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# The impact of selected adjuvants on glyphosate efficacy for control of field bindweed (*Convolvulus arvensis* l.)

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## ABSTRACT

The effects of different adjuvants in formulating glyphosate-based herbicides and their efficacy in controlling field bindweed (*Convolvulus arvensis* L.) were studied. The formulations were based on mixtures of glycerine (GL), phosphate ester of ethoxylated isodecyl alcohol (PEA) and alkyl polyglucoside (APG) adjuvants at different ratios. Effects of adding ammonium sulfate (ASF) to the glyphosate spray solution were also studied. Herbicides were applied to bindweed plants grown in pots with an experimental sprayer at a volume of 250 l/ha. Visual assessments of efficacy were carried out 3 weeks and 6 months after application, when the assessment of efficacy by weighting above– and underground plant mass was also performed. The best suppression of field bindweed was observed after the 3 week assessment, in the formulations with a high proportion of PEA or an equal proportion of PEA and APG. The best control regarding the assessment of above– and underground plant mass after 6 months was achieved by using formulations with a high proportion of GL with the addition of ASF. The achieved efficacy rates of all formulations after 6 months differed from the ones observed after 3 weeks, and the efficacy observed after 6 months was on average only 60–75 % of the observed after 3 weeks. No sufficient control of the bindweed rhizome system was observed after one treatment, regardless of using any of the selected glyphosate formulations.

Key words: herbicide, formulation, weed, control

## INTRODUCTION

Field bindweed (*Convolvulus arvensis* L.) is one of the world's top noxious weeds in temperate regions (Holm et al. 1977) and is among the most economically important perennial weeds in Slovenia. It can emerge in all agricultural crops and permanent plantations and, if not treated, can reduce yields by as much as 60% (Coombs et al. 2004). Bindweed reduces crop yield and value through competition for resources and by interfering with the harvest procedures (Lindenmayer et al. 2013). In addition, field bindweed can provide a breeding site for insects, attacking adjacent crops (Tamaki et al. 1975) and serves as an alternative host for viruses that cause plant diseases (Feldman and Gracia 1977, Holm et al. 1977). The control of bindweed with chemical and mechanical methods is difficult because of its vigorous regeneration capacity (Lindenmayer et al. 2013). Field bindweed is a very specific type of perennial weed, with the majority of the biomass formed below ground as a part of an extensive rhizome root system. The rhizome root system of individual plants was observed to extend 6 m in diameter and up to 9 m in depth through the soil zone. The fragmentation and dispersal of an underground root system can also lead to a very successful and rapid vegetative propagation (Holm et al. 1977).

Many herbicides have been relatively effective for short-term suppression of bindweed, but have not been very effective in long-term eradication (Westra et al. 1992). Constant herbicide use, supplemented with different non–chemical control methods and the repeating of the whole procedure over several years was found to be the most successful control strategy. No single application of herbicide or herbicide combination will provide a 100% eradication of bindweed (Westra et al. 1992). The most common active ingredients among selective herbicides in use for bindweed control are 2,4-D, picloram, dicamba, quinclorac and imazapyr (Lindenmayer et al. 2013).

Glyphosate (N–(phosphonomethyl)glycine) based non–selective post emerging systemic herbicides are one of the most widely used herbicides and are also very suitable for the control of perennial weeds such as bindweed (Westra et al. 1992, Baylis 2000). A variable response of field bindweed to glyphosate phytotoxicity may be related to plant age, plant vigour, environmental conditions (relative humidity, temperature, and soil moisture) and occurrence of field

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bindweed biotypes that differ in their response to a specific herbicide. The mentioned factors cause a huge efficacy variation. Efficacies for suppression of aboveground parts varied from 13% to 100% (DeGennaro and Weller 1984). However, available data suggest, that glyphosate efficacy for bindweed eradication (efficacy for control of underground plant parts) is much lower compared to the efficacy usually obtained at analysing the control of aboveground parts (Stone et al. 2005). At the beginning, after the herbicide application, it looks like the bindweed is successfully controlled, but afterwards plants quite often re-sprout from rhizome systems.

The use of adjuvants (surfactants, mineral and vegetable oils, emulsifiers and fertiliser salts, such as ammonium sulfate), can greatly enhance the activity of the foliage-applied herbicides (Kirkwood 1993). They can affect the amount of the herbicidal active substance absorption and translocation throughout the plant. Limited basipetal translocation has been identified as a potential reason for a significant variability noticed in herbicide control (Lauridson et al. 1983). Increasing the extent of active substance translocation to the underground parts is a very important factor in permanent eradication of bindweed (DeGennaro and Weller 1984).

Although cases of natural bindweed resistance to glyphosate are still rare, resistant populations and biotypes clearly exist (Baylis 2000). A low level of tolerance to glyphosate could be partially managed by using high quality adjuvants (Baylis 2000, Powles and Preston 2006).

The aim of this study was to examine the effects of the selected adjuvants (glycerine (GL), phosphate ester of ethoxylated isodecyl alcohol (PEA) and alkyl polyglucosides (APG)) on the increasing efficacy of glyphosate-based herbicides utilised for controlling field bindweed (*Convolvulus arvensis* L.).

## MATERIALS AND METHODS

The experiment was designed as a standard pot experiment for testing herbicide efficacy to control weeds. Field bindweed (*Convolvulus arvensis* L.) was collected from an agricultural field and then planted into plastic pots with a volume of 10 litres. The plants were collected in May from a single field with a standard crop production practice and crop rotation, near the town Kidričevo in Slovenia. The bindweed population was exposed to different glyphosate formulations 3 times, in the last 10 years, according to the field owner's data. Plants were collected from a single field to minimize the variability of biotypes. The selected population of field bindweed had average properties in terms of herbicide resistance. The field owner provided information on the fact, that he was always able to manage the population, but never completely, and that the population slowly increased each year. In each plastic pot 3 plants were planted, each with a well-developed 25 cm long rhizome and shoot with 5 leaves. We assured a high level of uniformity among the planted plants. The plants were grown in pots for 5 months and glyphosate formulations were applied in October. After the treatment with glyphosate, the pots were placed inside a greenhouse for the winter period. Occasional watering was performed. The temperature in the greenhouse ranged from 1 to 18 °C during winter. The soil in the pots never dried out or froze during winter. In May of the following year, a year after planting, the plants were separated from the soil, the aboveground shoots were weighed and the rhizome mass was measured. A pot trial was designed as an experiment, with 12 different treatments and an additional untreated control in 5 repetitions. Each treatment variant consisted of 25 pots, and together with the controlled ones, we maintained 325 pots. The group of 5 pots was statistically considered as one repetition.

A statistical analysis was performed with the SPSS statistical analysis program for analysing random groups with the Tukey HSD test. The efficacy data (%) were transformed prior to calculations with an arcus–sinus–square (X) transformation.

## Formulations of glyphosate based herbicides

Six samples (formulations) of glyphosate (N-(phosphonomethyl) glycine) based herbicides with different adjuvants, labeled with the code numbers (S1, S2, S3, S4, S5 and S6) were tested. Each formulation contained 360 g/l of glyphosate acid (480 g/l glyphosate isopropylamine salt). The Formulations (Table 1) were prepared by Pinus TKI d.d. company (Rače, Slovenia) which manufactures herbicides. Two types of alkyl polyglucosides (APG) were used: APG-0810-China ($C_{16}H_{32}O_6$) and APG-1214-Europe ($C_{18}H_{36}O_6$). APG is a non-ionic surfactant. The applied glycerine (GL) was standard pure glycerine ($C_3H_8O_3$). The phosphate of ethoxylated alcohol (PEA) (phosphate ester of ethoxylated isodecyl alcohol; $C_{26}H_{57}O_5P$) was used as an anionic emulsifier. All formulations were applied with or without the addition of an ammonium sulfate fertiliser ((NH4)2SO4), containing 20.6% of N, which was produced by the company Agrochem d.o.o.. The abbreviation ASF will be used throughout the text to denote ammonium sulfate fertilizer.

## Application of glyphosate

The application of tested formulations was performed using the experimental sprayer Technoma Euro-Pulve (France). Water consumption was set to 250 l/ha and the nozzle Teejet XR 110015 was used at an operating pressure of 3 bars with a droplet size of 125 to 145 µm. Tested formulations were applied to potted bindweed plants at a rate of 4 litres per hectare (1440 g of glyphosate per hectare). Each formulation was applied in both variants; the variant without the addition of ASF (S1A, S2A, S3A, S4A, S5A and S6A) and the variant with the addition of ASF (S1B, S2B, S3B, S4B, S5B and S6B). ASF was added to the water before adding the glyphosate formulation.

5 kilograms of ASF (2 % concentration) were added to tap water with a hardness rate of 14 °dH and used on a surface of one hectare. The air temperature was 22 °C at the time of application and the relative humidity was 68%. After treatment, all potted plants were left to dry outdoors for 25 to 30 minutes.

Plants were not irrigated or wetted 4 days after application. After that, normal irrigation was performed to prevent the soil

**Table 1: The content of tested formulations**

| Component | For. 1 (S1) | For. 2 (S2) | For. 3 (S3) | For. 4 (S4) | For. 5 (S5) | For. 6 (S6) | Control |
|---|---|---|---|---|---|---|---|
| Glyphosate | 360 g | 360 g | 360 g | 360 g | 360 g | 360 g | / |
| PEA | 100 g | 100 g | / | 100 g | 100 g | 140 g | / |
| APG -China | / | 100 g | 200 g | 70 g | 50 g | / | / |
| APG – EU | / | / | / | / | 50 g | 80 g | / |
| Glycerine | / | 30 g | / | / | / | / | / |
| Water | TRL | TRL | TRL | TRL | TRL | TRL | / |

PEA - phosphate of ethoxylated alcohol; APG - alkyl polyglucoside. TRL - the remainder to the1L

from drying out in the pots. Average daily temperatures, during the 3 week period after application, ranged from 9 °C to 23 °C.

At the time of application, the field bindweed shoots had 20 to 35 leaves and 35 to 65 cm long rhizomes with a thickness of 0.5 to 2.3 mm. Plants from 20 randomly chosen control pots were removed from pots to check the length and the diameter of rhizomes before herbicide application. The theoretical leaf area index (LAI) was approximately 1.35. The plants were not in vigorous growth, they were partially developing flowers and partially at the end of the flowering stage. The mass ratio of over– and underground organs was about 1.5 / 1. Above and underground parts of plants from 20 randomly chosen control pots were weighed before herbicide application.

## Evaluation of herbicide formulation efficacy

The efficacy of the tested formulations was assessed in two ways; according to the method of visual assessment (Bleiholder 1989) and according to the method of weighing plant organs (Rao 2000). The first visual evaluation was performed 3 weeks and another 6 weeks after the glyphosate application. The results of the second visual evaluation were not considered as relevant, because they were obtained at the beginning of the winter period, when plants stop growing. It was not possible to differentiate whether the degradation of the aboveground parts was due to the effect of herbicide or the approaching winter period. A visual evaluation of plants grown in pots provides similar information to the visual evaluation of plants developing in fields, but it does not provide complete information on the real efficacy of herbicides. We thus decided that plant part weighing as an additional method of efficacy evaluation had to be applied (see discussion section).

For the calculation of herbicide efficacy based on the weighing of plant parts, we removed the plants from the soil 6 months after herbicide application and separated the rhizomes from the aboveground parts with scissors. Only green aboveground parts and fresh, live rhizomes where weighted. All dried and necrotic rhizomes were removed and were not weighted. The procedure was the same for the control and for the treated plants. The efficacy of the herbicide EF (%) was calculated as a ratio between the mass of plant parts from treated, and untreated plots (Rao 2000).

EF (%) = ((MASS of CONTROL – MASS of TREATED) ÷ MASS of CONTROL) × 100

# RESULTS AND DISCUSSION

## Efficacy of preparations after three weeks

The average efficacy was very high after 3 weeks, regardless of the moderate dose of glyphosate (Table 2). This is due to the plants having a relatively small mass of over– and underground organs, and because the ratio of the aboveground organ mass in relation to the rhizome mass, was high. Differences between the preparations were very small. The highest efficacy was achieved in S1B (ASF added) and lowest in S2A (ASF not added) (Table 2). The addition of ASF resulted in a minimum increase of efficacy. The effect of adding ASF was mainly seen in the reduction of variability (smaller standard error and range of values) in the variants. We cannot explain, whether the experimental design was not sensitive enough to show the differences, or if there were no differences in the short–term efficacy of glyphosate formulations. These differences were too small to be recognized as statistically significant.

In the evaluation of herbicide efficacy on perennial weeds, methodological obstacles in trial implementation are encountered, making it difficult to obtain relevant information on weed eradication. An evaluation shortly after application usually results in high efficacy ratings, which decrease over time in later re–evaluations (DeGennaro and Weller 1984, Stone et al. 2005). High average short–term efficacies of glyphosate were observed in our experiment (Table 2), regardless of added adjuvants, and the results were consistent with many similar experiments (DeGennaro and Weller 1984, Sherrick et al. 1986a, Baylis 2000, Hoss et al. 2003, Stone et al. 2005).

Perennial weeds can have the majority of their plant mass in the soil, where only a limited amount of absorbed herbicide is translocated (Pereira and Crabtree 1986, Steckel and Wax 1997, Hoss et al. 2003). If evaluations are carried out after a month or more after application it is difficult to separate the extent to which the recovery of the weed resulted from plant parts exposed, or not exposed to herbicide. When new shoots develop from rhizomes that have not been exposed to herbicide and they are included into the evaluation, the

**Table 2: Results of efficacy evaluation after three weeks**

| Variant<br>A- ASF not added<br>B- ASF added | | Assessment of the efficacy<br>(%, visual, average of 25 assessments) | | |
|---|---|---|---|---|
| | | Mean ±<br>standard error | Stat. differences<br>(HSD 0.05) | Range of values |
| 1 | S1A | 96.4 ± 7.97 | ab* | 70 - 100 |
| 2 | S 1B | 99.9 ± 0.6 | a | 97 - 100 |
| 3 | S 2A | 95.8 ± 9.82 | b | 60 - 100 |
| 4 | S 2B | 96.6 ± 7.66 | ab | 65 - 100 |
| 5 | S 3A | 97.8 ± 9.99 | ab | 50 - 100 |
| 6 | S 3B | 98.3 ± 4.93 | ab | 80 - 100 |
| 7 | S 4A | 97.3 ± 10.1 | ab | 50 - 100 |
| 8 | S 4B | 97.8 ± 9.99 | ab | 50 - 100 |
| 9 | S 5A | 99.6 ± 2.0 | ab | 90 - 100 |
| 10 | S 5B | 99.3 ± 3.03 | ab | 85 - 100 |
| 11 | S 6A | 99.4 ± 1.52 | ab | 95 - 100 |
| 12 | S 6B | 98.4 ± 5.71 | ab | 75 - 100 |
| Comparison of the effect of adding ASF. | | | | |
| | S 1 – 6 A | 97.7 ± 7.86 | A* | 50 - 100 |
| | S 1 – 6 B | 98.4 ± 6.09 | A | 50 -100 |

* Means marked with the same letter do not differ significantly according to the results of the Tukey test (α = 0.05). ASF - ammonium sulfate fertilizer ($(NH_4)_2SO_4$, 20.6 % N) added at rate of 5 kg ASF / ha / 250 litres of water.

efficacy of the herbicide can be estimated incorrectly.

In the pot experiment, all plant parts were exposed to herbicide and recovery was possible only from treated parts, therefore bindweed recovery was only attributed to the insufficient herbicide efficacy. The problem of the pot experiment is the ratio between the above– and underground mass of plant organs, which can differ from that of the plants developing in nature. In the case of perennial weeds, the under–ground mass of plants is often several times higher in favour of underground organs (Holm et al. 1977). As a result of the mentioned problem, the level of efficacy obtained in the pot trials is always to some extent higher than in field trials. The amount of herbicide that enters the rhizomatous system is higher in the pot experiment than in field.

In this experiment, the primary focus of research was not the determination of the absolute efficacy for a given dose, but a comparison of the effectiveness of different adjuvant formulations with the same dose of active substance. The term "efficacy" in this manuscript, refers only to the short period of suppression of bindweed, and not to the eradication due to the moderate amount of glyphosate used. It is known from experiences that glyphosate, at moderate doses (2000 to 2500 g ai/ha), cannot be sufficient to eradicate bindweed, regardless of the preparation formulation (DeGennaro and Weller 1984).

Differences between the formulations were not seen only in short-term plant damage, but also in the prolonging of the regeneration period after treatment, which was also reported by other researchers (Sherrick et al. 1986a, Sherrick et al. 1986b). This has an impact on the competitive relationship between bindweed and cultivated crops. If the suppression effect lasts long enough, the cultivated plant can out-compete bindweed and consequently bindweed cannot cause high yield loss. If bindweed recovers fast, it can still cause yield loss despite being treated with a herbicide.

## Efficacy of tested formulations after six months

The efficacy after six months, obtained by measurements of fresh leave mass or of living root system mass differs significantly from the visual evaluation after 3 weeks. For most of the pots containing the treated plants, no development of new shoots was observed after 6 months. In the non-treated control pots bindweed shoots were 25 do 40 cm long. This demonstrates a very high efficacy of glyphosate (over 97 %) when observing the above ground parts of the plants (Table 3). When the soil was separated from the rhizomatous system, live rhizomes were found in most pots, despite the completely dead aboveground parts. This suggests that visual assessment of efficacy based only on the aboveground parts of the plant, cannot be an entirely objective assessment of long-term herbicide efficacy. Some statistical differences among different preparations were also noticed. Depending on the recovery of the aboveground parts, the highest efficiency was observed in

**Table 3: Results of efficacy evaluation after six months**

| Variant: A- ASF not added B- ASF added | | Assessment of the efficacy (%) (method weighing, average of 25 assessments) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Mean ± standard error | | Stat. differences (HSD 0.05) | | Range of values | |
| | | above-ground mass | rhizomes | above-ground mass | rhizomes | above-ground mass | rhizomes |
| 1 | S 1A | 90.6 ± 12.2 | 39.5 ± 20.3 | e* | de* | 60 - 100 | 5 - 81 |
| 2 | S 1B | 96.6 ± 5.22 | 62.5 ± 19.6 | abc | a | 79 - 100 | 5 - 90 |
| 3 | S 2A | 93.1 ± 10.0 | 38.9 ±18.6 | cde | e | 52 - 100 | 14 - 100 |
| 4 | S 2B | 97.7 ± 5.86 | 62.9 ±13.5 | ab | a | 76 - 100 | 26 - 78 |
| 5 | S 3A | 93.5 ± 10.41 | 49.8 ±16.2 | bcde | bcd | 55 - 100 | 7 - 78 |
| 6 | S 3B | 97.4 ± 4.43 | 57.7 ±16.5 | ab | abc | 86 - 100 | 12 - 84 |
| 7 | S 4A | 96.9 ± 4.64 | 55.7 ±18.2 | abc | abc | 84 - 100 | 5 - 81 |
| 8 | S 4B | 98.7 ± 2.65 | 56.5 ± 7.9 | a | abc | 92 - 100 | 39 - 70 |
| 9 | S 5A | 92.1 ± 11.8 | 47.9 ± 14.8 | de | cde | 59 - 100 | 17 - 76 |
| 10 | S 5B | 95.4 ± 5.25 | 56.0 ± 28.1 | abcd | abc | 78 - 100 | 5 - 86 |
| 11 | S 6A | 95.5 ± 7.65 | 58.3 ± 16.1 | abcd | abc | 70 - 100 | 30 - 100 |
| 12 | S 6B | 98.3 ± 3.28 | 60.0 ± 26.9 | a | ab | 90 - 100 | 15 - 89 |
| Comparison of the effect of adding ASF. | | | | | | | |
| | S 1 – 6 A | 95.07 ± 16.2 | | A* | A* | 59 - 100 | 5 - 100 |
| | S 1 – 6 B | 95.9 ± 7.08 | | A | A | 52 -100 | 5 - 90 |

* Means marked with the same letter do not differ significantly according to the results of the Tukey test (α = 0.05). ASF - ammonium sulfate fertilizer ($(NH_4)_2SO_4$, 20.6 % N) added at rate of 5 kg ASF / ha / 250 litres of water.

S6B and S4B and the lowest in variant S1A (Table 3). In view of this, it can be concluded that the addition of APG or PEA increases the efficacy of glyphosate formulations for control of the aboveground parts. The ratio of 100 g PEA / 70 g APG was the most effective. However, this ratio was not favourable from the perspective of rhizome eradication efficacy. This is a completely new finding, which was not published in any of the available literature sources. We tested two forms of APG (Chinese S4 and European S6) and the differences between both formulations, in terms of suppression of aboveground parts of plants, were not significant. Nevertheless, the fact that the concentration of APG in both formulations was not exactly the same, has to be taken into account.

Differences in efficacy for the control of rhizomatous systems were more notable, with the highest efficacies obtained in S1B and S2B (Table 3). The most favourable formulation was the one with the equal proportion of APG and PEA. The efficacy of S6B and S4B formulations did not differ significantly from the S1B and S2B formulations. Again, the S1A formulation gave the worst overall result.

Adding ASF has slightly increased the efficacy of suppressing both the above- and underground plant part growth. All variants from group B were slightly better than the ones from group A. The differences were statistically significant only in the cases of the S1A / S1B and S2A / S2B comparisons. The highest effect of adding ASF was observed in the S1A variant. The rhizome control efficacy increased from 39.5 to 62.5 %. We speculate that the S1 formulation (based only on phosphates of ethoxylated alcohols) has a higher rate of glyphosate binding to mineral cations present in hard water, than others. However, that was not proven in our experiment.

The relationship between efficacies calculated on the basis of the above– and underground parts were similar in all treatments. This allowed an integration between the results. The control efficacy of rhizomes was on average between 60 and 75% of the one observed in the control of aboveground parts of the plant. We speculate that the high efficacy in control of rhizomes was a result of the pot experiment limitations already mentioned in the discussion above, and is higher than usually obtained in field conditions (Hoss et al. 2003, Stone et al. 2005).

Various adjuvants to glyphosate in various proportions result in differences of its absorption and movement through the phloem of the plant and to the underground parts (Sherrick et al. 1986a). Since glyphosate acid is negatively charged, its ability to diffuse across the hydrophobic bilayer of plant tissues is limited. In addition, the negative electrical potential across the plasma membrane represents a significant thermodynamic barrier (Riechers et al. 1994). An important effect of adjuvants is influencing the ion binding, and field research has shown, that cationic adjuvants are more effective than nonionic in increasing glyphosate phytotoxicity, but nonionic adjuvants can also significantly increase glyphosate uptake (Riechers et al. 1994). Most herbicides must cross the epicuticular wax and plasma membrane before reaching their site of action, and the ability of adjuvants to influence the structure of the leaf epidermis (swelling of pectin fibrils and opening the channels between the tiles of cuticle wax) is important. This is called the penetrating effect. Too aggressive adjuvants can collapse the membrane integrity and reduce the absorption of glyphosate or the ability to move out of this zone (Sherrick et al. 1986b, Zabkiewicz 1999). Another effect of adjuvants could be speeding up or slowing down the movement of glyphosate acid bonded to the adjuvants through the phloem. This effect is poorly investigated, but some research results indicate, that surfactants possibly do not have a direct effect on herbicide translocation (Zabkiewicz 1999). It is also possible that adjuvants can prevent the binding of substances from the phloem juice to glyphosate acid and limit the formation of conjugates. Conjugated glyphosate acid generally moves slower, but not in all cases.

The highest efficacy achieves formulations that successfully bind interfering ions and have a limited impact on the structure of the epidermis (Riechers et al. 1994, Zabkiewicz 1999). Physiological stress to the aboveground part of the plants should not be too strong, because it can slow down the movement of glyphosate to the roots. Theoretically, higher short–term efficacy can result in loss of long–term efficacy of the product.

In our trial, the best result was observed in the variant containing glycerine (Table 3). Perhaps the glycerine has the ability to change the permeability of the bindweed epidermis and allows prolonged absorption of glyphosate and at the same time slows down the initial stress on the plant membranes.

The results of our experiment support the findings, that nonionic and cationic surfactants possess the ability to influence the cell membrane's permeability to glyphosate and are in accordance with a more complex study presented by Riechers et al. (1994).

## CONCLUSIONS

Glyphosate-based herbicides had a higher short–term efficacy for the control (suppression) of aboveground parts of field bindweed (*Convolvulus arvensis* L.) than for the control of rhizome systems, regardless of differences among added adjuvants. The efficacy level obtained for rhizome system control was significantly lower, usually about 60–75 % of that observed in aboveground parts.

The ratios between the various adjuvants (phosphate ester of ethoxylated isodecyl alcohol, glycerine and alkyl polyglucosides) had an impact on the long–term efficacies for suppression of rhizomes. Adjuvants possibly affected the proportion of glyphosate transferred to the rhizomatous system.

It can be concluded that glyphosate at the tested dose in our experiment (1440 g ai/ha) cannot be sufficient for an eradication of a field bindweed population, regardless of the adjuvants' formulation. Such doses can, in an optimal scenario, only suppress plant development for a limited period, just enough to cause a temporal loss of its competitiveness to crops during their main yield formation stage. After that, bindweed can fully recover in the usual conditions.

The addition of ammonium sulfate has somewhat improved efficacy for all formulations. All variants with added ammonium sulfate were somewhat, but not significantly more effective. Adding ammonium sulfate is particularly important in the preparation of spray mixture where very hard water is used and in cases where the glyphosate formulation contains only phosphates of ethoxylated alcohols.

For possible eradication of field bindweed (*Convolvulus arvensis* L.), higher doses of glyphosate, repeated treatments, combining glyphosate with other herbicides, and a combination of chemical and non-chemical control measures are necessary.

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# Učinki izbranih dodatkov na učinkovitost pripravkov na osnovi glifosata za zatiranje njivskega slaka (*Convolvulus arvensis L.*)

## IZVLEČEK

Preučevali smo učinke različnih dodatkov za formuliranje herbicidov na osnovi glifosata na njihovo učinkovitost pri zatiranju njivskega slaka (*Convolvulus arvensis* L.). Preučevani dodatki so bili na osnovi zmesi glicerina (GL), fosfatnega estra etoksiliranega alkohola (PEA) in alkil poliglukozida (APG). Dodatno smo preučevali učinke dodajanje amonijevega sulfata (ASF). Pripravke smo nanašali na rastline slaka, ki so uspevale v lončkih s poskusno škropilnico pri porabi 250 l/ha. Vizualne ocene učinkovitosti smo izvedli 3 tedne in 6 mesecev po nanosu herbicidov. Dodatno smo 6 mesecev po nanosu opravili oceno učinkovitosti s tehtanjem nadzemne in podzemne mase rastlin. Najvišjo učinkovitost po 3 tednih je imela formulacija z visokim deležem PEA ali z enakim deležem PEA in APG. Najvišjo učinkovitost glede na tehtanje nadzemne in podzemne mase rastlin po 6 mesecih so imele formulacije z visokim deležem GL ter z dodatkom ASF. Učinkovitosti vseh formulacij po 6 mesecih so se značilno razlikovale od ugotovljenih po 3 tednih. Po 6 mesecih so bile v povprečju samo še 60-75% od ugotovljenih pri 3 tednih. Rezultati poskusa nakazujejo, da s samo eno aplikacijo pripravkov, ne glede na uporabljene formulacijske dodatke v poskusu, ne moremo poškodovati rizomskega sistema slaka do te mere, da bi s tem povzročili trajno uničenje rastline.

Ključne besede: herbicid, formulacija, plevel, kontrola