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Research Article

The effectiveness of herbicidal desiccants and application times on seed yield and earliness of soybean

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Abstract

Two herbicidal desiccants and five application times at different reproductive stages of soybean were investigated for earliness without significant reduction in seed yield and quality. Glyphosate and diquat were applied to soybean cv. 'Arısoy' (maturity group III) at growth stages of R_5, R_6, R_7 and R_8. Full maturity (FM) and uprooted plants at each growth stage were also used as a control. Plant height, first pod height, pod number per plant, seed weight per plant, thousand seed weight, seed yield and oil ratio were investigated. The results showed that plant height was not affected by desiccants and application times. Lower seed weight per plant, thousand seed weight, seed yield, and oil ratio were obtained from earlier reproductive stages, especially at R_5, and R_6, but glyphosate produced higher seed yield and oil content than diquat. Both desiccants considerably reduced seed yield when applied at R_5 and R_6. Mean seed yield enhanced from 1,364 to 3,036 kg ha^{-1} in first year and from 1,097 to 2,804 kg ha^{-1} in second year as the growth stages extended from R_5 to R_8. Diquat was more effective desiccant for accelerating soybean harvest than glyphosate, while higher seed yield was obtained from glyphosate spraying at R_5 and R_6 stages. Increased seed yield was observed in diquat application when the soybean growth stages were delayed from R_5 to R_8. It was concluded that glyphosate should be applied at R_7 in soybean for earliness with 7-10 days in harvest and no desiccant should be suggested before R_7 stages.

Keywords: application stage; defoliation*; Glycine max* L., growth stage; seed yield

Introduction

Turkey imports soybean seeds, cake, raw and refined oil every year and the import value has reached up to 2 billion dollars nowadays (Anonymus, 2019). Soybean is an economically important for our poultry industry due to rich protein and oil contents of the seeds. The production of soybean is strictly supported by the Turkish government to meet the demand of soybean products (Kolsarıcı *et al.*, 2015), while its cultivation has been limited into Mediterranean region, subtropical climatic zone of Turkey (Kulan *et al.*, 2017). For these reasons, the sowing area of soybean must be expanded to increase the production of soybean under different regions with temperate ecology. Central Anatolian region, characterized as continental climate with snowy and cold winter, and dry and temperate summer, has a potential to meet the demand of soybean. Torunlar and Nazlıcan (2018) estimated that approximately 9.5 million ha are suitable for soybean production in this region.

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However, its cultivation is inhibited by two main problems dealing with low temperature in spring months, and rainy and cold weather conditions in autumn, which lead to limiting vegetation period from planting to harvest; consequently, soybean growing period must be shortened or accelerated by several cultivation methods.

One of the most promising methods for shortening growing period is the use of harvest aid chemicals, which are referred as desiccants and defoliants. They have successfully been applied for earlier harvest than normal (Pereira *et al*., 2015). Among these chemicals, paraquat, diquat and glyphosate have been commonly used for desiccation in soybean (Azlin and McWhorter, 1981; Zagonel, 2005; Boudreaux and Griffin, 2011) in order to accelerate maturity. Therefore, this study aimed to investigate the possibilities of herbicidal desiccants such as diquat and glyphosate, extensively used as weed killer, for shortening the harvest period without causing a significant decrease in seed yield and quality of soybean.

Materials and Methods

Description of the study site

Field experiments were established in 2016 and 2018, at the experimental field of Department of Field Crops, Eskişehir Osmangazi University, Eskişehir-Turkey. Soybean cultivar 'Arısoy' with maturity group III was used and experienced for growing performance under Eskişehir conditions by Kulan *et al.* (2017). The soil of the experimental areas was loamy with 0.88-1.76% organic matter and slightly alkaline (pH = 7.6-8.2). The seeds were planted on April 29, 2016 and April 17, 2018. The climate was characterized as continental climate by warm and dry in summer months, cold and snowy during winter. In the experimental years, mean temperatures during the growing period were 17.5 °C and 18.8 °C, respectively. Total rainfall was 170 mm in 2016 and 228 mm in 2018. Because rainfall was insufficient to supply soybean water requirement, springer irrigation was applied when the plants needed.

Experimental procedures

The planting was done manually with plant density of 70 × 3 cm. Each plot was consisted of four rows and the plot size was 2.8 m by 4 m with dimension of 11.2 m^2. The desiccant treatments were arranged according to soybean growth stages. They were applied when the soybean plants reached to R_5, R_6, R_7 and R_8 stages described as following. No desiccant spraying was performed in full maturity and the plants were harvested manually.

R_5: Visible seed in pod of the four uppermost nodes on the main stem

R_6: Beans touching inside pods of the four uppermost nodes on the main stem

R_7: Pod mature in colour anywhere on plant

R_8: Approximately 50% of the pods mature in colour and containing mature seed

Full maturation: 95% of pods reached to maturation and seed moisture below 13%

The desiccants of diquat at 6,000 mL ha^{-1} and glyphosate at 8,000 mL ha^{-1} with 300 L water per hectare were pulverized onto the plants in each growth stage by backpack sprayer. Also, naturally full maturity (FM) was used for comparing the investigated parameters to the desiccant applications. Uprooted and dried plants on soil surface at each growth stage were evaluated as control (C).

In both years, the plants were fertilized with 30 kg ha^{-1} nitrogen and 60 kg ha^{-1} P_2O_5 before sowing. Pre-emergence herbicide (Linuron 450 g L^{-1}) was applied to kill weeds after sowing and hand hoeing was performed at 30 days after emergence along with nitrogen of 200 kg ha^{-1} as ammonium sulphate. Additional nitrogen dose (urea) of 200 kg ha^{-1} was broadcasted prior to first irrigation. At maturity, ten plants were randomly selected from each plot and were used to determine yield and yield components. The oil percentage was determined by Soxhelet extraction (Gerhardt Soxtherm 414, Germany) method using n-Hexane as a solvent. The experiment was designed by randomized complete blocks with four replicates and comparison of the means was done by Duncan's Multiple Range Test using MSTAT-C (Michigan State University v. 2.10) software.

Results and Discussion

The results of analysis of variance with significance levels of the main effect of the years, desiccants and applications times, two- and three-way interactions on the investigated parameters were shown in Table 1. The results from each experimental year were also given separately in Table 2 and Table 3. A significant difference between the experimental years was determined in all the parameters except for oil ratio. The longer plant height and first pod height were obtained in the second year, while higher seed weight, pod number and seed yield were recorded in the first year. Desiccants clearly affected the yield parameters of soybean and glyphosate was superior to diquat. The highest one thousand seed weight and seed yield were detected in glyphosate application without any changes in oil ratio. Application time significantly influenced the parameters and delayed application times promoted seed yield. The highest oil ratio was measured in R_6 with 21.1%.

Table 1. Main effects of year, desiccant and application time on seed yield and yield components of soybean

Factors	Plant height (cm)	First pod height (cm)	Pod number per plant	Seed weight (g plant^{-1})	Thousand seed weight (g)	Seed yield (kg ha^{-1})	Oil ratio (%)
Years							
1st Year	103.8 b	13.5 b	129.5 a	38.5 a	143.6 a	2,441 a†	20.3
2nd Year	114.1 a	21.1 a	51.4 b	12.5 b	103.7 b	2,228 b	20.2
Desiccant							
Control	111.6	17.2 b	97.7 a	26.9	119.8	2,222 b	20.1
Diquat	104.1	16.5 b	89.8 b	25.7	123.9	2,237 b	20.6
Glyphosate	111.1	18.2 a	83.8 b	23.9	127.2	2,544 a	20.1
Application time							
R_5	107.0	16.8 bc	85.6 b	11.7 e	88.6 c	1,231 d	19.0 c
R_6	107.9	19.8 a	86.3 b	20.1 d	117.4 b	2,000 c	21.1 a
R_7	109.2	16.1 c	100.8 a	36.2 a	137.4 a	2,651 b	20.9 ab
R_8	113.1	17.5 b	89.6 b	32.8 b	137.6 a	2,869 a	20.2 b
FM	107.5	16.1 c	89.8 b	26.8 c	137.2 a	2,921 a	20.2 b
Analysis of Variance (ANOVA)							
Year (Y)	*	**	**	**	**	*	ns
Desiccant (D)	ns	**	**	ns	ns	*	ns
Application time (AT)	ns	**	**	**	**	**	**
Y×D	ns	**	**	ns	ns	ns	ns
Y×AT	ns	**	**	**	**	**	*
D×AT	ns	**	**	**	**	**	ns
Y×D×AT	ns	**	**	**	ns	**	*

*, ** show significance level at $p<0.05$ and $p<0.01$ respectively; ns: non-significant; †: Means followed by same letter(s) are not significant.

Table 2. Changes in plant height, first pod height, pod number, seed weight of soybean affected by desiccants and application times

	1st year				2nd year			
Stage	Uprooted	Diquat	Glyphos.	Mean	Uprooted	Diquat	Glyphos.	Mean
	Plant height (cm)							
R_5	109	103	102	105	115	96	116	109
R_6	106	96	102	102	110	107	125	114
R_7	107	95	104	102	110	116	122	116
R_8	115	104	105	108	119	118	118	118
FM	111	93	103	102	113	113	113	113
Mean	110	98	103		113	110	119	
	First pod height (cm)							
R_5	15.5 b	14.3 bc	13.7 c	14.5 b	14.5 d	20.4 bc	22.8 bc*	19.2 b
R_6	19.5 a	13.8 bc	14.5 bc	15.9 a	23.6 ab	21.5 bc	26.0 a	23.7 a
R_7	11.8 d-g	11.2fg	13.5 cd	12.2 c	19.4 c	20.4 bc	20.3 bc	20.1 b
R_8	14.2 bc	11.6 efg	11.5 efg	12.4 c	20.9 bc	20.8 c	26.4 a	22.7 a
FM	13.2 cde	11.1 g	13.0 c-f	12.4 c	19.9 c	19.6b c	19.6 bc	19.7 b
Mean	14.8 a	12.4 b	13.2 b		19.7 b	20.5 b	23.0 a	
	Pod number per plant (number plant^{-1})							
R_5	127 bc	123 c	110 c	120 b	53 abc	46 cd	34 e	44 c
R_6	113 c	126 bc	119 c	119 b	44 d	54 abc	49 bcd	49 b
R_7	167 a	134 bc	131 bc	144 a	61 a	52 a-d	56 ab	56 a
R_8	123 c	150 ab	127 bc	133 a	47 bcd	60 a	52 a-d	53 ab
FM	129 bc	133 bc	131 bc	131 ab	54 abc	54 abc	54 abc	54 a
Mean	132	133	124		52	53	49	
	Seed weight per plant (g)							
R_5	15.5 e	17.7 de	17.5 de	16.9 d	7.8 gh	5.7 h	5.9 h	6.5 c
R_6	29.5 c	25.0 cd	28.0 c	27.5 c	17.3 ab	10.0 fg	10.6 efg	12.6 b
R_7	65.6 a	45.2 b	59.0 a	56.5 a	18.8 a	14.9 bcd	14.1 bcd	15.9 a
R_8	47.1 b	62.2 a	47.0 b	52.0 a	12.4 def	16.4 abc	12.2 def	13.6 b
FM	40.9 b	47.0 b	31.5 c	39.8 b	13.8 cde	13.8 cde	13.8 cde	13.8 b
Mean	39.7	39.4	36.5		14.1 a	12.2 b	11.3 b	

*: Means followed by same letter(s) are not significant at $p<0.05$. FM: Full maturation

No significant changes were observed in plant height of soybean as affected by desiccants and application times (Table 2). Plant height was measured between 95 cm and 115 cm in the first year and it was recorded as 96-119 cm in the second year. It means that the plants stop growing or little growth occurs after R_5 stage. A significant two-way interaction of desiccant × application' time for first pod height, pod number and seed weight per plant was found. In both years, uprooted and glyphosate applied plants in R_7 gave the highest pod height, while the plants treated with diquat showed in R_8. Similarly, the highest pod number and seed weight per plant were detected in R_7 stage of the plants uprooted and treated with glyphosate. Pereira *et al.* (2015) determined no significant differences between glyphosate and diquat for pod number plant^{-1} and seed weight in spite of higher pod number plant^{-1} in earlier application of glyphosate. However, diquat produced higher pod number and seed weight in soybean plant in R_8 stage. It means that the activity of diquat was faster than glyphosate and it effectively desiccated soybean plants when it was applied. Our observation showed that it dried firstly the leaves during 3 days after spraying, but main and branch stems took longer time compared to glyphosate to desiccate. This finding was supported by Whigham and Stoller (1979), they stated that the most effective desiccant for hasten harvest date of soybean was paraquat and it decreased seed weight and yield when applied before R_7 stage.

Table 3. Changes in thousand seed weight, seed yield and oil ratio of soybean affected by desiccants and application times

	1st year				2nd year			
Stage	Uprooted	Diquat	Glyphos.	Mean	Uprooted	Diquat	Glyphos.	Mean
	Thousand seed weight (g)							
R_5	95 d	108 de	126 c	110 c	55 e	72 d	74 d*	67 c
R_6	119 c	126 c	146 b	130 b	100 c	106 bc	107 abc	104 b
R_7	154 ab	156 ab	168 ab	159 a	115 ab	107 ab	115 ab	116 a
R_8	157 ab	168 ab	161 ab	162 a	113 ab	119 a	108 abc	113 a
FM	172 a	149 ab	148 b	156 a	118 a	118 a	118 a	118 a
Mean	140	142	150		100	104	104	
	Seed yield (kg ha^{-1})							
R_5	883 f	1,154 f	2,055 de	1,364 c	773 g	1,010 g	1,508 f	1,097 d
R_6	1,739 de	1,643 e	2,216 cd	1,866 b	1,987 de	2,126 de	2,292 cd	2,135 c
R_7	3,001 ab	2,659 bc	3,027 ab	2,896 a	1,871 e	2,565 bc	2,784 ab	2,407 b
R_8	3,081 ab	2,766 ab	3,278 a	3,042 a	2,940 a	2,640 abc	2,507 bc	2,696 a
FM	3,175 ab	2,984 ab	2,948 ab	3,036 a	2,771 ab	2,821 ab	2,821 ab	2,804 a
Mean	2,376	2,241	2,705		2,068 b	2,232 ab	2,382 a	
	Oil ratio (%)							
R_5	18.8 d	18.9 d	20.1 c	19.2 b	19.1 cd	16.6 d	20.2 bc	18.6 c
R_6	20.4 bc	21.2 a	20.2 bc	20.6 a	21.9 abc	22.6 ab	20.1 bc	21.6 a
R_7	20.6 abc	20.7 abc	20.4 bc	20.6 a	20.7 abc	23.1 a	19.9 bc	21.2 ab
R_8	20.7 abc	20.5 abc	20.2 bc	20.5 a	19.0 cd	21.4 abc	19.2 cd	19.9 bc
FM	20.5 abc	20.9 ab	20.4 bc	20.6 a	19.8 bc	19.8 bc	19.8 bc	19.8 bc
Mean	20.2	20.4	20.3		20.1 ab	20.7 a	19.8 b	

*: Means followed by same letter(s) are not significant at $p<0.05$. FM: Full maturation

A thousand seed weight of soybean was considerably influenced by desiccants and application times in both years (Table 3). It was the lowest in the plants uprooted or treated with diquat or glyphosate in R_5 and R_6 stages. Increased soybean growth led to increasing a thousand seed weight but it was changed by desiccants. Reproductive stage of R_7 and later stages produced heavier seed weight (168 g) at application of glyphosate, and diquat at R_8 with 168 g. In second year, similar findings were recorded as delayed desiccant application time resulted in increasing seed weight. Toledo *et al.* (2014), Pereira *et al.* (2015), Finoto *et al.* (2017) and Rosado *et al.* (2019) supported the finding that seed weight improved when desiccant application was performed in later growth stages of R_6, but significant differences among desiccants. Significant changes in seed yield of soybean were determined according to desiccants and application times. In both years, R_5 and R_6 gave lower seed yield whatever desiccants were. Bennett and Shaw (2000) observed that early desiccant applications (R_5 and R_6) reduced the seed yield in soybean. Both diquat and glyphosate applied at R_7 and R_8 produced the seed yield as much as full maturity. Except for full maturity, the highest seed yield was obtained from glyphosate treatment at R_8 with 3,278 kg ha^{-1} in the first year and 2,784 kg ha^{-1} in the second year. It was determined that the critical growth stage for desiccant spraying was at R_7 because the desiccant applications in earlier stages caused a drastic reduction in seed yield. The results are in line with the findings of Zagonel (2005), Pereira *et al.* (2015), Finoto *et al.* (2017) and Araújo *et al.* (2018) who found that seed yield was promoted by delayed harvest time and adverse effects of desiccants on the soybean yield were identified. Rosado *et al.* (2019) stated that significant reduction in seed yield of soybean with paraquat application on R_8, while Guimarães *et al.* (2012) determined that glyphosate had higher seed yield compared to ammonium glyphosinate and paraquat. Soltani *et al.* (2013) reported that no reduction in dry edible bean yields when desiccants (glyphosate and saflufenacil) were applied at full maturity. Furthermore, Ratnayake and Shaw (1992) stated that the adverse effects of herbicides were observed on seed yield, germination or seedling development of soybean when were applied at R_8. Rahman *et al.* (2004) and Finoto *et al.* (2017) reported that early desiccation resulted in a

dramatic decline in seed germination, seedling growth and seed vigour of soybean. If desiccant application times were retarded, seed yield of soybean reduced. In the study of Cerkauskas *et al.* (1982), seed yield was severely affected when paraquat was applied before full maturity. Likewise, reduction in seed yield and quality were observed when glyphosate was applied 3 to 4 wk before harvest (Azlin and McWhorter, 1981). Our results showed that oil content was remarkably changed by desiccants and application times and the lowest oil content was apparently obtained in R_5 stage exposed to both diquat and glyphosate in both years. Diquat application at R_6 in first and R_7 in second year resulted in the highest oil content in soybean. Our results are supported by Finoto *et al.* (2017), who reported that early harvest clearly declined oil content of soybeans treated with diquat.

Desiccants allowed for accelerating of harvest time by 19-25 days when they were treated in R_5 and R_6 however, these stages created an unacceptable yield reduction (Table 4). On the other hand, in R_7 stage their application resulted in earliness between 9 and 16 days depending on the number of days without precipitation. In addition, glyphosate gave longer harvest time from spraying than diquat to desiccate the plants during the experimental years. Our results are in line with the findings of Pereira *et al.* (2015) and Araújo *et al.* (2018).

Table 4. Harvest dates of soybean subjected to the desiccants and application times in 2016 and 2018 years

Applic. stage	1st year			2nd year		
	Uprooted	Diquat	Glyphos.	Uprooted	Diquat	Glyphos.
R_5	2 September	20 September	1 October	19 August	1 September	5 September
R_6	11 September	20 September	6 October	02 September	11 September	16 September
R_7	29 September	10 October	13 October	16 September	21 September	24 September
R_8	13 October	20 October	20 October	25 September	30 September	30 September
Full maturity	25 October			5 October		

Conclusions

In conclusion, desiccants may successfully be used as harvest aid chemicals for earliness and leaf defoliation in soybean, but timing is essential to produce enough seed yield and quality. In the study, it was determined that R_7 stage of soybean was the crucial for high yielding soybean production without quality loss. The application of desiccants led to earliness between 7 and 10 days compared to untreated control although the effectiveness of desiccants was very different from each other and diquat dried the soybean plants more rapidly than glyphosate. For this reason, diquat should be preferred if soybean plant was in later than R_7 stage. It was concluded that glyphosate application at growth stage of R_7 should be advised for shortening harvest date of soybean.

Authors' Contributions

Both authors read and approved the final manuscript.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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