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WEED VEGETATION AND INTEGRATED WEED CONTROL OF POPPY (*PAPAVER SOMNIFERUM*)

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1. Introduction

Neolithic remains of opium poppy (*Papaver somniferum* L.) are known throughout Europe. The domestication which has probably occurred around the Aegean Sea was followed by introductions to all continents with suitable climates. Currently, there are only a few countries worldwide where significant legal production of poppy takes place, including Australia (Tasmania), Hungary, Turkey, Spain and India, and also Czech Republic, France and Croatia. In Hungary, poppy has a long tradition as a rural garden crop, but large-scale cropping of poppy in arable fields has only started in the 1930's. Now the cultivation is concentrated in specific poppy-growing districts of Hungary which are close to the special environmental demands of the crop. Poppy is either used as (i) pharmaceutical crop (alkaloids are extracted from its dry capsule) or (ii) food crop (poppy seeds are a traditional ingredient in several European cuisines), and the production target strongly determines every aspect of the cultivation.

At the beginning of its vegetation period poppy develops slowly, it has only a weak competitive ability against weeds, and it is relatively susceptible to herbicides. For this reason, the weed control system of poppy is complex and it demands a high level of technological knowledge from farmers. Depending on preceding crops, sowing technologies, crop development stages and weed species composition, the weed management of poppy should include multiple chemical and mechanical treatments and herbicide rotations.

2. Aims of the research

The success of poppy cultivation is highly influenced by the weed vegetation of the poppy growing area. The national weed records of arable lands do not include poppy fields, although in order to increase the efficiency of weed control strategies a deep knowledge of weed communities of poppy would be essential. The main goal of this research was to fill the gap by recording the weed communities in poppy and to give an overview of these on a national level.

Weed species composition is influenced by numerous environmental and agrotechnical factors. Many researchers have tried to define the importance of these factors. Because of the large climatic gradient and the variety of soil types, environmental factors have been proven to be more important than agrotechnical ones as to Hungarian maize and sunflower fields and the weed species composition of stubble-fields. In the case of poppy growing, such an extended dominance of environmental factors was unexpected, since the climatic and soil characteristics of Hungarian poppy growing regions are relatively similar to each other. Other goal of this research was to determine the importance of the environmental and agrotechnical factors influencing the weed species composition of poppy fields.

Generally, we can say that food and alkaloid poppy without weed control is impossible to grow. In order to increase the yield and the quality of harvest and because of its slow developing in the beginning it is necessary to decrease the weed competition. New chemicals on the market have made the chemical management of poppy easier. But the chemicals have to be used in the right phenological stage, which requires a high level of technological knowledge of farmers.

Because of the increasing labour costs and the new technologies manual weed management nearly disappeared from the technologies. Third goal of the research was to measure the popularity and distribution of certain weed control technologies.

According to the experiences of the recent years, preemergence herbicides do not dispose of the required efficiency and farmers prefer to use postemergence tools.

The application of mesotrione and tembotrione has recently become widely popular in the management of spring-sown poppy, although no scientific study has been published about the efficiency of herbicides in weed control of poppy field in Hungary. Fourth goal of this thesis was to identify the effect of different doses of mesotrione and tembotrione on the most important weeds on poppy fields with exact scientific methods.

3. Materials and methods

3.1 Recording of weed on national level and study on weed control technologies

3.1.1 Selection of farmers, circumstances during the fieldwork

As opium poppy is a highly infrequent crop even in Hungary, we could not effectively design a geographically stratified sampling procedure based on random selection procedures. Two Hungarian poppy trading companies and several contract providers were asked to identify poppy-growing farmers. Each farmer was mailed and phoned to ask whether they would permit access into their fields and consent to being interviewed about management factors. We generally surveyed only one poppy field from each farmer willing to cooperate. Two fields from the same farmer were investigated only if they differed in major management factors (sowing season, herbicides or mechanical weed control variables).

This resulted in a set of 102 arable fields across the poppy growing districts of Hungary (Fig. 1). Weed vegetation was sampled in the fields in four randomly selected 50 m^2 plots between 30. May and 14. June 2010. One plot was located on the field edge (inside the outermost seed drill line), whereas the remaining three plots were located inside the fields at different distances (between 10 and 300 m) from the edge. Percentage ground cover of plant species in the plots was estimated visually. In total, 408 plots were sampled (4 plots in 102 fields).

3.1.2 Collecting abiotic and agrotechnical information

A soil sample of ~1000 cm^3 was taken from each field as a mixture of 4 subsamples from the surveyed plots taken from the upper 10 cm soil layer after removing the surface litter. Soil analyses were carried out in a laboratory (belonging to UIS Ungarn GmbH) accredited by DAP (German Accreditation System for Testing).

Crop management information was obtained directly from the farmers. These referred to the sowing date, the preceding crops, the doses of sprayed herbicides, the number of mechanical weed control treatments, the crop cover, the row spacing, the size of the field and the tillage depth.

3.1.3 Statistical analysis

Next, we performed a multivariate analysis to determine the average community composition of the individual fields. For each field we averaged the cover values of the weed species across all the four plots. Mean cover values were then subjected to a Hellinger transformation, and were examined in a redundancy analysis (RDA) together with the management and environmental data. The number of explanatory variables was reduced by stepwise backward selection using a $p<0.05$ threshold for type I error, which lead to a minimal adequate model containing 15 terms.

3.2 Post-emergence herbicide trial

3.2.1 Description of the herbicides of the research

In 2012 and 2013, two field experiments were carried out in north-west Hungary near the Dunasziget region (47°56’44’’N, 17°20’06’’E, 120 m a.s.l.) on a loamy soil (pH 7.6, 1.5% humus, 18% $CaCO_3$). The experimental blocks were designated within a commercial grower’s field. We conducted a nationwide survey and found that the most typical weeds that impede poppy production could be found in this particular field.

It should be noted that the capsule of poppy plant and 10 cm of the stem below the capsule have the highest alkaloid content. Pharmaceutical companies tend to accept only these plant materials from growers, but due to the lack of appropriate harvesting technology and uneven crop height, farmers set the header of the combine

harvester close to ground level, and factories must take over all plant materials. For that reason, the dry weight of the capsule and stem were used as a term of crop yield.

Mesotrione HPPD (4 hydoxy-phenyl-pyruvate-deoyxgenase) is an enzyme inhibitor. Originally it was developed against dicotylenous plants and grass weeds and it is used mainly on maize fields. Typical effect of this herbicide is that weeds turn white, then dry. The chemical can be absorbed through both leaves and roots and they are transported towards the roots and shoot in the liber and the wood. Thank to this effect this chemical can be implemented in both pre- and prostemergent way. Mesotrione is effective against dicotylenous weeds grown from seed, since the absorption and translocation of the substance is very fast and its dissimilation is slow and limited.

Tembotrione is a relatively new chemical and it was developed against monocotyledons and dicotyledons in maize-growing. By inactivating the HPPD this chemical can too remove the carotinoid layer responsible for protecting the chlorophyll of the plant from harmful UV rays. Without this protection the chlorophyll degradates soon, the treated plants turn white, later brown and die. When these herbicides were first available on the Hungarian market, the farmers had to apply for special permissions if they wanted to use them on poppy fields. The authorities permitted their usage on poppy fields in 2006 and 2012.

3.2.2 Distribution of fields, weed control, data processing

A randomized complete block design with four replications was used in the experiment. The individual plot size was 1.5 x 1.5 m. The herbicides under investigation (Table 2) were: mesotrione (Callisto® 4SC, 480 g a.i. L^{-1}, Syngenta) and tembotrione (Laudis®, 44 g a.i. L^{-1}, Bayer), the latter was applied in combination with the safener isoxadifen-ethyl (Laudis®, 22 g a.i. L^{-1}, Bayer). These herbicides were sprayed either with Lemken Primus equipment with 0.5 mm air sprayer nozzles using 200 l ha^{-1} water volume at 2.5-3 bar pressure or with a Schachtner plot sprayer with TeeJet XR11004 nozzles using 200 l ha^{-1} water volume at 3.2 bar pressure.

According to the recommendations of a Hungarian alkaloid processing company, post-emergence treatments were performed on two occasions (Table 2) on both years with the poppies at the 6 leaf stage (2 May 2012 and 6 May 2013; POST 1) and 8–12 leaf stage (28 May 2012 and 24 May 2013; POST 2). Most weeds were at the 4-8 leaf stage by the time of the first herbicide application in both years and most of them had 6-10 leaves in 2013 and more than 10 leaves in 2012 by the second treatment-occasion, respectively. A hand weeded control and an untreated control were also established. Hand weeding was carried out twice, several days before the two treatment occasions. Crop injury was rated visually 7, 14, 21 and 28 days after the treatments.

As the pods began to ripen (28-29 June 2012 and 2 July 2013), the above-ground parts of the poppies and weeds were cut from a 1 m^2 quadrant located at a geometric centre for each experimental plot. Plants were separated and every individual cutting was counted and sorted by species. Samples were oven dried at 75 °C for 72 h then dry weights were measured.

Meteorological data (temperature and precipitation) were collected from a nearby station (University of West-Hungary, Mosonmagyaróvár). Decadic averages were calculated and compared with pluriennial averages. As the weather conditions of the two years differed remarkably the two years were evaluated separately.

All data were subjected to analysis of variance and treatment means were compared by Tukey's HSD test at p=0.05 level. The entire statistical analysis was performed in the R Environment (R Development Core Team, version 3.0.2).

4. Results and discussions

4.1 Results and analyse of the weed records and weed control technologies

4.1.1 Weed cover and distribution of weed species

Altogether 173 weed species were recorded. *Papaver rhoeas* (common poppy) was the most abundant weed species both in alkaloid and food poppy fields. Field edges were significantly more species rich than field cores (mean richness are 16.44 and 9.01 species, respectively; $p<0.01\%$).

In alkaloid and food poppy *Papaver rhoeas* was on the first place in the coverage range with 3.2% and 5.82% average values. Further species with high cover values on alkaloid poppy fields are: *Fallopia convolvulus* (2.43%), *Chenopodium album* (2.25%), *Polygonum aviculare* (2.12%), *Echinochloa crus-galli* (1.58%), *Ambrosia artemisiifolia* (1.36%), *Sonchus asper* (0.8%) and *Convolvulus arvensis* (0.72%).

Further important weeds in poppy: *Descurainia sophia* (1.56%), *Fallopia convolvulus* (1.26%), *Convolvulus arvensis* (1.03%), *Consolida regalis* (0.93%), *Galium aparine* (0.9%), *Polygonum aviculare* (0.89%), *Tripleurospermum inodorum* (0.89%) and *Ambrosia artemisiifolia* (0.84%).

The following families are mainly present in the weed cover on alkaloid poppy fields: *Polygonaceae* (19.2%), *Poaceae* (19.1%), *Chenopodiaceae* (14.3%), *Papaveraceae* (13.8%) and *Asteraceae* (12.8%). These five plant families gave nearly 80% of the weed cover. The most important families in food poppy were: *Papaveraceae* (23.4%), *Poaceae* (14.3%), *Asteraceae* (11.4%), *Brassicaceae* (9.6%) and *Polygonaceae* (9.3%). These five plant families gave almost 70% of the weed cover.

The examination of the life-form spectra revealed, that the most dominating annuals in spring-sown alkaloid poppy are the late-summer ones, whereas in autumn-sown food poppy the spring and

early-summer ones. This is related to the fact, that the last field-works connected to the sowing have a decisive effect on the composition of weeds on the field. The poor representation of perennials shows that these can be controlled by the applied agrotechnical methods.

4.1.2 The impact of environmental and agrotechnical factors on weed species composition in poppy

The full RDA model explained 54.8% of the variance, while, the reduced model (comprising 15 explanatory variables) still explained 34.3% of the total variation in species data. According to the RDA and pRDA models, the most important predictor was sowing season, which was followed by preceding crop, soil texture, soil Mg content, mesotrione, temperature, isoxaflutole, soil $CaCO_3$ content, fertilizer N and row spacing. Although neighbouring habitat, fertilizer K, precipitation, altitude and mechanical weed control remained in the model in the course of backward selection, they did not explain significant amounts of variation in species composition.

Six of the ten most significant variables influencing the weed species composition in communities on poppy fields were agrotechnical, and only four were environmental. This can be attributed to the compliance of the strict agrotechnical regulations and to the narrow ecological tolerance of poppy resulting in various agrotechnical but short environmental gradients.

4.1.3 Assessment of applied weed control technologies

The farmers cooperating with the study were cultivating poppy on an area of 4.754 hectares. 3020 hectares were alkaloid poppy fields, 1734 were food poppy fields. Our study includes 1363 hectares poppy fields of which 1086 were used for growing alkaloid, 277 hectares for the cultivation of food poppy. The study revealed that preemergent weed control was used on 27.7% of the fields with the combination of isoxaflutole and ciprosulfamid. On the remaining areas we observed

postemergent weed control. On 37.58% of the alkaloid fields and on 8.95% of food poppy fields we recorded double postemergence herbicide application. In most of the cases mesotrione was the main active ingredient in use: on 82.15% of alkaloid and 62.05% of food poppy. The reason for that is that the effect of „basic" herbicides lasts for a maximum of 4 weeks even despite of a sufficient amount of precipitation that is necessary to incorporate the herbicide into the soil, but at this stage the poppy plant is not able to hold down weed. The main ingredient used in the second weed control process was tembotrione and izoxadifen-ethyl. These ingredients have been found on 55.24% of the alkaloid areas and on 46.9% of the food poppy areas. Thanks to their fast knockdown effect and their enhanced spectrum of efficiency the combination of these products is very popular amongst poppy farmers. Protection against monocotyledons came into action on 100.7 hectares, which is equivalent to 7.4% of the fields. A targeted way of weed control was applied on areas covered with *Fallopia convolvulus* and *Convolvulus arvensis* – mostly through the application of fluroxypyr-mepthyl on 5.5% of the examined area. Nowadays both chemical and mechanical methods can be used for weed control, but it has to be pointed out that regardless of chemical treatment (if allowed by the row spacing) cultivator should be used at least twice within the development stage of the plant, which is not only important for weed control but also for soil aeration. Since poppy is seen as a small culture, herbicide manufacturers often prohibit the usage of herbicides for these plants. As a consequence, only a few plant protection methods are available.

4.2. Results of the test with postemergent weed control

Amongst the most important weed plants the *Chenopodium album* could mostly been controlled successfully with help of the treatment, but the *Fallopia convolvulus* and the *Polygonum aviculare* were resistant to any kind of herbicide in 2012 – most likely because of the dry weather. *Papaver rhoeas* – which is related to the poppy plant in terms of taxonomy – could not be controlled significantly with tembotrione treatment. The one-time application of tembotrione did

not reduce the dry matter or the number of the targeted weeds either. The waxy cuticle of the poppy plants provided a natural protection against the tested herbicides, but temporary phytotoxic symptoms appeared after the tembotrione treatments. The results of the study show that the combination of mesotrione and tembotrione was the most effective, hence these substances should be used in the weed control of alkaloid poppy.

The results suggest that manual weeding is the best way of weed control regarding the cultivation of alkaloid poppy, but as a consequence of the given socio-economic circumstances this strategy would not be economical. Although mechanical weeding is possible thanks to the wide row spacing on approximately 30% of all alkaloid poppy fields country-wide, the usage of herbicides is vital in poppy cultivation.

Our experiment pointed out that the combined two-time and two-stage application mesotrione and tembotrione treatment is the most effective method in postemergent weed control on alkaloid poppy fields. Given the fact that the maximum allowed application level of mesotrione on poppy fields is 144 g/ha per year, we suggest farmers to use the combination of mesotrione and tembotrione. Although some farmers „unofficially" apply higher doses of mesotrione, this procedure should be replaced with the method, where the application of one dose of mesotrione is complemented by applying one dose of tembotrione. Since it is a common opinion amongst farmers that mesotrione is more effective when applied in soil, a few farmers replace mesotrione with two-time application of tembotrione – especially during drought. Although tembotrione can be useful in tackling fully grown plants as well, so it can be used later on too, but the results of the survey indicate that the application of mesotrione is vital in weed management on poppy fields. It has to be pointed out that the one-time usage of tembotrione has never reduced the dry matter or the number of weeds significally. Furthermore, the application of a double dose of tembotrione is not permitted and can also damage the poppy plant.

5. New scientific findings

1. I have country-wide examined the weeds appearing on the Hungarian alkaloid and food poppy fields and have found that in case of both food and alkaloid poppy the most common weed appearing is the corn poppy (*Papaver rhoeas*), which is related to the poppy crop in terms of taxonomy.

2. In this context I have also proven that there is a clear distinction between the weed flora of autumn-sown food poppy and that of spring-sown alkaloid poppy fields.

3. The redundancy analysis has shown that the most important agrotechnical variables in weed population management are sowing season and preceding crops, the most significant abiotic variables are soil texture and the magnesium content of the soil.

4. According to the questionnaires most of the farmers prefer the application of postemergent two-time spraying in the weed management of poppy fields, mostly by using triketone herbicides.

5. In my two-year-long experiment on weed management on small fields I found that the combination of the herbicides mesotrione and tembotrione are providing the best protection against weed populations on poppy fields.

6. List of Publications

Reviewed papers published in scientific journal

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Tóth K., Karácsony P., Pál R., Pinke Gy. (2012): A mákvetések legfontosabb gyomnövényei és gyomszabályozásának lehetőségei. KITAIBELIA 17:(1) p. 150. Aktuális Flóra- és Vegetációkutatások a Kárpát-medencében 9. Gödöllő, Magyarország: 2012.02.24 -2012.02.26. (*Poster*)

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