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# Johnsongrass (*Sorghum halepense* (L.) Pers.) Interference, Control and Recovery under Different Management Practices and its Effects on the Grain Yield and Quality of Maize Crop

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**Abstract:** Maize is an important crop grown on significant acreage around the world, and a major constraint for its growth is weed interference. Thus, field studies were conducted to examine johnsongrass interference, control, and recovery under different management practices and its effects on maize. Our results indicated that the most johnsongrass aboveground biomass was recorded in the nontreated and weed-infested for 55 days after sowing (DAS) treatments, while the lowest values were in nicosulfuron treatments (48 and 60 g a.i./ha). Among the various herbicide treatments, the greatest johnsongrass aboveground biomass was recorded in the isoxaflutole (applied pre-emergence at 99 g a.i./ha) + 1 hoeing treatment. Johnsongrass aboveground biomass at 78–85 DAS was 1.4- to 6.0-fold greater than that at 55 DAS, revealing johnsongrass recovery after nicosulfuron treatments. Johnsongrass competition had a significant impact on maize growth and grain yield. The main crop parameters, such as aboveground biomass, grain yield, and protein content, were lowest in the nontreated and weed-infested for 55 DAS treatments, while the greatest values of these parameters were recorded in the weed-free and nicosulfuron treatments. In conclusion, our results indicated that timely and effective chemical control of johnsongrass is essential for improving grain yield and quality of maize.

**Keywords:** competition; isoxaflutole; nicosulfuron; perennial weed; protein content

## 1. Introduction

Maize is a cereal crop, grown in significant acreage around the world for grain and biomass production. In 2017, worldwide maize production was about 1.135 billion tonnes, while the cultivated area was about 197 million hectares [1]. In the last 40 years, an increase of 51.5% in the cultivated area was recorded, while the yield was increased by approximately 65%, mainly due to the development of high yielding hybrids and improved cultural practices. Although maize yield could be affected by several parameters, such as fertilization, pests, irrigation, cultivated hybrids, and environmental conditions [2–5], weed competition is the main limiting factor affecting both the growth and yield of this crop [6,7]. This crop should be kept weed-free for the first six to eight weeks after sowing to obtain maximum yield [8]. Lehoczky et al. [7] reported that the maize biomass was 64% lower in weedy plots due to the weed competition.

Among the most prominent weed species affecting growth and cultivation of maize is johnsongrass (*Sorghum halepense* (L.) Pers.). This perennial weed is commonly found in the regions where maize crops are cultivated [9–11]. Its control is mainly based on post-emergence application of sulfonylurea (e.g., foramsulfuron, nicosulfuron, and rimsulfuron) and triketones herbicides (e.g., tembotrione) [11–13]. In fields with low johnsongrass density, early detection and control of small patches must be a part of integrated johnsongrass management systems [9]. Johnsongrass is a very competitive weed with a high reproductive capacity [14,15] and can cause 17%–81% yield losses in maize crops [11,16]. Moreover, this weed species expands rapidly in the field [9,17], while plants originating from rhizomes are more competitive than seedling plants [12,18,19]. Therefore, rhizomatous johnsongrass management is critical to achieving a high yield in a maize crop.

Thus, the aim of the present study was to examine the effects of johnsongrass on maize growth, grain yield, and protein content under different management practices. Emphasis was also placed on examining johnsongrass control and recovery under different nicosulfuron and isoxaflutole treatments. Nicosulfuron was applied post-emergence, while isoxaflutole was applied pre-emergence (PRE) followed by hoeing or post-emergence application of nicosulfuron. The study of johnsongrass recovery under different management practices is important to minimize the rhizome growth of johnsongrass and enhance maize yield and grain quality.

## 2. Materials and Methods

### 2.1. Study Site

Two field experiments were established in 2017 and 2018 at the University of Thessaly farm. The soil was sandy clay loam in texture (clay: 26%, silt: 36%, and sand: 38%) with a pH of 7.4. Meteorological data for both the cultivation periods are presented in Figure 1. Total precipitation during the cultivation period was 289 and 294 mm in 2017 and 2018, respectively. The field was plowed in October and again in the spring, when two passes with a chisel plow and a rotary tiller were made to prepare a fine seedbed. Maize (*Zea mays* cv. P1547) was planted on 3 May 2017 and 24 April 2018 using a pneumatic sowing machine. The inorganic fertilizer 15-15-15 (5% S) was applied at the time of planting (200 kg ha$^{-1}$) in a band near the seed row, while ammonium nitrate (34.5-0-0) was applied at 30 and 60 days after maize emergence in two equal doses (125 kg ha$^{-1}$).

### 2.2. Experimental Design

The experimental design was a randomized complete block design with eight treatments and three replicates. The plot size was 21 m$^2$ (3 by 7 m) and comprised four rows, with row spacing of 75 cm, and the distance between the plants within the row was 16 cm. The treatments were: (1) weed-free: johnsongrass was controlled by hand hoeing at 20 days after sowing (DAS), 35 DAS, and 55 DAS, (2) nontreated (weedy), (3) weed-infested for 55 DAS: johnsongrass was controlled by hand hoeing at 55 DAS, (4) isoxaflutole was applied at the of 99 g active ingredient (a.i.) ha$^{-1}$ and followed by one hand hoeing at 20 DAS (isoxaflutole + 1 hoeing), since at this period johnsongrass plants were beginning to recover from isoxaflutole damage (injury symptom: leaves turn white), (5) nicosulfuron at the rate of 48 g a.i. ha$^{-1}$, (6) nicosulfuron at the rate of 60 g a.i. ha$^{-1}$, (7) isoxaflutole (99 g a.i. ha$^{-1}$) + nicosulfuron (48 g a.i. ha$^{-1}$), and (8) isoxaflutole (99 g a.i. ha$^{-1}$) + nicosulfuron (60 g a.i. ha$^{-1}$).

Isoxaflutole (Merlin Flexx L, Bayer Hellas A.E.B.E., Athens, Greece; safener: cyprosulfamide) was applied directly after sowing, while nicosulfuron (Milagro 240 SC, Syngenta Hellas A.E.B.E., Anthousa Attikis, Greece) was applied when the maize plants reached 4–6 true leaf stage (BBCH-scale: growth stages 14–16) on 23 May 2017 and 16 May 2018. Herbicides were applied using a handheld field plot sprayer with six flat-fan nozzles calibrated to deliver 300 L ha$^{-1}$ of spray solution at 250 kPa pressure. The field was irrigated with sprinklers after the isoxaflutole application to thoroughly wet the top 7 to 10 cm of soil. After crop emergence, the field was irrigated using a drip irrigation system. The irrigation intervals varied throughout the growing season and ranged from 7 to 10 days, depending on maize growth stage and daily temperature.

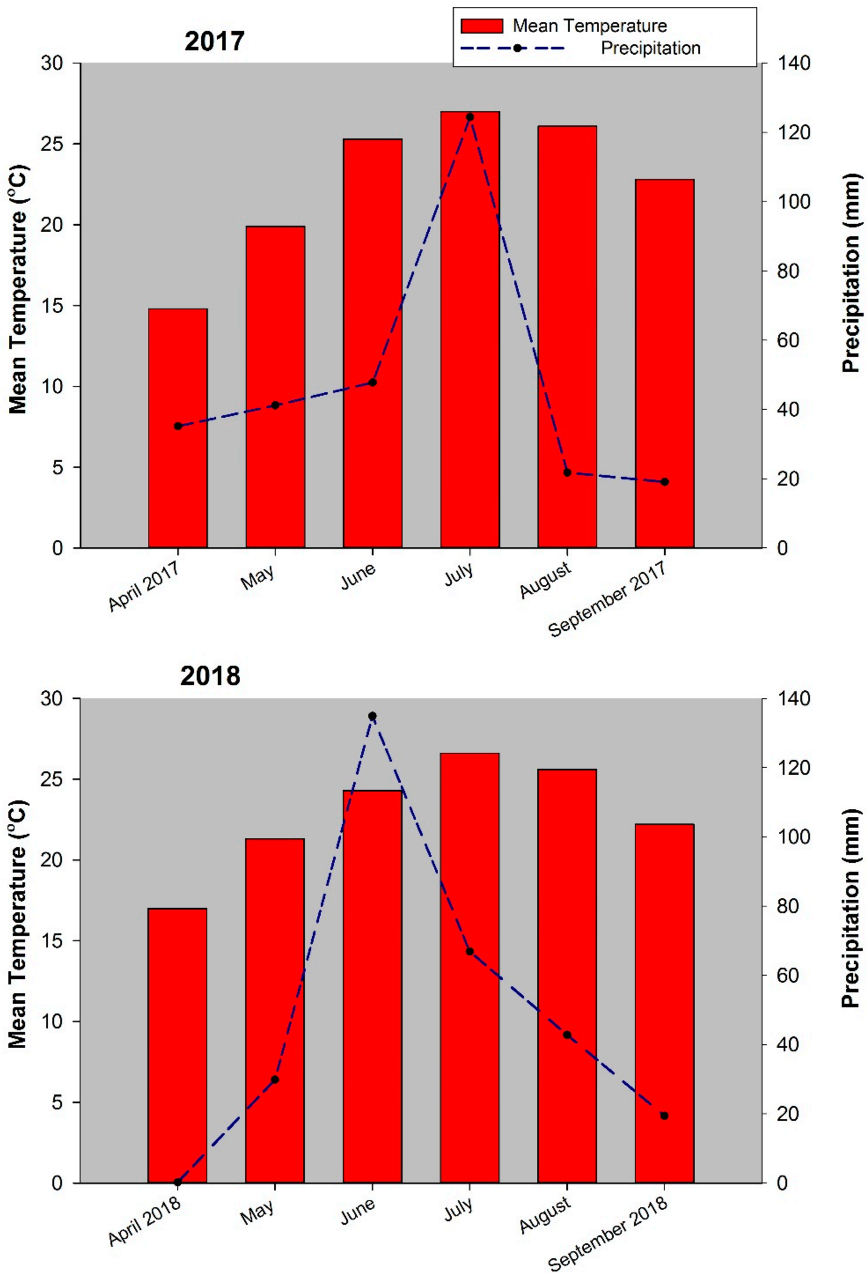


**Figure 1.** Mean temperature and precipitation in the experimental site (Velestino, Greece) in 2017 and 2018.

### 2.3. Data Collection

Maize height, stem diameter, and aboveground biomass were measured at 36–42 DAS (BBCH-scale: growth stages 16–19), 55 DAS (BBCH-scale: growth stages 19–21), and 78–85 DAS (BBCH-scale: growth stages 61–63). These measurements were recorded from five plants randomly selected from each plot. The aboveground biomass was determined after drying the samples at 60 °C for 96 h. The relative chlorophyll content (SPAD values) was also determined in the field at 36–42 DAS, 55 DAS, and 78–85 DAS, on fully expanded maize leaves using a handheld SPAD-502 chlorophyll meter (Konica Minolta Optics, Inc., Osaka, Japan). The chlorophyll content was measured on three leaves from three plants per plot. Moreover, johnsongrass aboveground biomass was measured at 36–42 DAS, 55 DAS, and 78–85 DAS. For aboveground biomass determination, a square quadrate (1 by 1 m) was used, and the johnsongrass plants were removed by cutting at ground level. Aboveground biomass was determined after drying these samples for 96 h at 60 °C.

For the determination of grain yield and yield components, plots were harvested in 17 October 2017 and 8 October 2018. Ten plants were randomly harvested to quantify ear length and grain yield. After harvest, 1000 grain-weight was measured by weighing three random 100-grain samples from each treatment [20]. Protein and starch content were determined in the dry grains by near-infrared reflectance (NIR) spectroscopy technique using the DA 7250 NIR analyzer (Perten Instruments, Hägersten, Sweden).

### 2.4. Statistical Analyses

Data from both years were separately subjected to statistical analyses (ANOVA), which was carried out using the SigmaPlot statistical package, v.12 (Systat Software, San Jose, CA, USA). When the ANOVA model was significant ($p \leq 0.05$), the difference between means was evaluated using a Fisher's LSD test ($p \leq 0.05$). Finally, a Pearson's correlation analysis was carried out to assess the relationship between johnsongrass aboveground biomass and maize parameters.

## 3. Results

### 3.1. Johnsongrass Aboveground Biomass

At first measurement (36–42 DAS), johnsongrass aboveground biomass ranged from 0 to 2557.8 kg ha$^{-1}$ in 2017 and from 0 to 2680 kg ha$^{-1}$ in 2018 (Figure 2). The most johnsongrass aboveground biomass was recorded in the nontreated and weed-infested for 55 DAS treatments, while the least values were recorded in the weed-free and nicosulfuron treatments. At the second measurement (55 DAS), the most johnsongrass aboveground biomass was also recorded in the nontreated and weed-infested for 55 DAS treatments. At the final measurement (78–85 DAS), johnsongrass aboveground biomass ranged from 111.1 to 8644.1 kg ha$^{-1}$ in 2017 and from 85.8 to 7588.9 kg ha$^{-1}$ in 2018, while there were statistically significant differences among the different management treatments. The most johnsongrass aboveground biomass was recorded in the nontreated plots, while there were no significant differences among the nicosulfuron treatments.

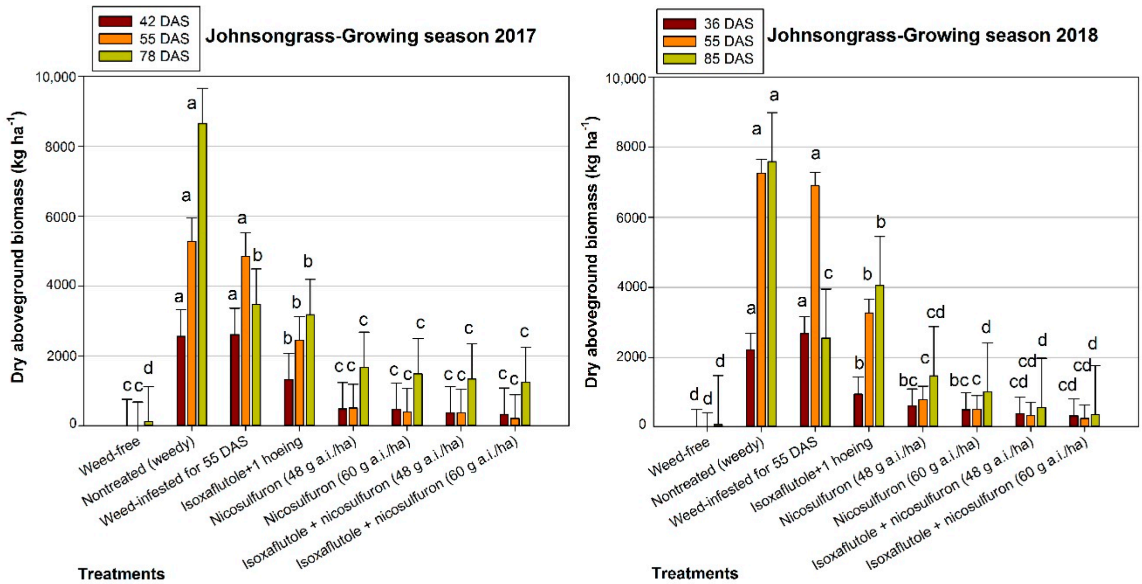


**Figure 2.** Johnsongrass aboveground biomass (kg ha$^{-1}$) as affected by the various treatments at 36–42 days after sowing (DAS), 55 DAS, and 78–85 DAS, in 2017 and 2018 (Velestino, Greece). For each measurement, bars followed by different letters indicate significant differences according to Fisher's LSD test ($p \leq 0.05$). Error bars indicate the $LSD_{5\%}$ values.

## 3.2. Maize Growth

Johnsongrass competition had a significant effect on the maize crop parameters, such as aboveground biomass, plant height, and stem diameter. Plant height ranged from 171.6 to 261.6 cm in 2017 and from 109.4 to 271.8 cm in 2018 for the final height measurements (78-85 DAS). In both the experiments, the lowest plant height (Figure 3) and stem diameter (Figure 4) were recorded in the nontreated and weed-infested for 55 DAS treatments. For these parameters, there were statistically significant differences among the herbicide treatments. The lowest plant height was recorded in the isoxaflutole + 1 hoeing treatment, while there were no significant differences among the four nicosulfuron treatments.

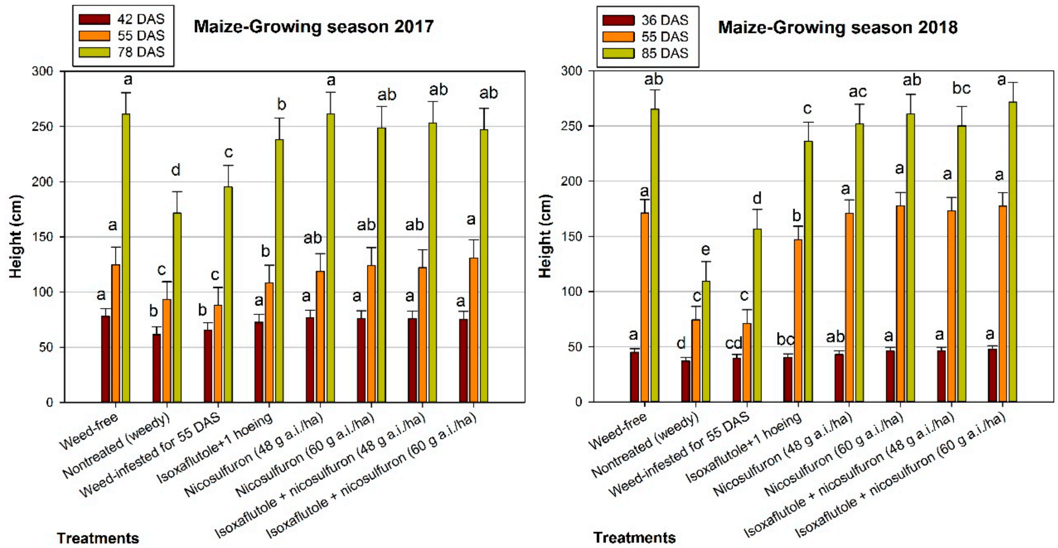


**Figure 3.** Maize height as affected by the various treatments at 36–42 days after sowing (DAS), 55 DAS, and 78–85 DAS, in 2017 and 2018 (Velestino, Greece). For each measurement, bars followed by different letters indicate significant differences according to Fisher's LSD test ($p \leq 0.05$). Error bars indicate the $LSD_{5\%}$ values.

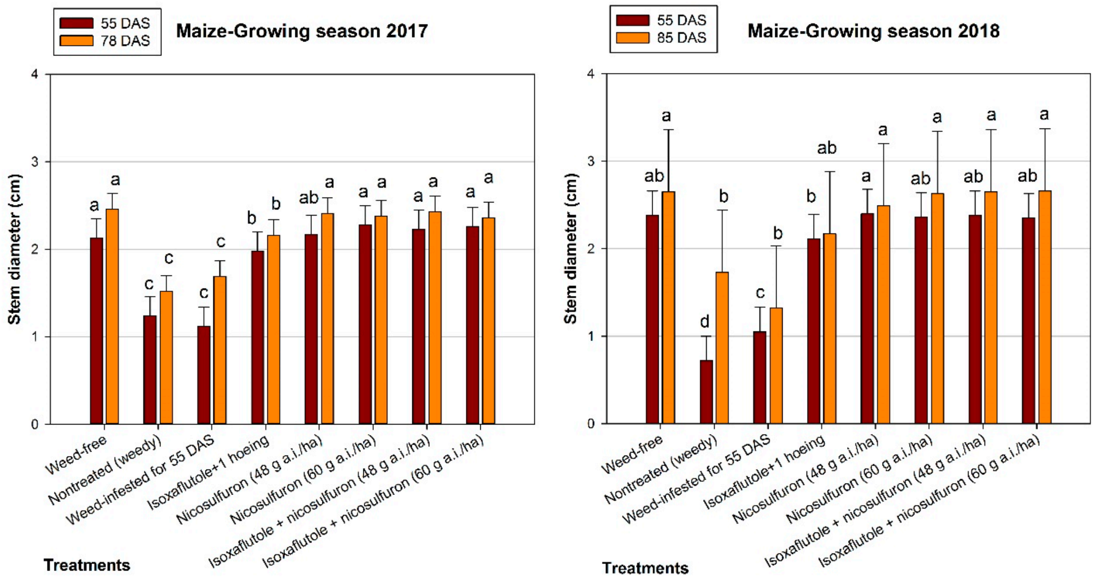


**Figure 4.** Maize stem diameter as affected by the various treatments at 55 days after sowing (DAS) and 78–85 DAS, in 2017 and 2018 (Velestino, Greece). For each measurement, bars followed by different letters indicate significant differences according to Fisher's LSD test ($p \leq 0.05$). Error bars indicate the $LSD_{5\%}$ values.

The maize aboveground biomass was also affected by johnsongrass competition, as the lowest maize aboveground biomass was recorded in the nontreated and weed-infested for 55 DAS treatments (Figure 5). The aboveground biomass ranged from 6378 to 17,155 kg ha$^{-1}$ and from 4453 to 22,592 kg ha$^{-1}$, in 2017 and 2018, respectively, for the final aboveground biomass measurements (78-85 DAS). Moreover, the lowest aboveground biomass was recorded in the nontreated, weed-infested for 55 DAS, and isoxaflutole + 1 hoeing treatments.

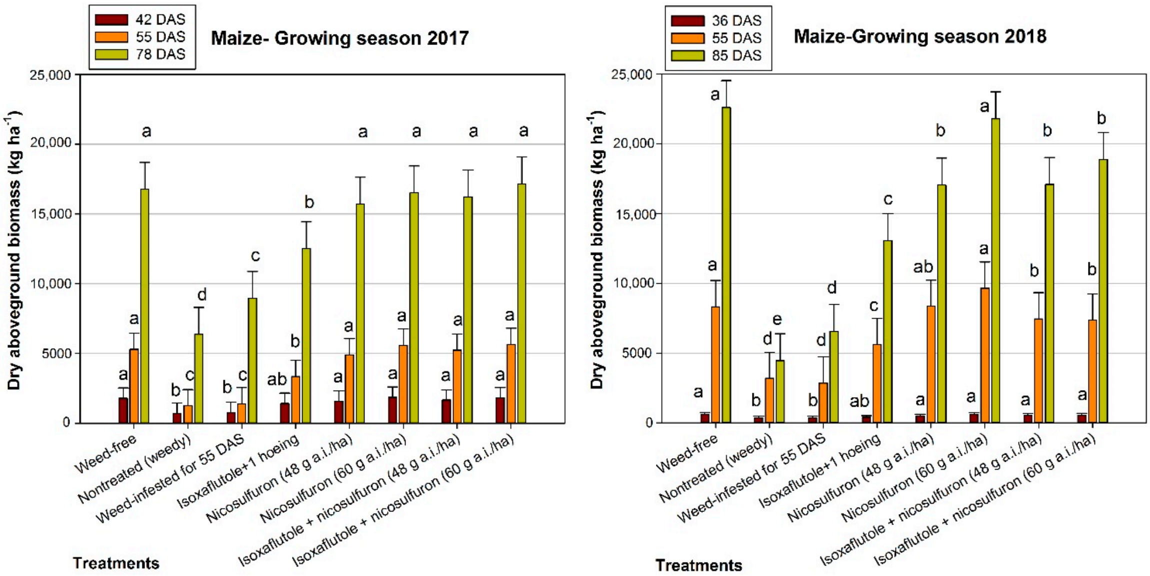


**Figure 5.** Maize aboveground biomass as affected by the various treatments at 36–42 days after sowing (DAS), 55 DAS, and 78–85 DAS, in 2017 and 2018 (Velestino, Greece). For each measurement, bars followed by different letters indicate significant differences according to Fisher's LSD test ($p \leq 0.05$). Error bars indicate the $LSD_{5\%}$ values.

### *3.3. Relative Chlorophyll Content*

At the final measurement, the SPAD values ranged from 38.37 to 57.77 in 2017 and from 32.07 to 59.97 in 2018. Similar to the maize biomass, the relative chlorophyll content of maize (SPAD values) was affected by johnsongrass competition, as the least values were observed in the nontreated and weed-infested for 55 DAS treatments, while there were no statistically significant differences among the nicosulfuron treatments for this parameter (Figure 6).

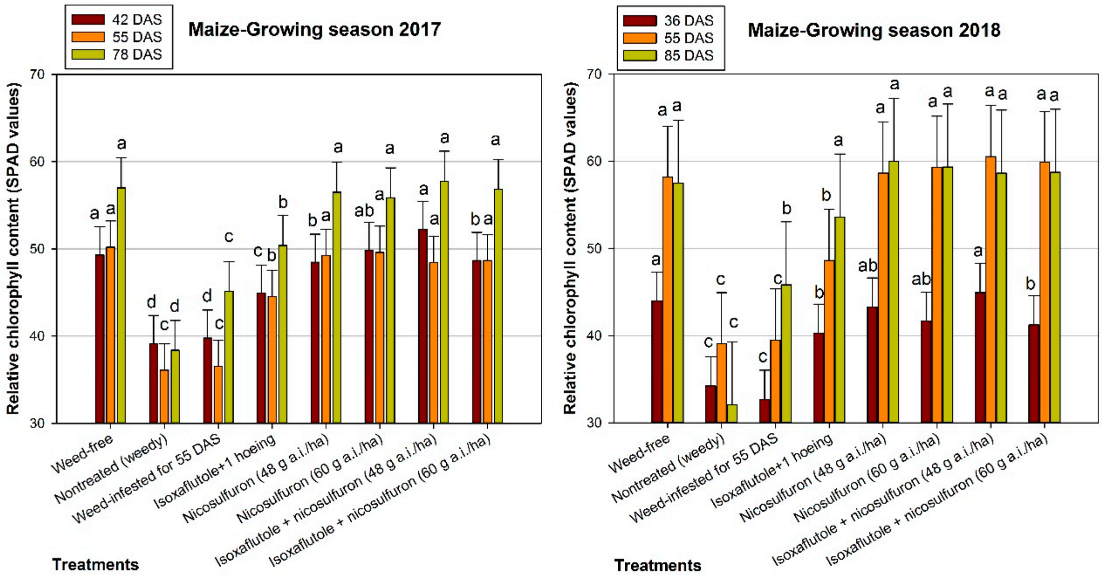


**Figure 6.** Maize relative chlorophyll content as affected by the various treatments at 36–42 days after sowing (DAS), 55 DAS, and 78–85 DAS, in 2017 and 2018 (Velestino, Greece). For each measurement, bars followed by different letters indicate significant differences according to Fisher's LSD test ($p \leq 0.05$). Error bars indicate the $LSD_{5\%}$ values.

### 3.4. Maize Yield and Quality

Johnsongrass competition had a significant effect on the maize yield, ear length, and 1000 grain-weight (Table 1). Grain yield ranged from 2841 to 13,949 kg ha$^{-1}$ in 2017 and from 1743 to 12,788 kg ha$^{-1}$ in 2018. In both the experiments, the least grain yield was recorded in the nontreated and weed-infested for 55 DAS treatments. Among the various herbicide treatments, the least grain yield was recorded in the isoxaflutole + 1 hoeing treatment, while the greatest values were recorded in nicosulfuron treatments. The ear length and 1000 grain-weight were also affected by johnsongrass competition, as the least values were recorded in the nontreated and weed-infested for 55 DAS treatments. The ear length ranged from 10.7 to 22.7 cm and from 11.9 to 22.2 cm, in 2017 and 2018, respectively. Moreover, the highest 1000 grain-weight and ear length were recorded in the weed-free and nicosulfuron treatments.

Similar to the maize yield, johnsongrass competition had a significant effect on the maize quality (Table 2). Protein content ranged from 7.12% to 8.19% in 2017 and from 6.70% to 7.83% in 2018. In both years, the least protein content was recorded in the nontreated and weed-infested for 55 DAS treatments. Moreover, there were statistically significant differences among the management treatments. Within the different management treatments, the least protein content was recorded in the untreated and weed-infested for 55 DAS treatments, while there were no statistically significant differences among the nicosulfuron treatments and weed-free treatment. Starch content ranged from 62.07% to 64.83% in 2017 and from 62.87% to 64.57% in 2018. In both years, the starch content was affected by johnsongrass competition, as the least values were recorded in the nontreated and weed-infested for 55 DAS treatments, while the greatest starch content was recorded in the weed-free and nicosulfuron treatments.

**Table 1.** Maize grain yield, ear length, and 1000 grain-weight as affected by the various treatments at the harvest stage, in 2017 and 2018 (Velestino, Greece). Means followed by different letters indicate significant differences according to Fisher's Least Significant Difference (LSD) test ($p < 0.05$).

| 2017 Treatments | Ear Length (cm) | 1000 Grain-Weight (g) | Grain Yield (kg ha$^{-1}$) |
|---|---|---|---|
| Weed-free | 22.3 ab | 423.6 a | 13,320 a |
| Nontreated (weedy) | 10.7 f | 288.0 e | 2841 d |
| Weed-infested for 55 DAS | 13.9 e | 320.0 d | 5582 c |
| Isoxaflutole + 1 hoeing | 19.6 d | 361.0 c | 8983 b |
| Nicosulfuron (48 g a.i. ha$^{-1}$) | 21.3 bc | 401.3 b | 11,899 a |
| Nicosulfuron (60 g a.i. ha$^{-1}$) | 22.6 ac | 408.3 ab | 12,220 a |
| Isoxaflutole + nicosulfuron (48 g a.i. ha$^{-1}$) | 21.2 b | 407.3 ab | 12,861 a |
| Isoxaflutole + nicosulfuron (60 g a.i. ha$^{-1}$) | 22.7 a | 421.3 a | 13,949 a |
| LSD$_{5\%}$ | 1.30 | 18.81 | 2325 |
| **2018 Treatments** | **Ear Length (cm)** | **1000 Grain-Weight (g)** | **Grain Yield (kg ha$^{-1}$)** |
| Weed-free | 21.7 a | 369.9 a | 12,141ac |
| Nontreated (weedy) | 11.9 d | 280.7 d | 1743 f |
| Weed-infested for 55 DAS | 13.8 c | 302.9 c | 3391 e |
| Isoxaflutole + 1 hoeing | 18.3 b | 331.3 b | 7938 d |
| Nicosulfuron (48 g a.i. ha$^{-1}$) | 20.8 a | 362.1 a | 11,432 bc |
| Nicosulfuron (60 g a.i. ha$^{-1}$) | 21.9 a | 372.5 a | 12,359 a |
| Isoxaflutole + nicosulfuron (48 g a.i. ha$^{-1}$) | 21.8 a | 365.7 a | 11,184 b |
| Isoxaflutole + nicosulfuron (60 g a.i. ha$^{-1}$) | 22.2 a | 367.2 a | 12,788 a |
| LSD$_{5\%}$ | 1.47 | 15.79 | 945.51 |

**Table 2.** Maize protein and starch content as affected by the various treatments at the harvest stage, in 2017 and 2018 (Velestino, Greece). Means followed by different letters indicate significant differences according to Fisher's Least Significant Difference (LSD) test ($p < 0.05$).

| Treatments | 2017 | | 2018 | |
|---|---|---|---|---|
| | Protein Content (%) | Starch Content (%) | Protein Content (%) | Starch Content (%) |
| Weed-free | 8.19 a | 64.70 a | 7.73 a | 64.10 ab |
| Nontreated (weedy) | 7.27 c | 62.07 c | 6.70 c | 63.00 c |
| Weed-infested for 55 DAS | 7.12 c | 62.77 b | 6.91 c | 62.87 c |
| Isoxaflutole + 1 hoeing | 7.78 b | 64.07 a | 7.37 b | 63.60 bc |
| Nicosulfuron (48 g a.i. ha$^{-1}$) | 8.06 a | 64.83 a | 7.68 a | 64.57 a |
| Nicosulfuron (60 g a.i. ha$^{-1}$) | 8.16 a | 64.73 a | 7.73 a | 64.30 ab |
| Isoxaflutole + nicosulfuron (48 g a.i. ha$^{-1}$) | 8.10 a | 64.63 a | 7.75 a | 64.23 ab |
| Isoxaflutole + nicosulfuron (60 g a.i. ha$^{-1}$) | 8.04 a | 64.80 a | 7.83 a | 64.07 ab |
| LSD$_{5\%}$ | 0.151 | 1.085 | 0.229 | 0.802 |

## 4. Discussion

### *4.1. Johnsongrass Control*

Greatest johnsongrass aboveground biomass was recorded in the nontreated and weed-infested for 55 DAS treatments. At the final measurement (78–85 DAS), among the herbicide treatments, the most aboveground biomass was recorded in the isoxaflutole + 1 hoeing treatment (Figure 2). Stephenson and Bond [21] reported that the herbicides thiencarbazone-methyl + isoxaflutole and isoxaflutole applied PRE, provided 74% to 76% rhizomatous johnsongrass control, while Ortiz et al. [22] observed that isoxaflutole provided excellent johnsongrass seedling control (100%).

Nicosulfuron applied at 48 and 60 g ha$^{-1}$ decreased johnsongrass biomass by 81–88%. Rosales-Robles et al. [23] also reported that nicosulfuron applied at a lower rate (26.3 g ha$^{-1}$) provided at least 90% johnsongrass control. Similar nicosulfuron efficacy (94%) against johnsongrass in field experiments was also observed by Johnson et al. [24]. Moreover, high efficacy against this weed was provided by the herbicide foramsulfuron at the rate of 45 g ha$^{-1}$ [25]. Currently, in Chile, Italy, and Hungary, resistance of johnsongrass populations to acetolactate synthase (ALS) inhibiting herbicides was identified in the maize fields [26,27]. To reduce the johnsongrass resistance selection pressures to sulfonylureas (e.g., nicosulfuron and foramsulfuron), the application of other herbicides (e.g., tembotrione and isoxaflutole; 4-hydroxyphenylpyruvate dioxygenase (4-HPPD) inhibitors) or herbicide mixtures is necessary. According to Damalas et al. [11], tembotrione efficacy against johnsongrass was less (60–63%) than that of our results obtained for nicosulfuron, while the mixtures of this herbicide with nicosulfuron or foramsulfuron improved johnsongrass control (82–86%).

Isoxaflutole retarded johnsongrass growth with plant foliage turning white for a short period, and thus, the johnsongrass plants were shorter at nicosulfuron application than those in the nontreated plots. Despite these effects, the pre-emergence application of isoxaflutole has not significantly increased the efficacy of nicosulfuron against johnsongrass, although it is well known that the growth stage of johnsongrass at the time of application affects herbicide efficacy. According to Eleftherohorinos and Kotoula-Syka [28] and Djurkić et al. [29], the post-emergence herbicides (e.g., nicosulfuron) provided the greatest efficacy when johnsongrass plants are 10–35 cm tall. In another study, Johnson and Norsworthy [30] reported that nicosulfuron efficacy decreased as johnsongrass size increased at application. Furthermore, in both years, johnsongrass aboveground biomass in the final measurement at 78–85 DAS was 1.4 to 6.0-fold greater than that in the second measurement at 55 DAS, revealing that the recovery from herbicide injury of johnsongrass plants was observed in nicosulfuron treatments.

### 4.2. Maize Growth

Johnsongrass competition had a significant effect on the maize growth and relative chlorophyll content. Plant height, stem diameter, aboveground biomass, and relative chlorophyll content were affected by johnsongrass competition, as the least values were recorded in the nontreated and weed-infested for 55 DAS treatments. It is important to point out that the experimental field in the present study was highly infested by rhizomatous johnsongrass that strongly competed with the maize plants for root space, nutrients, water, and light. Lehoczky et al. [7] also reported that maize and weeds strongly compete for nutrients. These researchers also found that the nitrogen content in weedy plots was 4.73 times lower than in the weed-free plots. In this regard, the application of nicosulfuron in maize improved plant growth due to the reduction of weed competition and thereby the increase of chlorophyll content. In comparison to the weed-free treatment, johnsongrass competition for 55 DAS reduced maize aboveground biomass by 47% to 71% in 2017 and 2018, respectively, while johnsongrass competition throughout the season (nontreated) reduced maize biomass by 62% to 80% in 2017 and 2018, respectively. These findings are confirmed by the results of the correlation analysis (Figure 7), since maize aboveground biomass showed a negative correlation with johnsongrass aboveground biomass ($r = -0.741$, $p < 0.05$ and $r = -0.837$, $p < 0.01$ in 2017 and 2018, respectively).

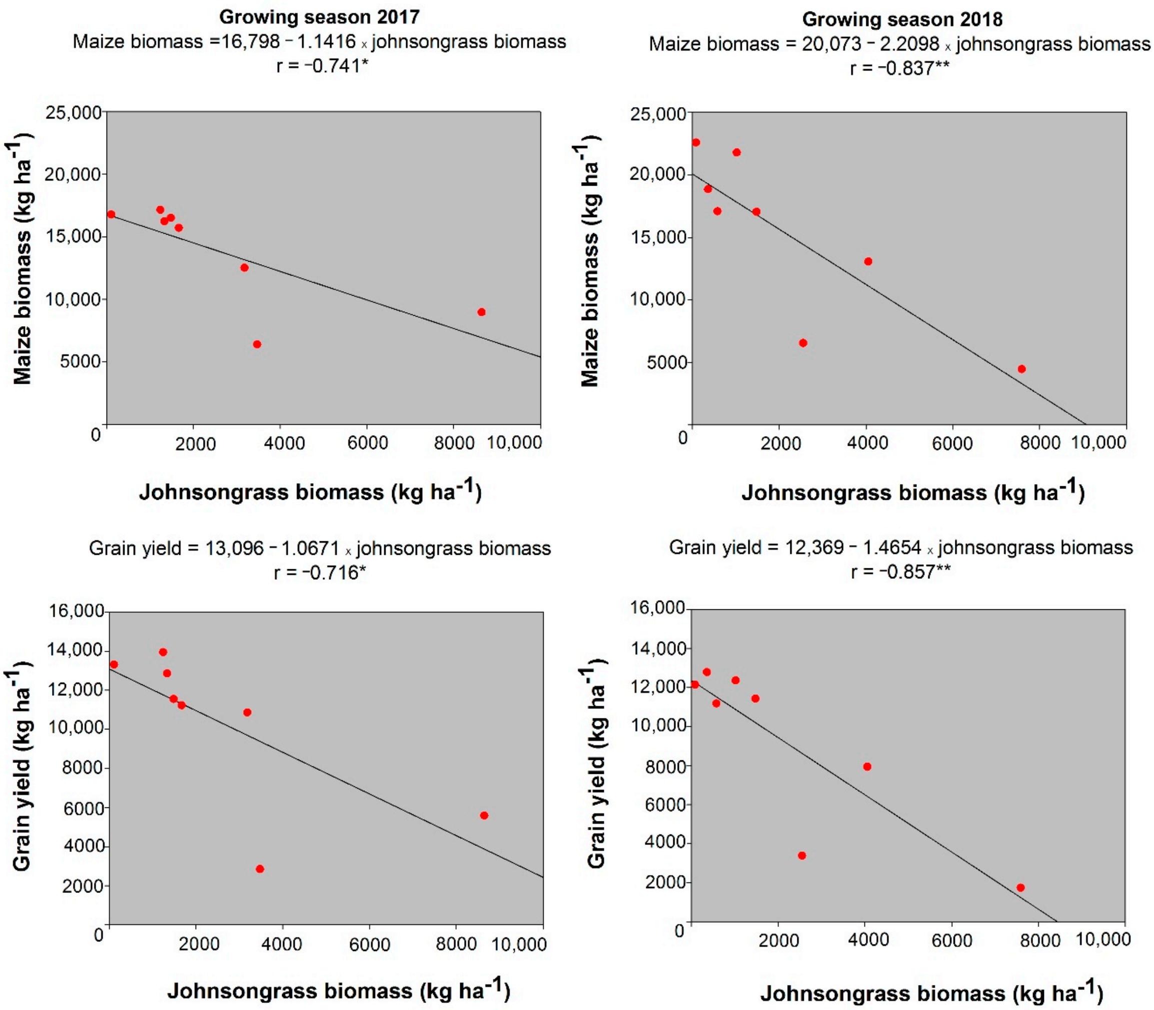


**Figure 7.** Pearson correlation coefficients between the main maize parameters (aboveground biomass and grain yield) and johnsongrass aboveground biomass. r was calculated using the linear equation ($n$ = 8), * significant at $p < 0.05$ and ** significant at $p < 0.01$.

Among the various herbicide treatments, the least maize aboveground biomass was observed in the isoxaflutole + 1 hoeing treatment, while the greatest values were recorded in the nicosulfuron (60 g a.i. ha$^{-1}$) and isoxaflutole + nicosulfuron (60 g a.i. ha$^{-1}$) treatments. Maize biomass was increased by 2.5 to 4.9 times in nicosulfuron plots than that of weedy plots, slightly greater than that reported by Gubbiga et al. [31], probably due to the high field infestation by johnsongrass in our study.

### *4.3. Maize Yield and Quality*

Johnsongrass competition had a significant effect on the maize yield and yield components. The ear length, 1000 grain-weight, and grain yield were affected by johnsongrass competition, as the lowest values were recorded for the nontreated and weed-infested for 55 DAS treatments. In both years, johnsongrass competition for 55 DAS reduced the maize grain yield by 58–72%, while in the nontreated plots, the grain yield was reduced by 79–86%. Similarly, Mitskas et al. [19] reported that johnsongrass competition reduced grain yield by 83%. The correlation analysis also revealed that grain yield showed a negative correlation with johnsongrass aboveground biomass (r = −0.716, $p < 0.05$ and r = −0.858, $p < 0.01$ in 2017 and 2018, respectively).

Among the various herbicide treatments, the least grain yield was observed in the isoxaflutole + 1 hoeing treatment, while its greatest values were recorded in the nicosulfuron (60 g a.i. ha$^{-1}$) and isoxaflutole + nicosulfuron (60 g a.i. ha$^{-1}$) treatments. In comparison to the weed-free treatment, johnsongrass competition throughout the season (nontreated) reduced ear length by 45% to 52% in 2018 and 2017, respectively, while 1000 grain-weight reduced by 24% to 32% in 2018 and 2017, respectively. Similarly, Mitskas et al. [19] also observed that the reduction of ear length in weedy plots was greater than that for 1000 grain-weight.

In general, the maize grain was of excellent quality. Starch and protein content ranged from 62.07% to 64.83% and from 6.70% to 8.19%, respectively. Labuschagne et al. [32] reported that the starch content at harvest in several maize genotypes ranged between 50.06% and 62.65%, while Silva et al. [33] observed that the protein content fluctuated between 6.9% and 10.5%; these value ranges are in agreement with our findings. Johnsongrass competition had a significant effect on the maize quality. In both the experiments, the lowest protein and starch content were recorded in the nontreated and weed-infested for 55 DAS treatments. In contrast, the greatest protein content was recorded in the weed-free and nicosulfuron treatments. In comparison to the weed-free treatment, johnsongrass competition for 55 DAS reduced the protein content by 11–13%. These findings are confirmed by the results of the correlation analysis since protein content showed a negative correlation with johnsongrass aboveground biomass (r = −0.789, $p < 0.05$ and r = −0.850, $p < 0.01$ in 2017 and 2018, respectively). Similarly, Mohammadi et al. [6] reported that the grain protein content in maize was 9.7% lower in weedy plots due to the weed competition. Reduction of the grain quality (e.g., gluten content) due to weed interference was also demonstrated in durum wheat by Karkanis et al. [34].

## 5. Conclusions

The results of this study indicated that johnsongrass competition had a strong impact on the growth, yield, and quality of maize. Johnsongrass competition for 55 DAS reduced the maize grain yield by 58–72%, while in the nontreated plots, the grain yield was reduced by 79–86%. Reduction in the grain quality (e.g., protein and starch content) due to johnsongrass competition was also observed. Among the various management treatments, the least maize aboveground biomass, grain yield, and protein content were observed in the nontreated and weed-infested for 55 DAS treatments, while its greatest values were recorded in nicosulfuron treatments. Additionally, the results of this study indicate that the pre-emergence application of isoxaflutole has not significantly increased the efficacy of nicosulfuron against johnsongrass. Finally, johnsongrass aboveground biomass at the final measurement (78-85 DAS) was 1.4 to 6.0-fold greater than that in the second measurement (55 DAS), revealing the recovery of johnsongrass plants in nicosulfuron treatments.

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## References

1. FAO (Food and Agriculture Organization of the United Nations). FAOSTAT Database. Available online: www.fao.org/faostat (accessed on 2 January 2019).
2. Sekhar, J.C.; Karjagi, C.G.; Kumar, B.; Rakshit, S.; Soujanya, L.; Kumar, P.; Singh, K.P.; Dhandapani, A.; Dass, S.; Kumar, R.S. Genetics of resistance to *Sesamia inferens* infestation and its correlation with yield in maize. *Plant Breed.* **2015**, *134*, 394–399. [CrossRef]
3. Marković, M.; Josipović, M.; Šoštarić, J.; Jambrović, A.; Brkić, A. Response of maize (*Zea mays* L.) grain yield and yield components to irrigation and nitrogen fertilization. *J. Cent. Eur. Agric.* **2017**, *18*, 55–72. [CrossRef]

4. Assefa, Y.; Carter, P.; Hinds, M.; Bhalla, G.; Schon, R.; Jeschke, M.; Paszkiewicz, S.; Smith, S.; Ciampitti, I.A. Analysis of long term study indicates both agronomic optimal plant density and increase maize yield per plant contributed to yield gain. *Sci. Rep.* **2018**, *8*, 4937. [CrossRef] [PubMed]
5. Hussain, H.A.; Men, S.; Hussain, S.; Chen, Y.; Ali, S.; Zhang, S.; Zhang, K.; Li, Y.; Xu, Q.; Liao, C.; et al. Interactive effects of drought and heat stresses on morpho-physiological attributes, yield, nutrient uptake and oxidative status in maize hybrids. *Sci. Rep.* **2019**, *9*, 3890. [CrossRef] [PubMed]
6. Mohammadi, G.R.; Mozafaril, S.; Najaphy, A.; Ghobadi, M.E. Corn (*Zea mays* L.) seed vigour and quality as influenced by weed interference and living mulch. *Adv. Environ. Biol.* **2012**, *6*, 1026–1031.
7. Lehoczky, É.; Márton, L.; Nagy, P. Competition for nutrients between cold-tolerant maize and weeds. *Commun. Soil Sci. Plant Anal.* **2013**, *44*, 526–534. [CrossRef]
8. Takim, F. Weed competition in maize (*Zea mays* L.) as a function of the timing of hand-hoeing weed control in the southern Guinea savanna zone of Nigeria. *Acta Agron. Hung.* **2012**, *60*, 257–264. [CrossRef]
9. Andújar, D.; Barroso, J.; Fernández-Quintanilla, C.; Dorado, J. Spatial and temporal dynamics of *Sorghum halepense* patches in maize crops. *Weed Res.* **2012**, *52*, 411–420. [CrossRef]
10. Follak, S.; Essl, F. Spread dynamics and agricultural impact of *Sorghum halepense*, an emerging invasive species in Central Europe. *Weed Res.* **2013**, *53*, 53–60. [CrossRef]
11. Damalas, C.A.; Gitsopoulos, T.K.; Koutroubas, S.D.; Alexoudis, C.; Georgoulas, I. Weed control and selectivity in maize (*Zea mays* L.) with tembotrione mixtures. *Int. J. Pest Manag.* **2018**, *64*, 11–18. [CrossRef]
12. Chiriţa, R.; Grozea, I.; Sarpe, N.; Lauer, K.F. Control of *Sorghum halepense* (L.) species in western part of Romania. *Commun. Agric. Appl. Biol Sci.* **2008**, *73*, 959–964. [PubMed]
13. Barroso, J.; Maxwell, B.D.; Dorado, J.; Andújar, D.; San Martín, C.; Fernández-Quintanilla, C. Response of *Sorghum halepense* demographic processes to plant density and rimsulfuron dose in maize. *Weed Res.* **2016**, *56*, 304–312. [CrossRef]
14. Scopel, A.L.; Ballare, C.L.; Ghersa, C.M. Role of seed reproduction in the population ecology of *Sorghum halepense* in maize crops. *J. Appl. Ecol.* **1988**, *25*, 951–962. [CrossRef]
15. Atwater, D.Z.; Kim, W.; Tekiela, D.R.; Barney, J.N. Competition and propagule density affect sexual and clonal propagation of a weed. *Invasive Plant Sci. Manag.* **2017**, *10*, 17–25. [CrossRef]
16. Vasilakoglou, I.; Dhima, K.; Eleftherohorinos, I. Allelopathic potential of bermudagrass and johnsongrass and their interference with cotton and corn. *Agron. J.* **2005**, *97*, 303–313.
17. Horowitz, M. Spatial growth of *Sorghum halepense* (L.) Pers. *Weed Res.* **1973**, *13*, 200–208. [CrossRef]
18. Ghosheh, H.Z.; Holshouser, D.L.; Chandler, J.M. Influence of density on johnsongrass (*Sorghum halepense*) interference in field corn (*Zea mays*). *Weed Sci.* **1996**, *44*, 879–883. [CrossRef]
19. Mitskas, M.B.; Tsolis, C.E.; Eleftherohorinos, I.G.; Damalas, C.A. Interference between corn and johnsongrass (*Sorghum halepense*) from seed or rhizomes. *Weed Sci.* **2003**, *51*, 540–545. [CrossRef]
20. Karkanis, A.; Alexiou, A.; Katsaros, C.; Petropoulos, S. Allelopathic activity of spearmint (*Mentha spicata* L.) and peppermint (*Mentha* x *piperita* L.) reduces yield, growth, and photosynthetic rate in a succeeding crop of maize (*Zea mays* L.). *Agronomy* **2019**, *9*, 461. [CrossRef]
21. Stephenson, D.O.; Bond, J.A. Evaluation of thiencarbazone-methyl and isoxaflutole-based herbicide programs in corn. *Weed Technol.* **2012**, *26*, 37–42. [CrossRef]
22. Ortiz, A.; Martínez, L.; Quintana, Y.; Pérez, P.; Fischer, A. Resistance of johnsongrass [*Sorghum halepense* (L.) Pers.] to herbicides nicosulfuron and foramsulfuron+iodosulfuron in Venezuela. *Bioagro* **2014**, *26*, 71–78.
23. Rosales-Robles, E.; Chandler, J.M.; Senseman, S.A.; Prostko, E.P. Influence of growth stage and herbicide rate on postemergence johnsongrass (*Sorghum halepense*) control. *Weed Technol.* **1999**, *13*, 525–529. [CrossRef]
24. Johnson, W.G.; Jianmei, L.I.; Wait, J.D. Johnsongrass control, total nonstructural carbohydrates in rhizomes, and regrowth after application of herbicides used in herbicide-resistant corn (*Zea mays*). *Weed Technol.* **2003**, *17*, 36–41. [CrossRef]
25. Torma, M.; Kazinczi, G.; Hódi, L. Postemergence herbicide treatments in maize against difficult to control weeds in Hungary. *J. Plant Dis. Prot.* **2006**, *20*, 781–786.
26. Hernández, M.J.; León, R.; Fischer, A.J.; Gebauer, M.; Galdames, R.; Figueroa, R. Target-site resistance to nicosulfuron in johnsongrass (*Sorghum halepense*) from Chilean corn fields. *Weed Sci.* **2015**, *63*, 631–640. [CrossRef]

27. Panozzo, S.; Milani, A.; Scarabel, L.; Balogh, Á.; Dancza, I.; Sattin, M. Occurrence of different resistance mechanisms to acetolactate synthase inhibitors in European *Sorghum halepense*. *J. Agric. Food Chem.* **2017**, *65*, 7320–7327. [CrossRef]
28. Eleftherohorinos, I.G.; Kotoula-Syka, E. Influence of herbicide application rate and timings for post-emergence control of *Sorghum halepense* (L.) Pers. in maize. *Weed Res.* **1995**, *35*, 99–103. [CrossRef]
29. Djurkić, M.; Knežević, M.; Ostojić, Z. Effect of rimsulfuron application on weeds in maize inbred lines in Croatia. *Cereal Res. Commun.* **1997**, *25*, 203–209. [CrossRef]
30. Johnson, D.B.; Norsworthy, J.K. Johnsongrass (*Sorghum halepense*) management as influenced by herbicide selection and application timing. *Weed Technol.* **2014**, *28*, 142–150. [CrossRef]
31. Gubbiga, N.G.; Worsham, A.D.; Corbin, F.T. Investigations into the growth suppressing effect of nicosulfuron-treated johnsongrass (*Sorghum halepense*) on corn (*Zea mays*). *Weed Sci.* **1996**, *44*, 640–644. [CrossRef]
32. Labuschagne, M.; Phalafala, L.; Osthoff, G.; van Biljon, A. The influence of storage conditions on starch and amylose content of South African quality protein maize and normal maize hybrids. *J. Stored Prod. Res.* **2014**, *56*, 16–20. [CrossRef]
33. Silva, P.R.F.; Strieder, M.L.; Coser, R.P.S.; Rambo, L.; Sangoi, L.; Argenta, G.; Forsthofer, E.L.; Silv, A.A. Grain yield and kernel crude protein content increases of maize hybrids with late nitrogen side-dressing. *Sci. Agric.* **2005**, *62*, 487–492. [CrossRef]
34. Karkanis, A.; Vellios, E.; Grigoriou, F.; Gkrimpizis, T.; Giannouli, P. Evaluation of efficacy and compatibility of herbicides with fungicides in durum wheat (*Triticum durum* Desf.) under different environmental conditions: Effects on grain yield and gluten content. *Not. Bot. Horti Agrobo.* **2018**, *46*, 601–607. [CrossRef]