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Weed management in soybean with a special focus on the control of purple nutsedge (*Cyperus rotundus*)

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Abstract. Purple nutsedge (*Cyperus rotundus* L.) is globally an important perennial weed. Infestations from this species lead to significant losses in yield and quality of crop production. A field study was conducted at Kopaida region in Greece, to evaluate the efficacy of different herbicides for the weed management in soybean. The evaluation of the herbicides was based on the efficacy against purple nutsedge and the effect on soybean biomass production and crop seed yield. Treatments included an untreated control, two pre-emergence applications (with S-metolachlor and pendimethalin), as well as three post-emergence applications (with trifloxysulfuron, bentazone and pyrithiobac sodium). A single application of S-metolachlor maintained the density of purple nutsedge at 15 plants per m^2 in soybean and allowed the crop to compete adequately with the weed. S-metolachlor also resulted in a seed yield of 3.26 tn ha^{-1}, a value 52% higher than the untreated control and 38–45% higher than the other herbicides. The results from this study demonstrated that a combination of high seed density in soybean and effective application of herbicides like S-metolachlor can lead to economically acceptable yields.

Key words: field crops, weed management, purple nutsedge, herbicides, yield.

INTRODUCTION

Substantial crop yield and economic losses can occur if weeds are not adequately controlled (Auškalnienė & Auškalnis, 2006; Pacanoski & Mehmeti, 2019). *Cyperus rotundus* (purple nutsedge) is a perennial, noxious weed worldwide which poses a major threat for many important crops (Lawal & Oyedeji, 2009; Singh et al., 2010). It is often referred as one of the worst and most problematic weeds globally (Brecke et al., 2005). The propagation and spreading of purple nutsedge is carried out mainly by tubers, while this species has an extended subterranean network of creeping rhizomes (Bryson et al., 2003; Webster et al., 2008). The underground propagules (tubers) have varying levels of dormancy and can resprout producing multiple plants even within the same cultivation period. This trait often makes this weed noxious and tolerant to several conventional control methods which mostly aim on aboveground biomass of purple nutsedge, such as chemical control and mechanical means (Tuor & Froud-Williams, 2002; Bryson et al., 2003; Iqbal et al., 2019; Travlos et al., 2009). Purple nutsedge can be acclimatized efficiently in a broad spectrum of environments and growing conditions showing significant tolerance in high temperatures, drought and inadequate light exposure (Tuor & Froud-Williams, 2002; Brecke et al., 2005). It competes strongly with several cultivated crops, such as cotton, maize and soybean (Tuor & Froud-Williams, 2002; Das et al., 2014). This capability makes this species a serious threat for the crop yields, resulting to severe yield losses and increasing the production costs (Tuor & Froud-Williams, 2002; Iqbal et al., 2019).

Soybean (*Glycine max* (L.) Merr.), one of the most important legumes (Degola & Jonkus, 2018; Degola et al., 2019), is a species with a slow initial growth and relatively poor competition with weeds (Das et al., 2014; Datta et al., 2017). Especially in the first growth stages of soybean, the interference with weeds can result in great yield losses (Datta et al., 2017). The timing and the extent of the canopy coverage of the soybean is an important parameter for the interference with weeds, because extensive leaf surface of the canopy doesn't allow solar radiation to reach soil surface and be utilized by the quite competitive purple nutsedge (Tuor & Froud-Williams, 2002). The competition of purple nutsedge with soybean extends up to crop seed maturity and is usually associated with poor control achieved with conventional herbicide application (Das et al., 2014). By the use of practices like narrowed rows, the soybean gains advantage over annual and perennial weeds because the canopy formation is enhanced and leads to earlier canopy closure, reducing the light capturing ability of weeds (Norsworthy, 2004). This trait is often combined currently with an increase in plant density, which along with narrow row spacing improves crop competitiveness (Datta et al., 2017). Due to the fact that they are based on active ingredients with different MOAs than post-emergence herbicides, pre-emergent herbicides reduce selection pressure on subsequent post-emergent herbicide applications and remove much of the early season weed competition for crops (Travlos et al., 2014; Gage et al., 2019; Pacanoski & Mehmeti, 2019).

During the last years and especially since several herbicides are no longer registered in a EU level, there have been many reports that many weeds have become extremely difficult to control with several herbicides and often herbicide resistant (Travlos & Chachalis, 2010; 2012). In addition to this, there is a global lack of selective herbicides that control weeds like purple nutsedge (Kumar et al., 2012). Consequently, a limited number of active ingredients is used in many countries, leading often in overreliance to them and loss of efficacy (Burke et al., 2008). The soil applied herbicide S-metolachlor is a typical example which is used by farmers against nutsedges (Boyd & Dittmar, 2018). There are also some post emergence herbicides such as trifloxysulfuron and pyrithiobac sodium which are recommended against purple nutsedge (Gannon et al., 2012; Banerjee et al., 2018). The objectives of this study were to evaluate the efficacy of several pre- and post-emergence herbicides against purple nutsedge in a high infested field and their effect on the productivity of soybean in terms of biomass and seed yield.

MATERIAL AND METHODS

Description of the Study Site

A field study was conducted in the experimental field of Agricultural University of Athens in Kopaida region in Greece (Latitude: 38°23'33.0 N, Longitude: 23°06'08.8 E, Altitude: 94 m above sea level) from May until September 2019. The soil was a clay loam with high organic matter. Weather data (mean monthly temperature and precipitation) during the growing period were obtained from the weather station of

National Observatory of Athens in Kopaida and can be shown in Fig. 1. This field had been cultivated for several years only with cotton with complete absence of rotation crops. Purple nutsedge densities in this field were usually high (over 40–50 plants m^{-2}) indicating that it was a high infested area. The control of purple nutsedge and other perennial weeds, such as *Sorghum halepense* which also occurred in the experimental field during the previous years, was conducted traditionally with hand-weeding, a practice that is still followed.

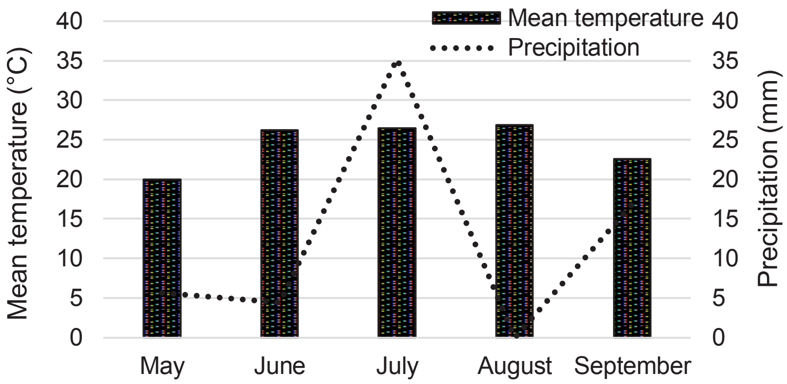

Figure 1. Weather data (mean monthly temperature and total month precipitation) during the growing period in the experimental area.

Treatments and Experimental Design

This study was carried out to evaluate different sole applications of chemical herbicides for the control of purple nutsedge in soybean. Soybean was seeded at 800,000 seed ha^{-1}, in a row configuration of 25 cm with a desired plant density of around 60–70 plants m^{-2}, with 5 cm distance between the seeds in the row and a 3-cm seed depth. The soil was tilled and harrowed prior soybean sowing, which was conducted on 19 May 2019. The experimental field was fertilized with a conventional 20-20-20 fertilizer the same day with the field cultivation. The plants were irrigated regularly almost every 2 weeks until 10 August, which was the last irrigation for soybean. After that, the plants followed the physiological maturity and the harvest conducted at 15 September.

The treatments included a) a non-treated control, two treatments with pre-emergence applications with b) S-metolachlor or c) pendimethalin, as well as three post-emergence applications with d) trifloxysulfuron, e) bentazone or f) pyrithiobac sodium. Trifloxysulfuron, bentazone and pyrithiobac sodium were applied at 26 days after sowing (DAS). The

Table 1. The treatments and application rates of the tested herbicides. PRE: Pre-emergence application, POST: Post-emergence application

Treatment	Active ingredient	Dose, g a.i. ha^{-1}	Application
1	-	-	Untreated control
2	s-metolachlor	1,248	PRE
3	pendimethalin	1,980	PRE
4	trifloxysulfuron	15	POST
5	bentazone	1,440	POST
6	pyrithiobac sodium	68.9	POST

untreated control was left without any herbicide application throughout the entire growing season. The plots were sprayed using a custom-built, compressed-air, low-pressure flat-fan nozzle experimental sprayer, calibrated to deliver 300 L ha^{-1} at 250 kPa. The treatments can be found in Table 1 and were replicated four times in a complete block design. The size of each plot was 1.25 m × 3.30 m. The plots were arranged in the field in a completely randomized block design.

The measurements were carried out from 14 days after treatment (DAT) and at week intervals until harvest and included: (1) density of purple nutsedge, (2) dry weight of purple nutsedge and (3) dry weight of soybean. Soybean yield was also recorded at harvest, at 119 days after sowing (DAS). Concerning the plant density records, a custom-built quadrat of an area of 1 m^2 was used across the weekly measurements. The quadrat was deposited in specific area inside each plot and this process was repeated twice in each plot.

Data Analysis

The experimental data were analysed using the STATGRAPHICS Centurion XVII Version statistical software (Statpoint Technologies Inc., The Plains, VA, USA). All data were subjected to multiple ANOVA. Treatment and replication effects were tested along with all possible interactions. Treatment means were separated using Fisher's protected LSD test at $P < 0.05$.

RESULTS AND DISCUSSION

Our findings have shown that the application of herbicides like S-metolachlor and bentazone maintained an average density of about 15 plants m^{-2} at 14 DAT (Fig. 2). This density is significantly lower ($P < 0.05$) than the corresponding values for the untreated plots and the plots treated with pendimethalin.

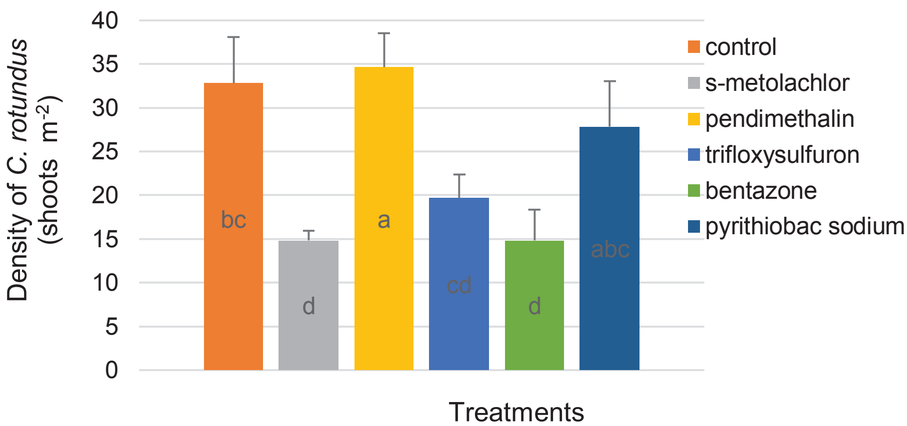

Figure 2. Purple nutsedge density two weeks after the post-emergence herbicide applications (14 DAT). Vertical bars denote the standard errors of the means.

The biomass of purple nutsedge also confirmed that the treatments with S-metolachlor was the most effective one for the control of this noxious weed (Fig. 3), partially due to the suppression of its regrowth and the lower density described above.

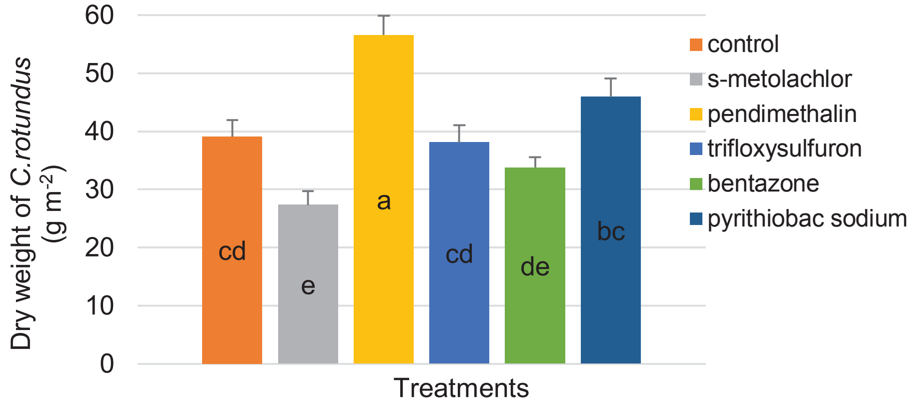

Figure 3. Purple nutsedge dry weight two weeks after the post-emergence herbicide applications (14 DAT). Vertical bars denote the standard errors of the means.

The dry weight measurements of soybean at 60 DAS (Fig. 4) showed that the growth was significantly higher in the treatment where S-metolachlor was applied ($P < 0.05$). This pattern was repeated until harvest date (data not shown), showing 2-3-fold higher growth of S-metolachlor than the other treatments and a significantly lower productivity in the cases of untreated plots and the plots treated with pendimethalin.

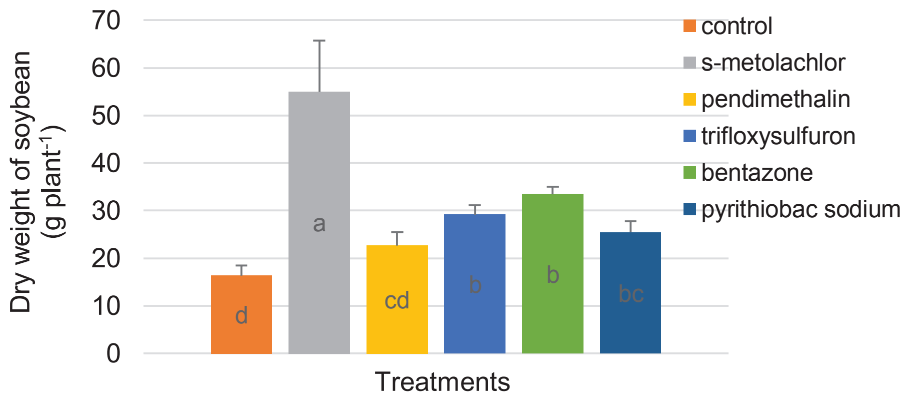

Figure 4. Soybean biomass for the several treatments at 60 days after sowing (60 DAS) or 34 days after the post-emergence herbicide applications (34 DAT). Vertical bars denote the standard errors of the means.

In Fig. 5, it is shown that seed yield of soybean treated with S-metolachlor was 3.26 tn ha^{-1}. This yield was 52% higher than the untreated plots and 38–45% higher than the other herbicides. This significantly higher yield can be attributed to the effective control of purple nutsedge observed during the growing period, which ensured a better soybean growth and a higher productivity. Our findings regarding the low yield in the untreated plots are in full agreement with Datta et al. (2017), who showed that weed competition especially in the first growth stages of soybean can result in great yield losses.

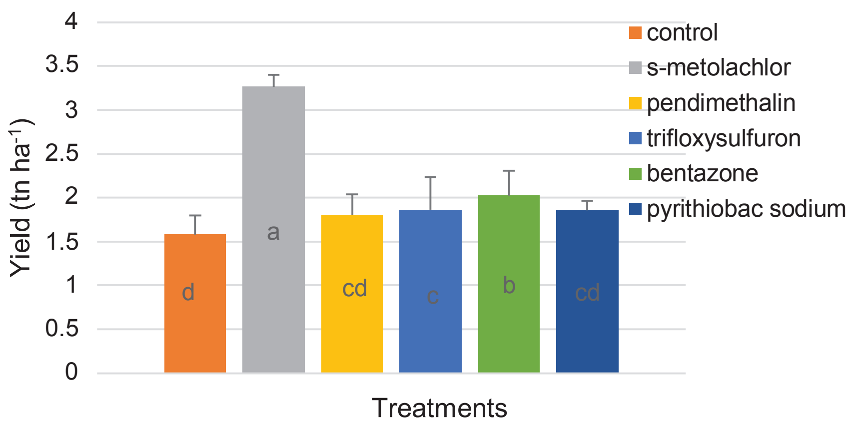

Figure 5. Soybean seed yield for the several treatments at harvest. Vertical bars denote the standard errors of the means.

S-metolachor proved to be a very effective herbicide against purple nutsedge, a finding previously reported by Norsworthy (2004) and Brecke et al. (2005). A pre-emergent application with S-metolachlor at a rate of 1,248 g a.i. ha^{-1} resulted in high soybean seed yield and provided a long-term control of purple nutsedge. The competition with nutsedge for water and nutrients was low in the crucial growth stages of flowering and pod-filling and consequently yield was high, in agreement with the findings of the study conducted by Wei et al. (2018). On the contrary, weed management programs in soybean which depend only on pendimethalin pre-emergence applications can't always eliminate the weed interference in crop, leading to low yields (Yadav et al., 2017). The same authors found that a single application of pendimethalin pre-emergence in soybean resulted in a seed yield of 1.7 tn ha^{-1}, a value comparable with the one found in our study. Therefore, several researchers suggested the combination of pendimethalin with hand-weeding in order to achieve high soybean yield (Rajput & Kushwah, 2004). Furthermore, mixtures can also give a solution, with the application of pendimethalin in a mixture with imazethapyr resulting in soybean seed yield higher than 2.5 tn ha^{-1} (Das & Das, 2018).

Our findings also revealed that the post-emergence herbicides trifloxysulfuron and pyrithiobac sodium were of intermediate efficacy when they were applied alone and didn't give a clear advantage to soybean. Kaur et al. (2019) stated that pyrithiobac sodium needs to be combined with other chemical or cultural methods in order to show significant results against purple nutsedge, which is in full agreement with our findings. Concerning trifloxysulfuron, this active ingredient acted better when it was tank-mixed with other herbicides against purple nutsedge (Gannon et al., 2012; Boyd & Dittmar, 2018). The integrated management of purple nutsedge should also focus on tuber viability (Brecke et al., 2005; Webster et al., 2008) and the regrowth. All the above show that competition among perennial weeds and cultivated plants should be assessed in a long-term basis and introduction of new active ingredients, novel tank mixes and adoption of integrated weed management approaches are of major importance.

CONCLUSION

In summary, a single application of S-metolachlor resulted in soybean seed yield of 3.26 tn ha^{-1}, a value significantly higher than the average yield in Greece (approximately 2.5 tn ha^{-1}). The adequate control of purple nutsedge during the crucial first crop growth stages allowed a better growth of soybean and a canopy closure that also suppressed the weed and resulted in high biomass and seed production for the crop. In all cases, integrated weed management (IWM) strategies need to be adopted.

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