development of *Sorghum bicolor* (L.) Moen. cultivation (Habyarimana et al., 2020).

The purpose of mechanical control is to remove weeds from the soil and to collect the rhizomes which expose them to drought. This process can be done by hand hoeing or tilling the soil. In addition, by repeatedly cutting the weeds, the nutrients present in the rhizome can be consumed (Ceseski et al., 2017).

The primary aim of using black plastic mulch is to control the growth of weeds in cultivated fields. Black plastic mulch is an important control method that prevents germination by blocking the light or reducing the oxygen. Moreover, it helps achieve high yield and high quality in vegetable production (Ngouajio and McGiffen, 2004; Lamont, 2005). Germinated weeds cannot penetrate the thick layer of this mulch. Black plastic mulch was found to be very effective against most annual weeds and some perennial weeds such as *Cynodon dactylon* (L.) Pers. and *S. halepense* (Chhokar et al., 2009). However, in some cases, it may not be effective on its own especially when it comes to weeds with rhizomes (Bangarwa et al., 2012). In the plum orchard, many grass (narrow-leaved) perennial weeds such as Johnson grass, purple nutsedge, and Bermuda grass were common. To control weeds' preemergence, herbicides diuron at 2.4 kg/ha, postemergence herbicide glyphosate at 1.6 L/ha, black polythene cover (mulch) 400 μm thickness, and monthly manual weeding were applied. Mulch was the most effective in suppressing the weeds and improved the fruit quality and yield (Kaur and Kaundal, 2009).

Pendimethalin can be used as a preplanting herbicide in areas with high weed density (Clarke et al., 2009). Pendimethalin is one of the dinitroaniline herbicide groups. It prohibits plant cell growth by inhibiting spindle formation during cell division (Devine et al., 1993). It is used to control grass and small-seeded broadleaf weeds (Byrd and York, 1987). Pendimethalin provides approximately 50% Johnson grass control 4 weeks after treatment (Langemeier and Witt, 1986). Pendimethalin prevents the germination of the seeds, but the rhizomes are not affected by this herbicide (Kumar and Tewari, 2004).

Postemergence herbicides are most effective against the rhizomes when used after flowering when the rhizomes are growing strongly. Fluazifop-P-butyl is a lipid biosynthesis inhibitor that blocks the synthesis of lipids needed for the growth and maintenance of cell membranes (Tu et al., 2001). In greenhouse tomato seedlings, Johnson grass was controlled by fluazifop-P-butyl approximately 100%. In the tomato field, it was quite effective when applied at the period when Johnson grass was 15–20 cm tall (Tepe, 1992). Ceseski et al. (2017) mentioned that the most effective control can be obtained when plants are between 18 and 40 cm tall, but applications can be repeated.

In some cases, Johnson grass can resist ACCase herbicides. Five ACCase-resistant biotypes of Johnson grass that differ significantly in their resistance pattern to ACCase herbicides have been reported. Some Johnson grass biotypes were found to be highly resistant to fluazifob-P-butyl (Smeda et al., 1997). Johnson grass's resistance to ACCase inhibitors can be controlled with other selective and non-selective herbicides with different modes of action (Smeda et al., 1997; Wilcut et al., 1999).

The aim of this study was to evaluate the effect of different control methods on the length of the life cycle stages, density, and biomass of Johnson grass, and to investigate the effect of these methods on the quantitative and qualitative indicators of tomato yield during the 2-year period of the study.

2. Materials and methods

2.1. Materials

2.1.1. The trial site and climatic characteristic

The experiment was carried out at the Faculty of Agriculture, Kahramanmaraş Sütçü İmam University, Turkey (37°35′37.3″ N 36°48′53.0″ E) in the two tomato cultivation seasons 2019–2020. Table 1 shows some climatic data for the experiment area during the 2019 and 2020 growing seasons obtained from the Kahramanmaraş Meteorology Station.

2.1.2. The tomato variety and the applications used in the trial

In this experiment, the tomato variety used was F1 Aegean pink. Tomato seedlings were planted for the first season on 10 June 2019, while for the second season they were planted on 7 May 2020. Tomatoes were planted with dimensions of 0.6 × 0.4 m. The trial field was already infested with Johnson grass, so there was no need to conduct infection.

The used black plastic cover (mulch) was 100 microns thick and had UV additives. Pendimethalin (330 g/L) was used at a dose of 5 L/ha as a preemergence herbicide. As postemergence herbicide, fluazifop-P-butyl (150 g/L) was used at a dose of 1 L/ha. For the application of the herbicides, a 12-L back pump and a pressure of 0.2–0.4 Mpa with flat copper nozzle supply spray with 80° angle were used.

2.2. Methods

2.2.1. Experiment design

The experiment was designed as a completely random block design with three replicates (block). The treatments were control methods, hand hoe, black plastic cover (mulch), preemergence herbicide pendimethalin, postemergence herbicide fluazifop-P-butyl, and control parcels. Hand hoe was performed 5 times as follows: 1st) one week after planting tomato, 2nd) two weeks after the first time, 3rd)

Table 1. Some climatic data of Kahramanmaraş Province during the experiment months for the 2019 and 2020 seasons.

Months Years	Minimum temperature (°C)		Maximum temperature (°C)		Average temperature (°C)		Average relative humidity (%)		Total precipitation (mm)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
May	9.1	8.5	39.3	39.5	23.1	22.4	47.4	54.4	31	0.4
June	16.9	14.4	39.9	41	27.2	27.8	50	50.2	1	0
July	18.9	18.4	41.1	41.6	28.4	28.7	49.7	46.4	0	0
August	20.7	17.9	43.1	43.9	29.5	29.8	50.4	40.9	0.2	0
September	14.7	14.1	37.9	38.8	26.3	27.7	43.3	42.8	5.2	0
October	11.5	9.1	34.9	35.9	21.3	21.9	56.8	39.1	3.6	23
Average	15.3	13.7	39.4	40.1	26.0	26.4	49.6	45.6	6.8	3.9

Kahramanmaraş Meteorology Station.

two weeks after the second time, 4th) three weeks after the third time, and 5th) three weeks after the fourth time. The timing of the hand hoe depended on the emergence of Johnson grass seedlings. After preparing the land a day before planting the tomato, the mulch was applied. Also, pendimethalin was sprayed 3 days before planting tomato and then mixed with the soil at a depth of 5 cm (Zaroug et al., 2014). Fluazifop-P-butyl was used when the average length of Johnson grass was approximately 20 cm (Tepe, 1992; Ceseski et al., 2017). In the control parcels, all growing weeds except Johnson grass were removed.

2.2.2. The effect of treatments on the phenological characteristics of tomato

To determine the effect of the treatments on the growth and development of tomatoes, the number of flowers was counted from the beginning of flowering until the end of seasons from the same plants. The number of branches and length of the plant were calculated before the first harvest.

2.2.3. The effect of treatments on tomato phomological characteristics

In the stage of tomato maturity, the indicators of fruit and yield were calculated from the same plants during successive harvesting processes. The average weight, length, and width of fruit, and the number of fruits/m^2 of the treatments from all harvesting processes were calculated.

2.2.4. The effect of treatments on tomato yield

Tomato total yield from all harvesting processes was calculated for 1 m^2 for each treatment by taking yield from the same plants. The percentage of lost tomato yield was calculated based on the yield of the hand hoe treatment according to the following formula.

Percentage of lost tomato yield = $[1 - (YX / Y0)] \times 100$, where YX is yield in treatment X, and Y0 is the yield in the hand hoe treatment.

2.2.5. The effect of treatments on the nutrient content of tomato fruits

To determine the effect of the treatments on the nutrient content of the tomato fruits (glucose, fructose, total moisture determination, calcium, color depth determination, protein, fat, and potassium), samples were collected from replications of each treatment and then analyzed at the University–Industry–Public Cooperation Development, Application and Research Center.

2.2.6. The effect of treatments on length of the life cycle stages of Johnson grass

As for Johnson grass, the dates of germination, the beginning of flowering, the beginning of maturity of the seeds (when their color began to turn dark brown) were recorded and the time required for each stage from the day of planting of tomato were calculated.

2.2.7. The effect of treatments on density and biomass of Johnson grass

A wooden frame with dimensions of 1 × 1 m was used and from within the frame the number of stems, number of tillers, and fresh and dry weight were calculated.

Weed density was calculated via the Density = B/n formula (Güncan, 2001). Here B is the total weeds number in the sample, and n is the number of samples.

The average length of 30 stems was calculated randomly from each square meter. Plants obtained from 1 m^2 were dried in room conditions (25 ± 2 °C) for a month; after that, the dry weight was calculated. At the end of the experiment, 1 m^2 was drilled with a depth of 50 cm in each treatment. The rhizomes were extracted from the soil and washed, the fresh weight was calculated and then dried in room conditions for a month; after that, the dry weight was calculated.

2.2.8. Soil properties of the trial area

Soil samples were collected from 6 sites within the experiment. The surface layer was taken at a depth of 30 cm. The samples were collected, and stones and plant residues were removed. Next, 2 kg were weighed and sent to the laboratory for analysis. The results of soil analysis are shown in Table 2.

2.2.9. Statistical analysis

To determine if there was a statistically significant difference among the results for each treatment, variance analyses were carried out using SPSS 20. The differences between means were tested by the ANOVA and Duncan's test. Values of $p \leq 0.05$ were considered significantly different. Also, the t-test was performed to determine significant differences between the 2 years of study for each treatment.

3. Results

3.1. The effect of treatments on the phenological characteristics of tomato

The results showed differences in the growth and development of tomatoes with different treatments. The average number of flowers during seasons was 35.5 flowers/m^2 in the hand hoe treatment and 13.5 flowers/m^2 in the pendimethalin treatment in 2019 and 47.7 flowers/m^2 in the hand hoe treatment and 15.8 flowers/m^2 in pendimethalin treatment in 2020. The number of flowers in all treatments was higher in 2020 with significant differences than in 2019 treatments except for the control parcels (Table 3). The average number of branches per plant in 2019 was 4.8 branches/plant in the hand hoe treatment and 1.8 branches/plant in pendimethalin treatment, while the numbers of branches/plant in 2020 were 5.5 and 2.0 branches/plant for the hand hoe treatment and pendimethalin treatment, respectively. The significant differences between treatments and years are shown in Table 3.

The highest mean plant length was observed in both years at hand hoe and mulch, while the lowest was observed in pendimethalin treatment. It is noted from Table 3 that the growth and development of tomato in the hand hoe treatment were the best in both years, followed by the mulch and fluazifop-P-butyl treatments, then the pendimethalin treatment, and finally the control parcels.

3.2. The effect of treatments on tomato phomological characteristics

There was no significant difference between all studied fruit characteristics between years 2019 and 2020 for the

Table 2. Some soil characteristics of the experiment area.

Analyzed parameter	Analysis results
Saturation (%)	68.20
pH	7.04
Salt (%)	0.30
Lime (%)	9.88
Organic substances (%)	3.32
K (mg/kg)	213.30
P (mg/kg)	67.52

Table 3. The difference in morphological characteristics of tomatoes according to the treatments in 2019 and 2020.

Treatments Years	Number. of flowers (m^2)		Number of branches (per plant)		Plant height (cm)	
	2019	2020	2019	2020	2019	2020
Hand hoe	35.5^{a}_{1}	47.7^{a}_{2}	4.8^{a}_{1}	5.5^{a}_{2}	63.9^{a}_{1}	66.7^{a}_{1}
Mulch	25.3^{b}_{1}	30.1^{b}_{2}	3.6^{b}_{1}	3.8^{b}_{1}	54.5^{b}_{1}	55.3^{b}_{1}
Pendimethalin	13.5^{c}_{1}	15.8^{c}_{2}	1.8^{c}_{1}	2.0^{c}_{1}	39.8^{d}_{1}	40.0^{d}_{1}
Fluazifop-P-butyl	27.4^{b}_{1}	31.0^{b}_{2}	3.7^{b}_{1}	3.9^{b}_{1}	49.2^{c}_{1}	49.4^{c}_{1}
Control	8.1^{d}_{1}	9.7^{d}_{1}	1.5^{c}_{1}	1.8^{c}_{1}	34.9^{d}_{1}	35.2^{d}_{1}

Values followed by the same letter(s) in the same column and values followed by the same number in the same row are not significantly different from each other at 0.05 level of probability.

same treatments. While there were significant differences in the average weight of fruit between the treatments, the highest average was in the hand hoe treatment in both years, and the lowest average weight of the fruit was in pendimethalin treatment. No significant difference was observed in terms of the weight of the fruit between the mulch and fluazifop-P-butyl treatments in both years (Table 4).

The highest mean length and width of fruit was in the hand hoe treatment in 2020 and they were 73.7 mm and 50.2 mm, respectively. According to the results, the best characteristics of the fruit were obtained from the hand hoe treatment, followed by the mulch and fluazifop-P-butyl treatments, while the characteristics of the fruit in the pendimethalin and control parcels were the lowest (Table 4).

3.3. The effect of treatments on tomato yield

There were significant differences between the yield of treatments and years. The highest yield was in the hand hoe treatment, followed by the fluazifop-P-butyl and then the mulch treatment, and the lowest was in the pendimethalin treatment and the control parcels. There was no significant difference between the fluazifop-P-butyl and mulch treatments in both years of the study. The highest yield obtained was 64.943 kg/ha from the hand hoe treatment in 2020, while the lowest yield was 11810 kg/ha from pendimethalin treatment in 2019 (Table 5).

The yield loss percentage was calculated based on the hand hoe treatment and the largest loss percentage was 89.3%–90.1% in control parcels for 2019–2020. The lowest loss percentage was in the fluazifop-P-butyl treatment 35.5%–43.7% in 2019–2020, respectively (Table 5).

3.4. The effect of treatments on the nutrient content of fruits

In the control against Johnson grass in tomato cultivation, while the glucose, fructose, and potassium ratios were found to be slightly higher in the hand hoe treatment than in other treatments, the oil and total moisture ratios were found to be similar. On the other hand, tomato fruit color was found to be similar in the hand hoe and mulch treatments, while the coloration was lower in other treatments. Table 6 shows the contents of some nutrients in the fruits for the treatments and this analysis was conducted for the 2020 season.

Table 4. Average weight, length, and width of fruit in 2019 and 2020.

Treatments Years	Average weight of the fruit (g)		Average fruit length (mm)		Average fruit width (mm)	
	2019	2020	2019	2020	2019	2020
Hand hoe	164.6^{a}_{1}	166.2^{a}_{1}	73.4^{a}_{1}	73.7^{a}_{1}	50.0^{a}_{1}	50.2^{a}_{1}
Mulch	148.8^{b}_{1}	149.4^{b}_{1}	68.1^{b}_{1}	68.2^{b}_{1}	48.6^{ab}_{1}	48.6^{ab}_{1}
Pendimethalin	112.6^{c}_{1}	114.3^{c}_{1}	53.6^{c}_{1}	54.0^{c}_{1}	46.7^{c}_{1}	46.8^{c}_{1}
Fluazifop-P-butyl	146.2^{b}_{1}	146.8^{b}_{1}	67.8^{b}_{1}	67.9^{b}_{1}	47.9^{bc}_{1}	48.1^{bc}_{1}
Control	76.5^{d}_{1}	80.8^{d}_{1}	46.7^{d}_{1}	49.0^{d}_{1}	36.5^{d}_{1}	36.7^{d}_{1}

Values followed by the same letter(s) in the same column and values followed by the same number in the same row are not significantly different from each other at 0.05 level of probability.

Table 5. Number of fruits, yield, percentage loss, and increase of yield for treatments in 2019 and 2020.

Treatments Years	Yield (kg/ha)		Yield losses %		Total number of fruits (m^2)	
	2019	2020	2019	2020	2019	2020
Hand hoe	47771^{a}_{1}	64943^{a}_{2}	-	-	29.0^{a}_{1}	39.1^{a}_{2}
Mulch	30241^{b}_{1}	35978^{b}_{2}	36.7^{a}_{1}	44.6^{a}_{1}	20.4^{b}_{1}	24.1^{b}_{2}
Pendimethalin	11810^{c}_{1}	13703^{c}_{2}	75.3^{b}_{1}	78.9^{b}_{1}	10.5^{c}_{1}	12.1^{c}_{1}
Fluazifop-P-butyl	30805^{b}_{1}	36563^{b}_{2}	35.5^{a}_{1}	43.7^{a}_{1}	21.1^{b}_{1}	24.9^{b}_{2}
Control	5112^{d}_{1}	6429^{d}_{2}	89.3^{c}_{1}	90.1^{c}_{1}	6.7^{d}_{1}	8.0^{d}_{1}

Values followed by the same letter(s) in the same column and values followed by the same number in the same row are not significantly different from each other at 0.05 level of probability.

Table 6. The fruits content of some nutrients.

Nutrients Treatments	Hand hoe	Mulch	Pendimethalin	Fluazifop-P-butyl	Control
Glucose (%)	3.18	2.68	1.77	1.73	1.19
Fructose (%)	2.13	1.87	1.23	1.4	0.94
Color depth	L*=39.22 a*=33.76 b*=27.93	L*=40.17 a*=33.92 b*=28.11	L*=37.33 a*=32.53 b*=26.64	L*=37.54 a*=33.26 b*=27.51	L*=36.26 a*=31.18 b*=25.47
Protein (%)	5.21	5.13	4.83	4.61	4.03
Fat (%)	0.06	0.06	0.06	0.07	0.08
Potassium (mg/kg)	29760	28510	28820	28390	28220
Calcium (mg/kg)	622.6	723.5	784.8	653.2	884.9
Total moisture (%)	94.58	94.75	94.81	94.95	95.26

*=D65 was made with daylight and 10 degrees' perspective. The fruits' color was L (brightness; 100 white, 0 black), a (+ red; – green) and b (+ yellow; – blue) was measured on the cheek area (Kaymak et al., 2010).

3.5. The effect of treatments on length of the life cycle stages of Johnson grass

It was found that Johnson grass was able to reach the holes in the mulch, which are designated for tomato (Figures 1a and 1b). The distance that the plant can crawl to reach the holes is increased by 1 m below the mulch (Figure 1c).

The required times for germination in the hand hoe and fluazifop-P-butyl treatments and the control parcels were not significantly different. Initially, germination could not be observed under the mulch, but it was noted in the holes after 7.7 days in 2019 and 8.7 days in 2020. Germination was significantly delayed in pendimethalin treatment compared to the other treatments (Table 7). The hand hoe treatment was excluded because Johnson grass was not allowed to reach this stage. There was a significant difference between all the treatments in terms of the number of days from planting tomato to the flowering of Johnson grass. Johnson grass in mulch treatment reached the flowering stage after 22.3–23.0 days and after 61.0–63.7 days in the fluazifop-P-butyl treatment in 2019 and 2020, respectively (Table 7).

As shown in Table 7, the maturity of the seed was after 51.7 days from the date of planting in the mulch treatment in 2019 and 52.3 days in 2020, while this period extended to 82.3–84.7 days in the fluazifop-P-butyl treatment in 2019 and 2020, respectively. There was a significant difference between all treatments in terms of Johnson grass growth.

3.6. The effect of treatments on density and biomass of Johnson grass

Johnson grass density differed between the treatments, but there was no significant difference between the years of study. The highest density was in control parcels, then in the pendimethalin treatment where it was 426.7–448.8 and 316.6–334.2 stem/m^2 in 2019 and 2020, respectively. While the Johnson grass density was zero in the hand hoe treatment, it was calculated as 202.9–217.3 stem/m^2 in the fluazifop-P-butyl treatment in 2019 and 2020 (Table 8).

The highest average tillering count was in the mulch treatment (7.6 tillering per plant) and the lowest was in the fluazifop-P-butyl treatment (4.1 tillering per plant) in 2020. The highest average stem length was in control parcels (143.7 and 144.5 cm in 2019 and 2020, respectively), followed by pendimethalin (114.4 and 117.2 cm in 2019 and 2020 respectively), while the shortest stem length was observed in the fluazifop-P-butyl treatment with 90.6 cm in 2019 and 93.0 cm in 2020 (Table 8).

The weight of fresh and dry stems was highest in the control parcels (3152.8 and 625.1, 3239.2 and 661.1 g), followed by the pendimethalin (1792.0 and 367.2, 1956.4 and 384.6 g) and the mulch treatment (1312.4 and 263.0, 1355.2 and 271.6 g), and the lowest was observed in the fluazifop-P-butyl treatment (918.2 and 191.3, 1009.4 and 218.3 g) in 2019 and 2020, respectively (Table 9).

In this research, it was found that Johnson grass rhizomes reach a depth of more than 50 cm, but after 30 cm, the density decreased (Figure 2).

The highest fresh weight of rhizomes obtained from 1 m^2 was in the control parcels (2512.8 g/m^2), followed by the mulch treatment (2309.9 g/m^2). However, the lowest weight of fresh rhizomes was in the hand hoe treatment (125 g/m^2) followed by the fluazifop-P-butyl (1401.3 g/m^2) for 2019. Likewise, the highest dry weight of rhizomes was in the control parcels, while the lowest was in the hand hoe treatment.

Figure 1. a, b: Johnson grass exiting the holes in the black plastic cover, c: the distance of the crawl under the black plastic cover.

Table 7. Effect of treatments on germination and growth of Johnson grass.

Treatments Years	Days of germination		Days of flowering		Days of maturation of seeds	
	2019	2020	2019	2020	2019	2020
Hand hoe	3.7^{a}_{1}	4.3^{a}_{2}	-	-	-	-
Mulch	7.7^{b}_{1}	8.7^{b}_{2}	22.3^{a}_{1}	23.0^{a}_{1}	51.7^{a}_{1}	52.3^{a}_{1}
Pendimethalin	11.1^{c}_{1}	11.7^{c}_{2}	32.0^{c}_{1}	33.3^{c}_{1}	63.7^{c}_{1}	64.3^{c}_{1}
Fluazifop-P-butyl	3.7^{a}_{1}	4.3^{a}_{2}	61.0^{d}_{1}	63.7^{d}_{2}	82.3^{d}_{1}	84.7^{d}_{2}
Control	3.7^{a}_{1}	4.3^{a}_{2}	25.7^{b}_{1}	26.0^{b}_{1}	55.3^{b}_{1}	56.0^{b}_{1}

Values followed by the same letter(s) in the same column and values followed by the same number in the same row are not significantly different from each other at 0.05 level of probability.

Table 8. The number of Johnson grass stems, tillering count, and length of the stems in various treatments.

Treatments Years	Density (stems/m²)		Tillering count (per plant)		Length of the stems (cm)	
	2019	2020	2019	2020	2019	2020
Hand hoe	0.0	0.0	0.0	0.0	0.0	0.0
Mulch	248.1^{b}_{1}	251.7^{b}_{1}	7.5^{c}_{1}	7.6^{c}_{1}	105.9^{ab}_{1}	107.8^{b}_{1}
Pendimethalin	316.6^{c}_{1}	334.2^{c}_{1}	6.4^{b}_{1}	6.6^{b}_{1}	114.4^{b}_{1}	117.2^{b}_{1}
Fluazifop-P-butyl	202.9^{a}_{1}	217.3^{a}_{1}	4.0^{a}_{1}	4.1^{a}_{1}	90.6^{a}_{1}	93.0^{a}_{1}
Control	426.7^{d}_{1}	448.8^{d}_{1}	6.5^{b}_{1}	6.7^{b}_{1}	143.7^{c}_{1}	144.5^{c}_{1}

Values followed by the same letter(s) in the same column and values followed by the same number in the same row are not significantly different from each other at 0.05 level of probability.

Table 9. Johnson grass fresh and dry weights of rhizomes and stems in various treatments.

Treatments Years	Fresh weight of stems (g)		Dry weight of stems (g)		Fresh weight of rhizomes (g)		Dry weight of rhizomes (g)	
	2019	2020	2019	2020	2019	2020	2019	2020
Hand hoe	0.0	0.0	0.0	0.0	125.0^{a}_{1}	136.7^{a}_{1}	30.7^{a}_{1}	33.5^{a}_{1}
Mulch	1312.4^{b}_{1}	1355.2^{b}_{1}	263.0^{b}_{1}	271.6^{b}_{1}	2292.1^{c}_{1}	2309.9^{c}_{1}	562.2^{c}_{1}	576.6^{c}_{1}
Pendimethalin	1792.0^{c}_{1}	1956.4^{c}_{1}	367.2^{c}_{1}	384.6^{c}_{1}	2234.8^{c}_{1}	2259.6^{c}_{1}	548.2^{c}_{1}	564.2^{c}_{1}
Fluazifop-P-butyl	918.2^{a}_{1}	1009.4^{a}_{2}	191.3^{a}_{1}	218.3^{a}_{2}	1401.3^{b}_{1}	1446.7^{b}_{1}	343.6^{b}_{1}	358.9^{b}_{1}
Control	3152.8^{d}_{1}	3239.2^{d}_{2}	625.1^{d}_{1}	661.1^{d}_{2}	2502.2^{d}_{1}	2512.8^{d}_{1}	613.7^{d}_{1}	615.3^{d}_{1}

Values followed by the same letter(s) in the same column and values followed by the same number in the same row are not significantly different from each other at 0.05 level of probability.

Figure 2. Johnson grass rhizomes at a depth of 50 cm and distributed in soil layers.

4. Discussion

The results of this experiment showed that the best yield in terms of quantity and quality was obtained from the hand hoe treatment. However, this method is disadvantageous especially in the phase where the tomato closes the rows and large areas. The yield reached 64.943 kg/ha for this treatment for tomato variety F1 Aegean pink in 2020 and 47.771 kg/ha in 2019; the difference between the two seasons is due to the delay in planting in the 2019 season, which led to the shortening of the tomato growing season. Although Johnson grass was prevented from growing in this treatment, the rhizomes were not completely eliminated at the end of the season. These rhizomes, together with the seed bank in the soil, will form the starting point of the weed population the following season (Güncan, 2013). In low-density situations, Johnson grass can be controlled by hand hoe and can be used in the early stages, when the seedlings are 2-3 weeks old (Newman, 1993). At the same time, repeated mowing helps prevent seed formation, rhizome yield, and shoot regrowth, which ultimately reduces the viability of weed to be established again (Newman, 1993; Uva et al., 1997).

The results of the mulch and fluazifop-P-butyl treatments were similar in many ways. While these two treatments have similar effects in terms of tomato yield, the mulch treatment was found to be more effective in terms of tomato quality.

The Johnson grass life cycle in the mulch treatment was faster than those in other treatments. The life cycle of Johnson grass in the treatment of fluazifop-P-butyl was delayed because the herbicide eliminated the weed, but the weed started to grow again, reached a high density, and completed its life cycle before the end of the season. Although Johnson grass was not able to penetrate the mulch and it may be an effective control method, as Chhokar et al. (2009) explained, the plant was able to crawl under the mulch, reach and exit the holes designated for the cultivated plant to complete its life cycle and this corresponds to what was mentioned by Bangarwa et al. (2012). Fluazifop-P-butyl decreased the density of Johnson grass by 90% (Chifan et al., 2019); however, the plant began to germinate again and complete its life cycle. Contrary to the results of this experiment, Tepe (1992) found that fluazifop-P-butyl was highly effective when applied at the period when Johnson grass was 15–20 cm tall in the field conditions. Perhaps the reason is that the biotype spread in Kahramanmaraş Province has acquired resistance. Smeda et al. (1997) mentioned that five ACCase-resistant biotypes of Johnson grass differ significantly in their resistance pattern to ACCase herbicides. Some Johnson grass biotypes were found to be highly resistant to fluazifop-P-butyl. Also, seedlings grown from rhizomes were more resistant than those grown from seeds (Burke et al., 2006).

It was also noticed that the fresh and dry weights of the rhizomes in the treatment of the mulch were the highest after control. This may be due to high temperatures and humidity under the mulch; in addition, the rhizomes were observed on the soil surface under the mulch due to the lack of light. Although these two treatments gave the best results, the percentage of losses of yield was large, which was 44.6% for mulch and 43.7% for the fluazifop-P-butyl treatments. Therefore, one of these methods cannot be used alone in controlling Johnson grass.

Although pendimethalin delayed the germination of weed, it reached maturity with slight differences from the other treatments; therefore, this herbicide was not of great importance in the control of Johnson grass. Clarke et al. (2009) indicated that pendimethalin can be used in areas with a high density of weeds. Kumar and Tewari (2004) mentioned that pendimethalin reduces the density of Johnson grass by up to 43% due to preventing the germination of the seeds, but the rhizomes are not affected by this herbicide. The yield loss rates were 75.3% in 2019 and 78.9% in 2020, which are close to the loss in the control parcels as the percentage of loss in yield reached 90.1%.

From these results, it is clear that Johnson grass is a strong, difficult-to-control weed, although the 2019 season was almost a month shorter than the 2020 season, no significant differences in biomass were observed between the two seasons, meaning that the grass can grow and develop in a short time to compete with the cultivated plant. On the other hand, tomato yield was affected by the short season, as yield in 2019 was approximately one-third less than that of 2020. Thus, planting delay affects the yield of the cultivated plant and does not affect the life cycle length of Johnson grass.

5. Conclusion

The Johnson grass life cycle in the mulch treatment was the fastest, while it was delayed in the treatment of fluazifop-P-butyl. Hand hoe was found to be the most effective control method in reducing the Johnson grass density and biomass in tomato production. It reduced Johnson grass biomass and density by 100%. Therefore, the highest tomato yield was obtained from the hand hoe treatment, fluazifop-P-butyl was the second, mulch was the third, and pendimethalin was the fourth. If an effective control method is not applied against Johnson grass in tomato production, the yield loss can be 90%.

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