Effect of water volume and water quality on the efficacy of glyphosate on some important weed species in Turkey

Einfluss von Wassermenge und -qualität auf die Wirksamkeit von Glyphosat bei wichtigen Unkrautarten in der Türkei

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Summary

The effect of spray water volume and water quality on the performance of three Roundup formulations were investigated in pot experiments to observe whether these factors influence the efficacy of herbicide on three important weed species occurring in Turkey. *Sorghum halepense, Cyperus rotundus* and *Portulaca oleracea* were used in the experiments. All Roundup formulations were applied at three different doses with two water volume rates (200 and 600 l/ha) and three different water qualities (clean water, clean water + $CaCl_2$ to simulate hard water and water of Büyük Menderes River). Experiments were carried out at the research station of Adnan Menderes University in the Aydin province of Turkey and replicated twice. Results of the studies showed that the performance of Roundup on weeds was not influenced by herbicide formulation, but significantly affected by water volume as well as water quality. However, the effect of these factors was variable depending on the weed species and the applied herbicide dose. Significant differences were observed mostly at reduced doses more apparently in the case of more sensitive weed species such as *P. oleracea* and *S. halepense*. *C. rotundus* was more tolerant against herbicide so that an influence of investigated factors on the efficacy was observed even with the recommended dose. In general, low volume treatments (200 l/ha) provided significantly higher weed control. Similarly, clean water improved the effectiveness of the herbicide on weeds. These results suggest that using clean spray water and low volume treatments improve the efficacy of glyphosate at the recommended and reduced rates depending on the sensitivities of weed species.

Keywords: *Cyperus rotundus*, formulation, *Portulaca oleracea*, *Sorghum halepense*

Zusammenfassung

Mit Gefäßversuchen wurde der Einfluss von Wassermenge bzw. -qualität auf die Wirksamkeit von drei verschiedenen Roundup-Formulierungen bei wichtigen Unkrautarten in der Türkei untersucht. *Sorghum halepense, Cyperus rotundus* und *Portulaca oleracea* wurden bei den Experimenten verwendet. Alle Formulierungen wurden mit drei Aufwandmengen aufgebracht, jede mit 2 verschiedenen Wassermengen (200 und 600 l/ha) und bei drei verschiedenen Wasserqualitäten (reines Wasser, reines Wasser + $CaCl_2$, um die Wasserhärte zu steigern, und Wasser aus dem Büyük Menderes Fluss). Die Versuche wurden am Forschungszentrum der Adnan Menderes Universität in Aydin, Türkei, durchgeführt und zweimal wiederholt. Die Ergebnisse zeigten, dass die Wirksamkeit von Roundup auf die Unkräuter nicht von der Formulierung beeinflusst wurde, aber der Einfluss von Wassermenge bzw. -qualität war signifikant. Jedoch waren die Einflüsse dieser Faktoren von der Unkrautart bzw. von den Aufwandmengen abhängig. Erhebliche Unterschiede wurden bei den reduzierten Aufwandmengen und bei den sensitiveren Arten beobachtet, wie z. B. *P. oleracea* und *S. halepense*. *C. rotundus* war gegenüber dem Herbizid unempfindlicher, so dass die untersuchten Faktoren sogar bei den empfohlenen Aufwandmengen keine Unterschiede der Wirkung verursachten. Im Allgemeinen lieferten Behandlungen mit niedriger Wassermenge signifikant höhere Bekämpfungsgrade. Reines Wasser erhöhte ebenfalls die Wirkung des Herbizids auf die Unkräuter. Aus diesen Ergebnissen geht hervor, dass die Wirksamkeit von Glyphosat bei Anwendung mit reinem Spritzwasser und verringertem Wasseraufwand bei den empfohlenen bzw. reduzierten Aufwandmengen in Abhängigkeit von der Empfindlichkeit der Unkrautarten verbessert wird.

Stichwörter: *Cyperus rotundus*, Formulierung, *Portulaca oleracea*, *Sorghum halepense*

1. Introduction

Efficacy of a herbicide against a weed is influenced by many factors, such as weed growth stage, type of herbicide formulation, application technique as well as the climatic conditions during the application (KUDSK and STREIBIG, 2003). Therefore, relationships between herbicide efficacy and such factors should be well defined to obtain consistently satisfactory weed control with any herbicide. On a worldwide basis, glyphosate is the most frequently used herbicide in crops, as well as on non-agricultural areas such as railways and roadsides. In Turkey, the main sector for weed control with glyphosate is perennial crops. Although glyphosate has been applied for a long time in Turkey, there is currently no real reported dissatisfaction in terms of glyphosate efficacy. However, some weeds, such as purple nutsedge (*Cyperus rotundus* L.), Johnsongrass (*Sorghum halepense* L. (PERS.) and common purslane (*Portulaca oleracea* L.) are reported to be difficult to control with glyphosate according to some growers as well as herbicide dealers. This experience was partly confirmed by some scientific studies carried out by DOGAN et al. (2008 and 2009). *Cyperus rotundus* and *Portulaca oleracea* were in some cases less sensitive to glyphosate as compared to some other important summer weeds occurring in southern and western Turkey. Therefore, special attention should be paid to optimize the glyphosate efficacy for these weeds species. Previous studies with glyphosate showed that the efficacy of this herbicide is affected by the formulation and adjuvants (NALEWAJA and MATYSIAK, 1995; ZOLLINGER, 2002), by water volume, and by quality of spray water in which a herbicide is dissolved (JORDAN, 1981; BUHLER and BURNSIDE, 1983; NALEWAJA and MATYSIAK, 1991). Based on this information, some experiments were planned aiming to evaluate the effects of spray water volume and spray water quality on the performance of glyphosate by using different glyphosate (Roundup) formulations.

2. Materials and methods

Pot experiments were carried out in the greenhouse of the Weed Science laboratory at Adnan Menderes University, Faculty of Agriculture, Turkey. Perennial weeds were grown from rhizomes and *P. oleracea* from seeds. A mixture of turf, sand, perlite and soil (1:1:1:1) was used as growing medium that is suitable for weed growth under greenhouse conditions.

Rhizomes of *S. halepense* were planted in 3.8-l pots and rhizomes of *C. rotundus* and seeds of *P. oleracea* were in 3.0-l pots. Experiments with *S. halepense* were carried out with four pots (replications) and with *C. rotundus* and *P. oleracea* with five replications. Each pot received a single individual plant. Three different glyphosate formulations were used in all experiments (Tab. 1), each at three doses (recommended dose 2160 g a.i./ha, 1620 g a.i./ha corresponding 75 % of the recommended dose and 1080 g a.i./ha corresponding to half dose).

Tab. 1 Glyphosate formulations that were used in the experiments.

Tab. 1 *Glyphosat-Formulierungen für die Versuche.*

Formulation	Trade name	Glyphosate content (g a.i./l)
MON 79376	Roundup Star	360
MON 79351	Not yet commercial in Turkey	480
MON 78273	Cayenne	540

All herbicide treatments were conducted by using a spray chamber via 11002 nozzle at 4 bar pressure. First the recommended doses of each formulation were adjusted. Other doses were then obtained as water dilutions.

2.1 Effect of water volume on the efficacy of glyphosate

With this aim, all herbicides were applied at three different doses by using 200 and 600 l/ha water volumes, respectively. Since the spray chamber was adjusted to deliver 200 l/ha water volume, each dose was split to 1/3 and the sprayer was run three times to simulate 600 l/ha water volume. Experiments were carried out two times. Experiments with *S. halepense* were carried out on 20.08. and

11.09.2009. Average plant heights at the beginning of the experiments were 25 and 22 cm, respectively. Experiments with *C. rotundus* were conducted on 11.08. and 25.08.2010 when plants had 5-6 true leaves. Experiments with *P. oleracea* were carried out on 18.08. and 04.09.2009, when the plants had 1-3 branches.

2.2 Effect of water quality on the efficacy of glyphosate

The quality of water on the herbicide efficacy was tested by using the optimal water volume based on the previous experiment module (200 l/ha). Herbicides were dissolved in three different water samples having different characteristics (Tab. 2).

Tab. 2 Features of spray water.

Tab. 2 *Eigenschaften des Wassers für die Spritzflüssigkeit.*

	Clean water	**Clean + $CaCl_2$**	**River water**
Total Hardness (German)	1.12 (very soft)	21.84 (hard)	22.40 (hard)
pH	6.31	6.64	7.56
EC (µS/cm)	46	846	1008
SAR (me/l)	0.63	0.12	1.85
K (me/l)	0.10	0.09	0.34
Ca (me/l)	0.10	7.35	2.37
Na (me/l)	0.19	0.23	3.58
Mg (me/l)	0.08	0.17	5.11
HCO_3^{-1} (me/l)	0.22	0.30	4.47
SO_4^{-2} (me/l)	0.21	0.26	3.51
B (ppm)	0.03	0.003	0.39

The first spray water source was locally available drinking water (clean water). The second water used was originated from the first water sample by adding $CaCl_2$ to simulate the hard water (Clean + $CaCl_2$). The third spray water was river water sampled from Büyük Menderes (Great Meander) River which is used for irrigation and also as spray water by many farmers of the region.

Experiments with *S. halepense* were carried out on 24.05. and 31.05.2010, when plants were in an average height of 33.6 and 50.0cm, respectively. Since results from water volume experiments showed that *S. halepense* could be controlled effectively even at half dose rates larger plants were used in these experiments to observe the effects of water quality and weed growth stage. Experiments with *C. rotundus* were carried out on 09. and 16.06.2010 at 4-5 and 5-6 leaf stages, respectively. Experiments with *P. oleracea* were conducted on 28.06. and 02.07.2010 when plants had 2-4 branches in both experiments.

2.3 Evaluations of the experiments

All experiments were carried out two times. In the case of *S. halepense* and *P. oleracea,* above ground parts of plants were harvested two weeks after treatment to determine fresh and dry weight. This was done three weeks after treatment in the case of *C. rotundus*, because the highest herbicide effect was observed visually at this time. Because of the high water content of *P. oleracea* it was not possible to dry this weed completely, therefore only fresh weight was determined. All data were subject to analysis of variance by using a general linear model procedure and the significance of experiment, formulation, dose, the subject of experiment (water volume or water quality) and the interactions among these factors were determined. To make the results from different experiments comparable, fresh and/or dry weight data was converted to percentage and analyses were made by using relative percent weights in relation to untreated plants. Since *P. oleracea* had no dry weight, only fresh weight results are given here, however similar results were obtained also with dry weight in the case of *S. halepense* and *C. rotundus*.

3. Results and Discussion

Results with *S. halepense* are shown in Table 3. Statistical analyses showed that water volume affected glyphosate performance significantly only in the first experiment at doses lower than recommended. The efficacies of these doses were significantly improved by using low water volumes (200 l/ha) which was obvious, especially with the half dose of the recommended rate. Formulation and all related interactions were not significantly different from each other in both experiments. Therefore data from all formulations were combined and illustrated in Table 3.

Statistical evaluations based on relative weed fresh weights showed that water volume and dose-volume interactions were significant in the case of *P. oleracea* and *C. rotundus*. However, other factors, such as experiment, formulation as well as all related interactions were not significant, so that data from both experiments and all formulations were pooled (Tab. 3).

In the case of *P. oleracea,* water volume was found to be significant only for 50 % herbicide dose, so that this dose applied in 200 l/ha volume provided about 99 % fresh biomass reduction as compared to untreated control plants. However, the same dose applied in 600 l/ha volume provided only about 82 % biomass reduction.

C. rotundus was less sensitive to glyphosate as compared to *S. halepense* and *P. oleracea*. This weed could not be controlled effectively with below recommended doses. An acceptable control (over 90 %) of this weed was achieved only at recommended application rate, when applied in 200 l/ha water volume. Same dose in 600 l/ha water volume provided insufficient efficacy (78 %).

Results from these studies suggested that the effect of water volume was significant but this effect was observed at different doses depending on the sensitivity of weed species. In the case of more sensitive weed species such as *S. halepense* and *P. oleracea,* significant effect of water volume was observed only at below recommended doses, while a significant improvement of the herbicide at recommended dose was observed only for *C. rotundus*, which is a less sensitive species against glyphosate. In all experiments lower water volume (200 l/ha) was the best treatment which can be attributed to that the active ingredient as well as the adjuvants were not diluted by water. This was also confirmed by some previous studies (JORDAN, 1981; BUHLER and BURNSIDE, 1983; CRANMER and LINSCOTT, 1990, 1991). On the other hand, leaf run-off may be another important factor responsible for the poor glyphosate efficacy when applied in higher water volume. However, this case was not experimentally investigated in our studies. CAWOOD et al. (1995) found that the deposition of cladinofop-propargyl on *Alopecurus myosuroides* was higher with lower water volume. In another study with glyphosate, DOGAN et al. (1999) found that spray deposition on *Sinapis alba* plants was significantly higher when herbicide was applied in 200 l/ha water volume as compared to 400 l/ha.

From these results it can be concluded that glyphosate should be applied in lower water volumes and this can lead to use the herbicide in lower doses in the case of more sensitive weed species, but also to an improvement of herbicide activity on difficult to control weed species.

Tab. 3 Relative fresh weights (%) of tested weed species as affected by water volume.

Tab. 3 *Relative Frischmasse nach Behandlung mit unterschiedlichem Spritzflüssigkeitsaufwand.*

Weed species	***S. halepense***				***P. oleracea****		***C. rotundus****	
Experiment	**				**NS**		**NS**	
	I		**II**					
Water volume (l/ha)	**200**	**600**	**200**	**600**	**200**	**600**	**200**	**600**
1080 g a.i./ha (50 %)	8.7 b	37.1 a	18.2 a	13.5 ab	1.6 b	18.0 a	34.2 a	41.4 a
1620 g a.i./ha (75 %)	4.5 b	15.7 b	5.8 b	11.5 ab	0.3 b	1.9 b	15.6 c	26.0 b
2160 g a.i./ha (recommended)	2.7 b	5.9 b	6.8 b	6.3 b	0.0 b	0.4 b	8.2 c	22.4 bc
SEM	4.02		3.36		2.91		3.96	

*results from both experiments were combined, **significant α = 0.01

3.1 Effect of water quality on the efficacy of glyphosate

The results of the first experiment with *S. halepense* showed that glyphosate provided over 95 % efficacy in all treatments regardless of the formulation and water quality. Results are not shown. Therefore, larger *S. halepense* plants were used in the second experiment to reduce glyphosate efficacy in order to observe the effect of water quality and weed growth stage. Results from the second experiment showed that water quality affected the glyphosate performance statistically significant ($\alpha = 0.01$) only at half dose (Tab. 4). The efficacy was significantly lower (just about 36 %) when applied with river water, which is used by many farmers in the region where the studies were undertaken. However, the same dose provided about 95 % efficacy when applications were done with clean water regardless of $CaCl_2$ supplementation. In the case of *P. oleracea*, results from both experiments showed that water quality had no statistical significant effect on the performance of all glyphosate formulations at all doses. Therefore results from these experiments are not given here. As shown in Table 4, water quality affected the performance of glyphosate on *C. rotundus* at all doses. Lowest herbicide efficacy was obtained with river water treatments that were significantly different at the 50- and 75 %-doses. In contrast to experiments with *S. halepense,* it was also possible to see the differences between clean water and clean water + $CaCl_2$ in these experiments. At the 50 %-dose clear water use provided significantly lower weed biomass as compared to the same quality supplemented with $CaCl_2$. Although the same tendency was observed with higher doses, there were no statistically significant differences among them.

Tab. 4 Relative fresh weight (%) of *S. halepense* and *C. rotundus* as affected by spray water quality.

Tab. 4 *Relative Frischmasse von S. halepense und C. rotundus nach Behandlung mit unterschiedlicher Wasserqualität.*

Water quality	***S. halepense****	***C. rotundus*****		
Herbicide dose	**50 %**	**50 %**	**75 %**	**100 %**
Untreated control	**100**			
Clean water	4.4 b	21.7 c	18.0 b	6.0 a
Clean water + $CaCl_2$	5.4 b	43.1 b	24.9 ab	11.9 a
River water	63.8 a	73.0 a	30.7 a	13.6 a
SEM	2.33	4.23		

*results from the second experiment, ** results from both experiments were combined

Results from water quality experiments showed that weeds were controlled more effectively when glyphosate was applied in clean water. Influence of water quality was dependent on the dose and weed species as in the case of the water volume experiments. Since *S. halepense* and *P. oleracea* were very sensitive to glyphosate, the effect of water quality was not observed clearly with these weed species. The effect of water quality on glyphosate performance was best observed with *C. rotundus* which is less sensitive to glyphosate when compared to the other two tested weed species. Glyphosate efficacy was ranked as clean water > clean water + $CaCl_2$ > river water.

From these results it can be concluded that the water hardiness is an important factor affecting glyphosate performance on difficult to control weeds in Turkey. NALEWAJA and MATYSIAK (1991) and THELEN et al. (1995) stated that hard water reduce glyphosate efficacy by reducing the absorption. According to HALL et al. (2000) Ca^{2+} which was added to clean water or when present in high amounts in river water antagonize glyphosate efficacy by forming insoluble complexes which lead to a reduction of cuticular penetration. Similarly glyphosate performance is negatively affected by Mg^{2+} which was especially high in river water (THELEN et al., 1995).

Although these factors are discussed here as the reason for poor glyphosate efficacy, many other factors and interactions among them could be contributing factors, such as EC, HCO_3^{-1}, SO_4^{-2} concentrations and the concentrations of some other cations. More detailed studies are required to quantitatively determine how far the contribution of any individual factor on the glyphosate efficacy is.

The most significant result of the study is that the efficacy of all glyphosate formulations can be improved by considering water volume as well as the quality. However weed sensitivity, weed development stage and/or herbicide dose are important factors to take into account. In the case of very sensitive weed species there is no need to improve glyphosate activity at the recommended dose. An improvement is needed, even at the label recommended dose, when difficult to control weeds dominate on the field. Using clean water in low volume could be a practical solution for growers to improve the *C. rotundus* control of glyphosate. Drinking water was used in these experiments just to show how water quality affect herbicide performance, however, in most cases using drinking water as spray carrier cannot be possible or economically feasible. However, improvement of some characteristics of the currently used spray water, such as filtration, pH adjustment, reduction of hardiness, or any other methods to prevent antagonism might be helpful to increase the herbicidal efficacy. Further studies are needed on this subject.

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