Scientific Papers. Series A. Agronomy, Vol. LXVI, No. 1, 2023
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

HERBICIDES APPLICATION FOR WEED CONTROL IN WINTER BARLEY (*Hordeum vulgare* L.)

Atanas SEVOV, Nesho NESHEV, Mariyan YANEV, Anyo MITKOV, Nikolina SHOPOVA

Agricultural University - Plovdiv, 12 Mendeleev Blvd, Plovdiv, Bulgaria

Corresponding author email: asevov@yahoo.com

Abstract

An uncontrolled weed flora can decrease winter barley's grain yield and quality. Winter barley (Hordeum vulgare L.) variety 'Emon' field trial was conducted in the growing seasons 2020/2021 and 2021/2022. The trial was stated in the experimental field of the Agricultural University-Plovdiv, Bulgaria. The experiment aimed to study the efficacy of herbicides for broadleaf weed control in barley. The following herbicides efficacy was evaluated: Sekator OD - 0.15 l ha^{-1}; Axial One - 1.00 l ha^{-1}; Biathlon 4 D - 55 g ha^{-1}; Granstar 75 DF - 15 g ha^{-1}; Aminopielik 600 SL - 2.00 l ha^{-1}. The herbicides were applied in spring at the phenophase end of tillering - the beginning of spindling of the crop (BBCH 29-31). The herbicide efficacy was recorded by the 10-score visual scale of EWRS (European Weed Research Society). At the particular infestation with Sinapis arvensis L., Anthemis arvensis L., Galium aparine L., Consolida regalis Gray., and Viola arvensis L. the highest overall efficacy and highest yield were recorded when Biathlon 4 D - 55 g ha^{-1} was applied.

Key words*: barley, weeds, control, yield, herbicide.*

INTRODUCTION

Barley (*Hordeum vulgare*) is a member of the grass family and it is a major cereal grain plant grown in temperate climates around the globe. It was one of the first cultivated grain crops (from more than 10,000 years ago) (Zohary and Hopf, 2000). According to data from the Bulgarian Ministry of Agriculture and Forestry in 2021the areas sown with barley were126 957hectares and the average barley grain yields were5.411t ha^{-1} (www.mzh.government.bg).

Weed infestation is one of the main factors leading to yields and quality reduction (Tonev et al., 2007). The frequent violations and mistakes that are made in practice, in the technology of growing winter cereal crops, in particular in the case of barley, require the mass use of the chemical weed control method. However, this is possible only through a good and thorough knowledge of the continuously updated list of new herbicidal products and their competent, correct, and timely application according to the specific requirements of the crop, the agro-ecological and economic conditions of the area (Tonev et al., 2007).

Parameters to consider when optimizing herbicide doses are weed species and stage of development, crop competitiveness, climatic conditions, application technique, formulation/adjuvant and combination with other pesticides (Kudsk, 2008), and applied systems for tillage (Young and Thorne, 2004).

A large number of experiments related to the chemical control of weeds in barley have been carried out on a global and national scale. It was found that the winter barley varieties "Veslets", "Aheloy-2", "Emon", and "Perun" obtained the highest yield when treated with the herbicide Weedmaster (Atanasova, 2010). The influence of herbicides for broadleaf weeds control applied alone and in combination with herbicides for grass weeds control was investigated. It was found that the herbicides Derby 175 SK, Sekator WG, and Lintur 70 WG showed good efficacy against the weeds (Atanasova, 2008). Chhokar et al. (2008) reported that the active substance pinoxaden successfully controlled the grass weeds *Phalaris minor* Retz., *Avena ludoviciana* Dur. and *Polypogon monspeliensis* (L.) Desf. in barley.

Experiments were conducted with two-row winter barley to determine the efficacy of 4 herbicides and their tank mixtures on *Avena sterilis* L. and *Sinapis arvensis* L. After the combined application of pinoxaden + 2.4-D +

florasulamthe efficacy of the treatment against weeds was the highest (92%) (Pala, 2020).
The current study aims to establish the efficacy of some herbicides against broadleaf weeds and the influence of the treatments on some growth and reproductive parameters of barley.

MATERIALS AND METHODS

The experiment was carried out in the experimental field of the Department of Agriculture and Herbology at the Agricultural University - of Plovdiv, Bulgaria. The experiment was carried out according to the randomized block design in three replications. The size of the harvesting plot was 20 m².
The variants of the trail were as follows:
1. Untreated control;
2. Sekator OD (25 g/l *iodosulfuron* + 100 g/l *amidosulfuron*) - 0.15 l ha^{-1};
3. AxialOne (45 g/l *pinoxaden* + 5 g/l *florasulam*) - 1.00 l ha^{-1};
4. Biathlon 4 D (54 g/kg *florasulam* + 714 g/kg *tritosulfuron*) - 55 g ha^{-1};
5. Granstar 75 DF (750 g/kg *tribenuron-methyl*) - 15 g ha^{-1};
6. Aminopielik 600 SL (600 g/l *2.4 D amine salt*) - 2.00 l ha^{-1}.
Herbicides were applied in the phenophase end of tillering (BBCH 30).
The efficacy against the weeds *Sinapis arvensis* L., *Anthemis arvensis* L., *Galium aparine* L., *Consolida regalis* Gray., and *Viola arvensis* L. by using the 10-score visual scale of EWRS (European Weed Research Society) was under evaluation. The herbicidal efficacy was recorded on the 14th, 28th, and 42nd day after treatment. The selectivity of the herbicide was recorded by the 9-score scale of EWRS on the 14th, 28th, and 42nd day after treatment.
For the experiment, the Bulgarian barley variety "Emon" was grown. The sowing density was 500 germinated seeds/m². In both years of the experiment, the preceding crop of barley was winter oilseed rape (*Brassica napus* L., hybrid PT 228 CL), which was grown according to the Clearfield® technology.
The tillage carried out before barley sowing was deep plowing, followed by discing and harrowing. Before sowing, fertilization with 300 kg ha^{-1} with NPK 15:15:15 and spring dressing with 300 kg ha^{-1} NH_4NO_3 was done.
The following biometrical and productive parameters of barley were studied:
- Plant height at the end of the vegetation (m);
- Ear length at the end of the vegetation (cm);
- Absolute seed mass (g) (Tonev et al., 2018);
- Hectoliter seed mass (kg) (Tonev et al., 2018);
- Barley grain yields (t ha^{-1}) by harvesting the entire experimental plot of all three replicates of each variant. The harvest was carried out with a Wintersteiger®field trial harvester.
Duncan's method with the SPSS 19 program (Duncan, 1955) was used for the statistical processing of the obtained data. Differences were considered significant at $p<0.05$.

RESULTS AND DISCUSSIONS

On Table 1 is presented the established herbicidal efficacy against the weeds. The application of carfentrazone-ethyl or metsulfuron-methyl in all studies effectively reduced the density and biomass of broadleaf weeds. (Bhullar et al., 2013). In our trial, on average for the period, on the 14th day after treatment, the efficacy against *S. arvensis* ranged from 47.5% for treatment 6 (Aminopielik 600 SL - 2.00 l ha^{-1}) to 72.5% in treatment4 (Biathlon 4 D - 55 g ha^{-1}) was found. On the next reporting date, the efficiency increased and reached 67.5-87.5% between variants on average over the experimental years. On the 42nd day after treatment, on average for the conditions of the experiment, the efficacy against the *S. arvensis* reached 100% in variants 3 (Askial One - 1.00 l ha^{-1}) and 4 (Biathlon 4 D - 55 g ha^{-1}). The efficiency of Sekator OD - 0.15 l ha^{-1} and Granstar DF - 15 g $ha^{-1}$was 90% and that of Aminopielik 600 SL - 2.00 l ha^{-1}-77.5% (the lowest among treatments).
On average for the period, the efficacy against *A. arvensis*on the 14th day ranged from 57.5% for treatment 6 (Aminopielik 600 SL - 2.00 l ha^{-1}) to 77.50% fortreatment 3 (Askial One - 1.00 l ha^{-1}) was recorded. At the next reporting date, the efficacy increasedto82.5-92.5% on average between treatments. On the 42ndday after treatment, on average for the conditions of the trial, the efficacy reached 100% in variants 3 (Askial One - 1.00 l ha^{-1}) and 4 (Biathlon 4 D - 55 g ha^{-1}).

Table 1. Efficacy of the studied herbicidal products against the weeds (%)

Treatments	*S. arvensis*								
	2021			2022			Average		
	14 day	28 day	42 day	14 day	28 day	42 day	14 day	28 day	42 day
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Sekator OD - 0.15 l ha^{-1}	60	80	90	65	85	90	62.5	82.5	90
3. Axial One - 1.00 l ha^{-1}	65	85	100	75	85	100	70	85	100
4. Biathlon 4 D - 55 g ha^{-1}	70	90	100	75	85	100	72.5	87.5	100
5. Granstar 75 DF - 15 g ha^{-1}	60	80	90	55	75	85	57.5	77.5	87.5
6. Aminopielik 600 SL - 2.00 l ha^{-1}	45	65	75	50	70	80	47.5	67.5	77.5
Treatments	*A. arvensis*								
	2021			2022			Average		
	14 day	28 day	42 day	14 day	28 day	42 day	14 day	28 day	42 day
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Sekator OD - 0.15 l ha^{-1}	70	90	100	75	80	95	72.5	85	97.5
3. Axial One - 1.00 l ha^{-1}	75	95	100	80	90	100	77.5	92.5	100
4. Biathlon 4 D - 55 g ha^{-1}	75	95	100	70	80	100	72.5	87.5	100
5. Granstar 75 DF - 15 g ha^{-1}	65	85	95	60	80	100	62.5	82.5	97.5
6. Aminopielik 600 SL - 2.00 l ha^{-1}	60	80	90	55	80	90	57.5	80	90
Treatments	*G. aparine*								
	2021			2022			Average		
	14 day	28 day	42 day	14 day	28 day	42 day	14 day	28 day	42 day
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Sekator OD - 0.15 l ha^{-1}	50	70	85	60	75	95	55	72.5	90
3. Axial One - 1.00 l ha^{-1}	55	75	85	60	80	85	57.5	77.5	85
4. Biathlon 4 D - 55 g ha^{-1}	60	80	85	70	75	90	65	77.5	87.5
5. Granstar 75 DF - 15 g ha^{-1}	50	65	70	55	60	65	52.5	62.5	67.5
6. Aminopielik 600 SL - 2.00 l ha^{-1}	40	50	55	45	50	65	42.5	50	60
Treatments	*C. regalis*								
	2021			2022			Average		
	14 day	28 day	42 day	14 day	28 day	42 day	14 day	28 day	42 day
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Sekator OD - 0.15 l ha^{-1}	50	70	85	55	75	90	52.5	72.5	87.5
3. Axial One - 1.00 l ha^{-1}	60	80	90	70	85	95	65	82.5	92.5
4. Biathlon 4 D - 55 g ha^{-1}	65	85	100	70	90	100	67.5	87.5	100
5. Granstar 75 DF - 15 g ha^{-1}	60	70	90	60	65	95	60	67.5	92.5
6. Aminopielik 600 SL - 2.00 l ha^{-1}	60	80	85	55	90	95	57.5	85	90
Treatments	*V. arvensis*								
	2021			2022			Average		
	14 day	28 day	42 day	14 day	28 day	42 day	14 day	28 day	42 day
1. Untreated control	-	-	-	-	-	-	-	-	-
2. Sekator OD - 0.15 l ha^{-1}	50	60	65	45	70	75	47.5	65	70
3. Axial One - 1.00 l ha^{-1}	60	70	85	55	75	80	57.5	72.5	82.5
4. Biathlon 4 D - 55 g ha^{-1}	65	85	90	75	90	95	70	87.5	92.5
5. Granstar 75 DF - 15 g ha^{-1}	50	60	70	45	70	80	47.5	65	75
6. Aminopielik 600 SL - 2.00 l ha^{-1}	40	50	55	45	55	60	42.5	52.5	57.5

On the 14th day after the herbicidal application, an efficiency of 65% against the weed *G. aparine* was reported for treatment4 (Biathlon 4 D - 55 g ha^{-1}). The efficiency of the other treatments on this datevaried from 42.5 to 57.5%. On the next reporting date, the efficacy increased and varied from 50 to 77.5%.

On the last evaluation date, the highest efficacy was recorded for treatment 2 (Sekator OD - 0.15 l ha^{-1}), and the lowest results for treatment 6 (Aminopielik 600 SL - 2.00 l ha^{-1}) - 60% only, which is insufficient to successfully control *G. aparine*.

On average for the period, on the 14th day after treatment, the efficacy against *C. regalis* was from 52.5% for treatment 2 (Sekator OD - 0.15 l ha^{-1}) to 67.5% in treatment 4 (Biathlon 4 D - 55 g ha^{-1}). On the next evaluation date, the efficacy increased and was from 72.5-85% among the variants on average for the research period. On the 42nd day after spraying, on average for the conditions of the study, the efficacy against *C. regalis* was 100% for variant 4 (Biathlon 4 D - 55 g ha^{-1}). An efficacy of 92.5% was reported for treatment 3 (Askial One - 1.00 l ha^{-1}) and 5 (Granstar 75 DF - 15 g ha^{-1}). The control of the weed by Aminopielik 600 SL - 2.00 l ha^{-1}(variant 6) was 90% on the third reporting date. On the last reporting date, the lowest efficiency was recorded for option 2 (Secator OD - 0.15 l ha^{-1}) - 87.5%.

In a trial conducted by Degenhardt et al. (2005), the application of the herbicidesfluroxypyr + 2.4-D provided efficient control of the weed *V. arvensis*. In our study, on average for the period, on the 14th day after application, the obtained efficacy was ranging from 42.5% in treatment 6 (Aminopielik 600 SL - 2.00 l ha^{-1}) to 70% in treatment 4 (Biathlon 4 D - 55 g ha^{-1}). On the 42nd day after spraying, on average for the study conditions, the efficacy against the weed *V. arvensis* reached the highest values with variant 4 (Biathlon 4 D - 55 g ha^{-1}) - 70%. Efficacy of 57.5% was reported for variants 3 (Askial One - 1.00 l ha^{-1}). In the other treatment, the control of the weed was not sufficient, and this species turned out to be one of the most difficult to fight under the conditions of the experiments conducted in 2021 and 2022.

Table 2 presents the established results for vegetative indicators of barley. Higher values for plant height were found in all variants where herbicide treatment was performed against weeds. The statement corresponds with other research findings (Hristova et al., 2021; Shabanet al., 2021; Yanev et al., 2021). The highest plants were measured in variant 3 (Biathlon 4 D - 55 g ha^{-1}) - 1.10 m average for the period. The plants from the control are the lowest - 0.87 m.

The plants from the untreated control have the shortest ears - 8.04 cm average for the period. All herbicide-treated variants had longer ears, with lengths from 13.13 to 13.50 cm. The longest ears were measured from the plants of variant 4 (Biathlon 4 D - 55 g ha^{-1}).

Table 2. Plant height (m) and ear length (cm)

Treatments	Plant height (m)		
	2021	2022	Average
1. Untreated control	0.83 c	0.90 c	0.87
2. Sekator OD - 0.15 l ha^{-1}	1.02 b	1.11 a	1.07
3. Axial One - 1.00 l ha^{-1}	1.12 a	1.01 b	1.07
4. Biathlon 4 D - 55 g ha^{-1}	1.06 b	1.14 a	1.10
5. Granstar 75 DF - 15 g ha^{-1}	1.09 a	1.00 b	1.05
6. Aminopielik 600 SL - 2.00 l ha^{-1}	0.98 b	1.07 c	1.03
Treatments	Ear length (cm)		
	2021	2022	Average
1. Untreated control	8.97c	7.11 c	8.04
2. Sekator OD - 0.15 l ha^{-1}	13.23 a	13.02 a	13.13
3. Axial One - 1.00 l ha^{-1}	13.57 a	12.99 a	13.28
4. Biathlon 4 D - 55 g ha^{-1}	13.59 a	13.41 a	13.50
5. Granstar 75 DF - 15 g ha^{-1}	13.64 a	13.17 a	13.41
6. Aminopielik 600 SL - 2.00 l ha^{-1}	12.87 b	11.78 b	12.33

Figures with different letters are with a proven difference by Duncan's multiple range test ($p < 0.05$).

According to Georgiev et al. (2014), the absolute seed mass is among the most important seed quality indicators. In our study, the parameter was influenced by the treatments and weed infestation. The highest absolute seeds mass was reported for variant 3 (Askial One - 1.00 l ha^{-1}) - 41.54 g. average for the period the lowest absolute seed mass was recordedfor the untreated control - 37.43 g (Table 3).

From the obtained data concerning the hectolitre seed mass of barley, it was observed

that all herbicide-treated variants had higher values for hectoliter seed mass compared to the untreated control. In the treated variants, the hectoliter mass varies from 69.75 to 70.83 kg. The seeds of the untreated control had a hectoliter mass of 67.92 kg on average.

Weed control leads to yield increase (Balyan and Malik, 1994; Tonev et al., 2007; Atanasova, 2008; Talgre et al., 2008; Buttar et al., 2015; Hristova et al., 2021; Shaban et al., 2021; Yanev et al., 2021). A high average yield was reported in all variants where herbicide treatment was performed (Table 3). The highest grain yield in variant 4 (Biathlon 4 D - 5.5 g/da) was reported - 6.33 t ha^{-1}. For the other variants, yields varied from 6.02 to 6.22 t ha^{-1}. The lowest yields were recorded in the untreated control - 4.61 t ha^{-1} (Table 3).

Table 3. Absolute seed mass (g), hectoliter seed mass (kg), and barley grain yields (t ha^{-1})

Treatments	Absolute seed mass (g)		
	2021	2022	Average
1. Untreated control	38.14 c	36.71 d	37.43
2. Sekator OD - 0.15 l ha^{-1}	41.29 b	42.11 a	41.70
3. Axial One - 1.00 l ha^{-1}	41.54 a	42.05 a	41.80
4. Biathlon 4 D - 55 g ha^{-1}	41.33 b	42.12 a	41.73
5. Granstar 75 DF - 15 g ha^{-1}	41.30 b	41.69 b	41.50
6. Aminopielik 600 SL - 2.00 l ha^{-1}	41.22 b	40.74 c	40.98
Treatments	Hectoliter seed mass (kg)		
	2021	2022	Average
1. Untreated control	67.33 b	68.50 d	67.92
2. Sekator OD - 0.15 l ha^{-1}	70.00 a	71.50 a	70.75
3. Axial One - 1.00 l ha^{-1}	70.33 a	71.33 a	70.83
4. Biathlon 4 D - 55 g ha^{-1}	70.67 a	70.50 b	70.59
5. Granstar 75 DF - 15 g ha^{-1}	70.50 a	71.00 a	70.75
6. Aminopielik 600 SL - 2.00 l ha^{-1}	70.00 a	69.50 c	69.75
Treatments	Grain yields (t ha^{-1})		
	2021	2022	Average
1. Untreated control	4.47 d	4.75 c	4.61
2. Sekator OD - 0.15 l ha^{-1}	5.97 c	6.06 b	6.02
3. Axial One - 1.00 l ha^{-1}	6.19 b	6.25 a	6.22
4. Biathlon 4 D - 55 g ha^{-1}	6.37 a	6.29 a	6.33
5. Granstar 75 DF - 15 g ha^{-1}	6.26 a	6.11 b	6.18
6. Aminopielik 600 SL - 2.00 l ha^{-1}	6.10 b	6.17 b	6.13

Figures with different letters are with a proven difference by Duncan's multiple range test ($p < 0.05$).

CONCLUSIONS

The application of Askial One - 1.00 l ha^{-1} (Treatment 3) and Biathlon 4 D - 55 g ha^{-1} (Treatment 4) controlled the weeds *S. arvensis* and *A. arvensis* to100%.

The application of Biathlon 4 D controlled *C. regalis* to 100% as well.Secator OD - 1.5 ml/da (Treatment 2) showed the highest efficacy results against the weed *G. aparine,* andthe highest average efficacy against *V. arvensis* was recorded after the application of Askial One - 1.00 l ha^{-1} (Treatment 3).

The highest results for the plant height, ear length, absolute seed mass, and barley grain yields after the application of Biathlon 4 D - 55 g ha^{-1} (Variant 4), and the highest hectoliter mass of the seeds was found after the application of Axial One - 1.00 l ha^{-1}(Treatment 3).

ACKNOWLEDGEMENTS

The research was financially supported by Project 17-12 at The Center of Research, Technology Transfer and Protection of Intellectual Property Rights at the Agricultural University of Plovdiv, Bulgaria.

REFERENCES

Atanasova, D. (2008). Influence of the treatment with foliar herbicides on malting barley (*Hordeum vulgare* L.). *Plant Science, 45*(3), 236–242.

Atanasova, D. (2010). The Influence of treatment with broadleaf herbicides on thewinter barley (*Hordeum vulgare* L.) productivity. *Field Crops Studies, 6(*3), 481–487.

Balyan, R. & Malik, R. (1994). Chemical Weed Control Studies in Barley (*Hordeum vulgare*). *Indian Journal of Weed Science, 26*(1&2), 1–5.

Bhullar, M., Kaur, S., Kaur, T., Singh, T., Singh, M., Jhala, A. (2013). Control of broadleaf weeds with post-emergence herbicides in four barley (*Hordeum* spp.) cultivars. *Crop Protection, 43*. 216–222.

Buttar, G., Singh, S., Kaur, T., Punia, S. (2015). Chemical weed control in barley. *Indian Journal of Weed Science, 47*(4), 383–385.

Degenhardt, R., Spaner, D., Harker, K., Mcgregor, W., Hall, L. (2005). Effect of Herbicides on Field Violet (Viola arvensis) in Direct-Seeded Spring Wheat. *Weed Technology, 19*(2), 359–371.

Duncan, D. (1955). Multiple range and multiple F tests. *Biometrics, 11*. 1–42.2.

Georgiev, G., Encheva, V., Nenova, N., Peevska, P., Encheva, Y., Valkova, D. Georgiev, G., Penchev, E. (2014). Characterization of the yield components of sunflower lines under the conditions of North-East Bulgaria. *Scientific Works, 3*(1), 121–131.

Hristova, H., Uzunova, K., Neshev, N., Yanev, M.,& Mitkov, A. (2021). Evaluation of increased rates of Starane Gold at the maize hybrid "Blason Duo". *Scientific Papers. Series A. Agronomy, LXIV*(2), 214–219.

Kudsk, P. (2008). Optimizing herbicide dose: a straightforward approach to reduce the risk of side effects of herbicides. *The Environmentalist*, *28*(1), 49–55.

Pala, F. (2020). The Effect of Post Emergence Herbicides and Their Mixtures on Grass and Broadleaf Weed control in Barley (*Hordeum vulgare* L.). *Fresenius Environmental Bulletin, 29*(2), 1206–1213.

Shaban, B., Neshev, N., Uzunova, K., Yanev, M., Mitkov, A. (2021). Comparative evaluation of increased rates of Sekator OD on the efficacy and growth traits in winter wheat. *Scientific Papers. Series A. Agronomy, LXIV*(2), 303–308.

Talgre, L., Lauringson, E., Koppel, M. (2008). Effect of reduced herbicide dosages on weed infestation in spring barley. *Zemdirbyste-Agriculture, 95*(3), 194–201.

Tonev, T., Dimitrova, M., Kalinova, Sht., Zhalnov, I., Spasov, V., (2007). Herbology. *Academic publisher of Agricultural University - Plovdiv*. 227. (Textbook in Bulgarian).

Tonev, T., Tityanov, M., Mitkov, A., Yanev, M., Neshev, N. (2018). A Guidebook for Exercises on General Agriculture and Herbology. *Publisher: "Biblioteka Zemedelsko Obrazovanie"*. Pages: 71–72. (A guidebook in Bulgarian).

Yanev, M., Neshev, N.**,** Mitkov, A., Nesheva, M. (2021). Control of mixed weed infestation in winter wheat. *Scientific Papers. Series A. Agronomy, LXIV*(2), 350–357.

Young, F. & Thorne, M. (2004). Weed-species dynamics and management in no-till and reduced-till fallow cropping systems for the semi-arid agricultural region of the Pacific Northwest, USA. *Crop Protection, 23*(11), 1097–1110.

Zohary, D., & Hopf, M. (2000). Domestication of Plants in the Old World: The Origin and Spread of Cultivated Plants in West Asia, Europe, and the Nile Valley (3rd ed.). *Oxford University Press* (OUP).

***https://www.mzh.government.bg/media/filer_public/2022/10/06/ra407_publication_crops_2021.pdf