Common ragweed (Ambrosia artemisiifolia L.) is native to North-America; ragweed pollen was detected in more than 60,000 year-old interglacial deposits in Canada (Bassett and Teresmae, 1962). The massive spread of ragweed in different parts of the world coincided with major socio-economic transitions that increased the area of disturbed land. In the 18th and 19th centuries in Canada, the settlement of European immigrants led to increased agricultural activity, large scale deforestation and soil disturbance resulting in an increased quantity of ragweed pollen in the region (Bassett and Crompton, 1975).

In Europe the first records of common ragweed are from Brandenburg, Germany, 1863 (Hegi, 1906) and from France, 1863 (Chauvel et al., 2006). Studying the herbarium specimens Chauvel and coworkers (2006) proved that the key factor of introduction of common ragweed to France was anthropogenic. Ragweed was found in Italy in 1907 (Mandrioli et al., 1998). The commercial trade between America and Europe and the transportation of food products and war equipments by the American troops during the First World War have contributed its spread (Kiss and Béres, 2006, Kazinczi et al., 2008a, b).

Common ragweed was first recorded in Hungary in 1908 (Jávorka, 1910). It was reintroduced again in the early 1920’s (Lengyel, 1923, Moesz, 1926) from the USA and Canada. Regular weed surveys since the 1950-ies detect the extension of the species in Hungary. The proportion of the agricultural area covered by ragweed in 1950 was 0.39 %, at that time ragweed was the 21st most frequent weed by area. By 1970, the ragweed covered area grew to 0.87 %, (8th most frequent weed species). In 1988, this proportion grew to 2.57 %, (4th most frequent), while by 1997 ragweed became the most dominant weed species, covering 4.7 % of the arable crop area (Béres, 2004). At that time, ragweed occurred on 5 million of the 6.5 million arable hectares, 700 000 ha was heavily infested (Tóth et al., 2004). Based on the data of the last weed survey in 2007-2008 ragweed is the most dominant species covering 5.3 % of the arable crop area (Novák et al., 2009).

Strong socio-economic transitions occurred in Hungary after the Second World War at the end of 1950-ies when private farms of different size were forced to unite in socialist cooperatives and state farms. Because of the lack of capital agricultural machineries were not available at the newly
organized big farms, which led to improper soil cultivation contributing to the establishment of the ragweed. From the beginning of the 1960-ies the occurrence of combine-harvesters resulted in further extensive spread of ragweed seeds between fields. Under these circumstances in 20 years ragweed became the 8th most frequent weed species in Hungary (Béres, 2003, Kazinczi et al., 2008a, b). At the same time the highly allergenic ragweed pollen was detected in the pollen traps in 1960-ies (Fehér and Járai-Komlodi, 1996).

During the 30-40 years history of the cooperatives and the state farms they became prosperous; the infrastructure was built up and highly educated expert specialists lead the agricultural production in Hungary. From the beginning of the 1990-ies under the formation of the young democracies the lands of the big state farms and cooperatives were divided and redistributed to the former owners or descendants. The new owners neither have the skill nor the capital to buy equipments necessary for proper cultivation. At the same time construction of new roads, motorways, shopping centers etc. created large disturbed areas where ragweed easily became established (Makra et al., 2005, Kiss and Béres, 2006). These circumstances resulted in further spread of ragweed in Hungary. The National Weed Survey in 2007-2008 revealed the presence of ragweed on 5.3 % of the arable crop area.

During the last 20 years common ragweed spread all over Europe. It was reported from Lithuania, Russia, Ukraine, Poland, Germany, Austria, Czech Republic, Slovakia, Croatia, Slovenia, Serbia, Switzerland, Italy, Asia and Australia (cf. Gudzinska, 1993, Brandes and Nitzsche, 2006. Laaidi and Laaidi, 1999, Milanova and Valkova, 2004, Stefanic et al., 2006, Bohren et al., 2006, Wan et al, 1995, McFadyen, 2000).

In Europe the Carpathian Basin, the Rhone Valley and the Po Valley are the most heavily infested regions (Kazinczi et al., 2008a, 2008b, Thibaudon et al., 2004, Fumanal et al., 2007, Mandrioli et al., 1998).

Weaver (2001) proved a 65-70 % yield decreasing effect at the high abundance of common ragweed in corn and soybean fields. Common ragweed caused 42-71% yield losses in maize depending from abundance (Varga et al., 2000). In white lupine (Lupinus albus L.) 18 ragweed plants/m² reduced the yield by 38 % (Béres, 1985). While in sunflower 10 ragweed plants/m² decreased the yield by 33 % (Kazinczi et al., 2007). At higher densities intraspecific competition among ragweed plants was stronger than the competition between maize and ragweed (Kazinczi et al., 2007). In Hungary the value of yield losses caused by A. artemisiifolia reaches 130 million EUR/year (Kőmíves et al., 2006).

Common ragweed as a wind polinated species produces a large quantity of pollen. One single plant is able to produce about 2.5-8×10⁹ pollen grains (Bagarozzi and Travis, 1998, Laaidi et al., 2003).

Allergies to Ambrosia pollen were first described by Wyman in the USA in the 1950-ies (Déchamp, 1995). Ambrosia artemisiifolia has been recognized as a significant cause of allergic rhinitis. Ten percent of the US population, 32 million persons considered to be ragweed sensitive. These people annually spend 225 million dollars on physician services, 300 million USD on prescription drugs and nearly 2 billion USD over the counter allergy medications (Bagarozzi and Travis, 1998).

One third of the Hungarian population suffers from allergy, two thirds of them have pollen sensitivity and at least 60 % of this pollen sensitivity is caused by A. artemisiifolia, 50-70 % of the allergic people...
are sensitive to ragweed pollen (Mezei et al., 1992). *Ambrosia artemisiifolia* is the main aero allergenic plant in Hungary as about the half of the total pollen production 35.9-66.9 % is made up by its pollen (Makra et al., 2005). The therapeutic costs of allergic people are estimated 110 million EUR/year in Hungary (Tóth et al., 2004).

Ziska and his co-workers (2003) studied the pollen production of *A. artemisiifolia* in rural and urban areas. The higher CO₂ concentration and higher air temperature in the urban area resulted in significantly greater pollen production than those of lower ones in the rural area.

Ziska and Caulfield (2000) found that the exposition of ragweed plants to the higher CO₂ concentration predicted for the year 2100 would double the quantity of pollen produced.

The main purpose of *Ambrosia* control is to reduce the production of allergenic pollen and seed (Bohren et al., 2008a). Different means of control can be applied in waste lands, and natural conservation areas, agricultural fields, along the roads and ditches and human impacted disturbed areas in towns. Mowing is a widely used mechanical method to control *Ambrosia* where application of herbicides is not desired (Bohren et al. 2008b).

The aim of the HALT Ambrosia project to improve the efficiency of control methods of common ragweed where the majority of pollen is produced e.g. cereal stubbles; sunflower fields, waste lands, road sides. Seed viability studies are carried out to estimate the role of the seed bank in the soil.

The aim of the mowing studies is:

1a. Improving the efficiency of mechanical ragweed control in urban areas based on mowing in the most vulnerable phenological stages of the plant.

1b. Identification the optimal time of mowing that most effectively decreases the biomass, number of male inflorescences and seed production of ragweed.

**C.1 Optimisation and adaption of thermal control measures**

Thermal weed control is an alternative treatment where neither chemical nor mechanical control is allowed or possible. Research activities are needed to develop innovative control systems especially for non-cropping areas because herbicide uses are very restricted within the EU. Since ragweed is also spreading in organically grown fields there is a strong demand to provide alternatives for organic farmers. The principle of thermal control is that temperatures above 60°C in the plant cells lead to nucleic acid denaturalization. This impact causes an irreversible damage of the plant tissue and leads to necrosis. Machinery for thermal weed control is working with flames, infrared or heated air and heated water (steam or boiling water), which is applied on the plants.

A small plot field experiment with transplanted ragweed (*Ambrosia artemisiifolia*) into gravel and grassland and a large scale field experiment on a roadside banquette in Brandenburg with a natural ragweed infestation were carried out. Thermal control treatments were hot air (gravel and grassland) and hot water (roadside) and flaming, the mechanical treatment was mowing and the chemical treatment was with the herbicide combination MCPA and Dicamba. The gravel and grassland
experiment was conducted at two growth stages of ragweed (BBCH 16-18 and 22-29), at the roadside ragweed was at BBCH 50-65. Dry matter yield of ragweed was assessed 9 weeks after the treatments were conducted in gravel and grassland and 4 weeks after the treatment at the roadside. In gravel and grassland the best eradication at both growth stages by thermal control was achieved by hot air in comparison to the untreated plots (significant at \( P<0.05 \)). And at the roadside significant lower dry matter was determined by hot water and flaming in comparison to the untreated plots (significant at \( P<0.05 \)).

The results of these experiments demonstrated the efficiency of thermal control methods based on hot air and hot water as an alternative to herbicide control and mowing in habitats where herbicide application is not allowed or mowing gives no sufficient eradication results, like on roadside banquettes.

The results of these experiments demonstrated the efficiency of thermal control methods based on hot air and hot water. Recent investigations in Germany and other European countries could also identify hot water systems as a promising tool (Rask et al., 2007; Dittrich et al., 2012). They concluded that at least 2 applications are necessary for a successful weed control. In general the hot water control is applied up to 4 times during the vegetation period but in our studies it was carried out one time only with very promising results. However, there are still gaps of knowledge in terms of the dose-response relation for Ambrosia (e.g. propane consumption in kg/ha) and also correct timing of the application is often difficult (Ascard, 1995). Investigation of the earlier Euphresco project on Ambrosia clearly pointed out the low competitiveness of Ambrosia (Holst, 2010). Therefore any direct control method should be as selective as possible to inhibit growth of Ambrosia by the competition of the surrounding vegetation. Despite its high regrowth capacity, there are no indications that Ambrosia is less susceptible against heat treatments like most of other weed species. Additional information is still required to develop a more specific guidance which enables the practical implementation. Focusing on eradication of Ambrosia we should know more about heat effects on seed viability in the soil seed bank in non-cropping areas. A critical point of thermal control methods is the energy input and the corresponding costs. Although a lot of improvement was achieved to optimise the cost-benefit ratio this will require an economic evaluation specified for different uses and scenarios.

References


C.2 Combination effects of cultural and mechanical control

Suppressing ragweed biomass with integrated farming methods

Ragweed can be a strong competitor to open row crops like sunflowers, maize, potatoes, pumpkins and legumes and can lead to high yield losses. But it also reacts very sensitively to competition. Therefore field trials were conducted in 2011, 2012 and 2013 with sunflower, maize and horse bean respectively. The treatments were the same for sunflower and maize: two row spacing with 35 and 70 cm widths (8 plants*m⁻² in each case) in combination with or without undersown white clover (Trifolium repens). Horse bean was sown in 25 and 50 cm row widths with 40 plants*m⁻² in each case and with or without perennial ryegrass (Lolium perenne). 2 g of ragweed was sown along one metre between two rows in the middle of each plot and were thinned out at the four-leaf stage to five plants per metre (one plant every 20 cm). The ragweed was harvested when its growth stage was in the range of beginning of budding until beginning of flowering in each year. At the same time the sunflower, maize and horse bean plants directly neighbouring on the left and right side of the 1 m ragweed row were harvested too. Fresh matter of sunflower, maize and horse bean and dry matter of ragweed was determined in order to detect the impact of row spacing and the undersown crop on ragweed, sunflower, maize and horse bean biomass.

Significantly lower (*P<0.05) dry matter of ragweed was found in narrowly spaced sunflower and maize plots with undersown white clover compared to the other treatments. Fresh matter of sunflower and maize therefore was not affected by wide or narrow spacing or by undersown clover. The horse bean plots showed different results: significantly lower (*P<0.05) dry matter of ragweed was found in the plots with the undersown crop and in the narrow spacing plots. In the wide spaced plots ragweed had the highest dry matter yield. The same was determined for the horse bean fresh matter: plots with the undersown crop and the narrow spaced rows affected the fresh matter of horse bean negatively. The results show that there is an impact of competition on dry matter of common ragweed and it can be assumed that seed production would be reduced as well. While sunflower and maize dry matter were not affected by narrow spacing and / or the undersown crop, horse bean reacted sensitively to this integrated methods with lower fresh matter yield.

The influence of different catch crops incorporated into the soil to weed competition in following crops
This experiment produced efficacy data for evaluation of influence of different cover crops sown in cereal stubbles and incorporated into the soil before sowing main crops in the following year. Besides the influence of different main crops and their sowing dates on ambrosia density and development were evaluated.

**Material and methods**

10 different catch crops were sown into cereal stubbles in August 2010. Catch crops - plant species in Randomized Complete Block Layout trial:

1. Untreated control
2. *Fagopyrum esculentum* (Čebelica)
3. *Helianthus annuus* (PR64H45), 65.000 seeds/ha
4. *Avena sativa* (Noni)
5. *Lolium multiflorum* (KPC laška)
6. *Guizotia abyssinica* (Mungo), 10 kg/ha
7. *Camelina sativa* (12 kg/ha)
8. *Raphanus sativus* L. var. *oleiformis* Pers. (Rauola), 30 kg/ha
9. *Brassica napus* L.var. *napus f. biennis* (Starška)
10. *Trifolium incarnatum* (Inkara)
11. *Phacelia tanacetifolia* (Balo), 15 kg/ha

In 2011 the rests of cover crops have been incorporated into the soil before 3 different crops have been sown. Each main plot was divided to four subplots where spring wheat (sown on 11th March 2011), spring barley (sown on 24th March 2011) and maize (sown in two different times, 16 March and 30 March 2011). Main plot size: 8 m x 17 m (136 m²). The following parameters were reported: weed species (according to the EPPO-Code, weed number per species, total weed coverage (%)) visually assessed and total weed biomass (dry matter), estimated at the last evaluation.

**Results**

All cover crops displayed strong suppressive effect and decreased weed species number and weed coverage compared to the control plots in fall of 2010. In contrast, no significant effect of catch crops on weed coverage and dry matter production in wheat, barley and maize plots in the spring of the following 2011 season was determined.

Italian ryegrass and buckwheat were germinating in the spring and appearing as volunteer weeds, so their use is not recommended. In barley wheat and maize, the greatest suppressive effect was exhibit by oats, buckwheat and niger seed, where weed coverage decreased compared to the control plots, where these catch crops were not incorporated.
Growth and development of common ragweed (Ambrosia artemisiifolia L.) under different nitrogen, water and competition levels

Objective of the experiment was to determine effect of various nitrogen levels, soil moisture level and competition levels on the growth parameters of ragweed.

Material and methods

Greenhouse pot experiment with randomized treatments in temporal blocks. Experiment was established as a factorial design with four replications. Two watering levels (50 % and 90 % of pot water-holding capacity), three randomized nitrogen levels (10, 50, 100 kg/ha) and three ragweed competition levels with no competition (one ragweed plant in the pot), medium competition level (one ragweed and one grass) and high competition level (one ragweed and five grasses) were selected as factors. Italian ryegrass (Lolium multiflorum L.) was chosen as competitor. Five destructive harvests were conducted throughout the life cycle to determine Common ragweed morphological and physiological parameters (leaf, stem, inflorescences, total dry matter, LA.) in growth stages V6 (6 leaf), V10, V14, full flowering and physiological maturity.

Results

The leaf, stem, total dry matter and leaf area of single-grown ragweed responded to medium and high N levels, whereas under neighbouring competition with Italian ryegrass, higher N levels were required to observe a response. Ragweed performance was strongly decreased by interspecific competition with Italian ryegrass. Increased resource availability enhanced competition intensity. Nitrogen affected seed production only in no competition stands.

Medium competition reduced the total dry matter by up to 58 %, whereas high competition reduced it by up to 85 %. Reproductive output was also strongly affected by competition. Medium competition reduced the seed weight per plant by up to 83 %; high competition reduced it further by up to 91 %. The higher water level had a weak effect on growth parameters, but only in the absence of competition. The greatest RGR was determined at early vegetative V10 growth stage. Relative growth rate (RGR) was affected by competition and water level, however the RGR under various N availability levels was similar. Ragweed is not a strong competitor in resource-rich conditions, but results under moderate water stress and low N inputs showed that ragweed growth was not greatly affected by moderate competition. Our results indicate that low-water and low-nutrient environments with an absence of competition are critical factors for the successful establishment and further spread of ragweed.
C.3 Perspectives for biological control of Ambrosia artemisiifolia in Europe

Though chemical and mechanical control methods have been developed and partially implemented in Europe, sustainable control strategies to mitigate its spread into extensively managed land and to reduce its abundance in badly infested areas are lacking. One management tool is biological control. Almost all natural enemies that have colonized A. artemisiifolia in Europe are polyphagous and impose only little damage, rendering them unsuitable for a system management approach. Two fungal pathogens have been reported to adversely impact A. artemisiifolia in the introduced range, but their biology makes them difficult for mass production and application as a mycoherbicide. In the native range of A. artemisiifolia, on the other hand, a number of herbivores and pathogens associated with this plant have a very narrow host-range and reduce pollen and seed production, the stage most sensitive for long-term population management of this winter annual. Examples for the successful application of classical biological control are reported from Australia and from China. Control agents used were butterfly and beetle species.

In Australia, the two agents Epiblema strenuana (butterfly) and Zygogramma bicolorata (beetle) are known to be widespread and exerting a degree of control in most of the affected areas in eastern Australia. There has been no formal assessment of the impact of these biocontrol agents on A. artemisiifolia. However, there is now much less A. artemisiifolia in southeastern Queensland and northern New South Wales than there was in the 1980s. The plant is now relatively rare and no longer causes significant allergenic symptoms in the flowering season. From an economic point of view, biological control of A. artemisiifolia is regarded as an outstanding success in Australia.

A prioritisation of biological control candidates for a classical or inundative biological control approach against common ragweed in Europe is a necessary prerequisite for the development of biological control. It should consider past experiences from North America, Asia and Australia. The biological control approach should be considered as an integral part of an integrated management approach against common ragweed in Europe. Along these lines, the COST action ‘SMARTER’ (www.ragweed.eu) was recently launched that aims at promoting biological control against common ragweed, integrating it with available chemical and physical control options, and developing habitat- and region-specific recommendations for a integrated management of common ragweed across Europe. The very recent report about finding a population of the oligophagous beetle Ophraella communa on Ambrosia in Italy shows the potential of a damage to Ambrosia by herbivores.

References

C.4 Management of contaminated soil

The spread of seeds within excavated material is an effective spreading route for common ragweed in Europe. Its relevance often increases with the abundance of ragweed in a region. In East-Germany, for example, road construction led to an increase of the ragweed population at road sides during the last years.

The use of soil contaminated with ragweed seeds at soil surfaces should be avoided. Contaminated soil should be deeply buried, disposed or decontaminated. It could be used at sites, where no suitable growing conditions for Ambrosia are present.

It should be avoided to transport contaminated soil in order to prevent seed losses during the transportation. If a transport is not avoidable contaminated soil should be transported only to a single site (no dispersal). If contaminated soil is used at the surface an effective combat of Ambrosia should be ensured over several years.

In most of the European countries no special measures are conducted to prevent the spread of common ragweed within excavated material, by now. In many European countries the awareness of the Ambrosia problem in the building industry is low and even if the sector is informed, without legal regulations usually no control or prevention measures occur (cost- and labour-intensive). Management programmes on a voluntarily base often did not reach the building sector in Germany.

Comprehensive legal regulations currently exist in Switzerland which could serve as an example for other countries.

The example of Switzerland, where ragweed is controlled effectively by now, demonstrates that it is necessary to increase awareness of the Ambrosia problem in the building sector.

In Switzerland a special legal obligation regarding the disposal of excavated material contaminated with organic material (Neobiota) exists in the canton Zürich. The regulation says: If an invasive plant species occurs at a construction site the building owner has to fill in a declaration. Contaminated soil that cannot be used at the site has to be disposed at authorized sites.

During the construction work the contaminated material must not be mixed with clean material and it has to be separated. During the excavation a consultant has to be present at the construction site. It has to be ensured that no contaminated material is lost during the transportation. After transportation to the disposal site a form with a report has to be sent to the authorities. 1-2 month after the measure an authorized consultant has to control whether invasive plants grow back at the site.
C.5 Optimisation of mowing for Ambrosia control

The aim of the work point: Mechanical control

_The influence of mowing at different growing stages on ambrosia development and seed production (I)_

This experiment produced efficacy data for mechanical measures (mowing) in correlation with ambrosia development. The influence of different mowing regimes on ambrosia was investigated in this trial.

**Material and methods**

Pot trial was carried out to check the possibility to completely prevent the pollen and seed formation by mowing ragweed plants only twice a season. We tried to mimic the development of ragweed plants growing on the highway margins and frequency of mowing of highway vegetation performed by highway Maintenance Company.

For each treatment there were 5 pots (10 l) with 5 ambrosia plants. Mowing was performed at 3 cm above soil surface.

Experimental treatments:

A. Mowing regime for second mowing: no additional mowing, after 4 weeks, after 6 weeks, after 8 weeks, after 12 weeks.
B. Mowing regime for second and third mowing: after 4 weeks – after 3 weeks, after 4 weeks – after 6 weeks, after 6 weeks – after 3 weeks, after 6 weeks – after 8 weeks – after 3 weeks, after 8 weeks – after 6 weeks, after 12 weeks – after 3 weeks, after 12 weeks – after 6 weeks

Ragweed plants were grown in plastic pots (10 l). 5 plants of ragweed were grown in each pot. Plants were mowed at different developing stages (2 leaves – 1. node, 4 leaves - 2. node, 8 leaves – 3. node) using scissors and we cut them at height of 3 cm above the soil level. Mowing was performed once, twice or three times a season in different time intervals (4, 6, 8 or 12 weeks).

In total there were 40 combinations of intervals between mowing and growing stages of plants at period of first mowing. Percentage of plants producing flowers, percentage of plants developing fertile seeds, amount of seeds produced per plant (pot) and fresh plant mass per pot at the end of October was measured.

**Results**

- One or two mowing of ragweed plants is not sufficient to completely prevent pollen and seed production.
- Our results indicate that pollen and seed production can be largely (-90 %) prevented with two optimal cuts at proper development stage.
- The reduction of produced seed is higher if the first mowing is performed at higher growth stage of plants (end of June or later).
- Ragweed plants produced less seed if time intervals between successive mowing are longer, especially in case if first mowing is performed at 2 leaves growth stage.
- If highway maintenance service decides to perform just two mowing a season, than first mowing should not be performed earlier than 3 nods growth stage and second mowing not earlier than 12 weeks after the first one.
- The most efficient system for pollen and seed production prevention is to perform first mowing at 3 node growth stage, repeat mowing after 8 weeks, and then the third one after 12 weeks.

**Regrowth of ambrosia after mowing at different growing stages (II)**

This experiment produced efficacy data for mechanical measures (mowing) in correlation with ambrosia development and the height of mowing. Besides the mowing, influence of the competition between ambrosia and other weed species was investigated in this trial.

**Experimental treatments**
1. Two mowing heights (3 cm and 6 cm above the soil surface)
2. Three growing stages (heights) of ambrosia at first mowing (20 cm, 40 cm, 60 cm)
3. Two time intervals between cuts (after 5 and 10 weeks)
4. Competition between ambrosia and other plants (no competition, competition with Lolium and Chenopodium)

**Material and methods**

For each treatment there will be 5 pots (10 L) with 5 ambrosia plants (and 5 weed species in case of competition). This pot trial was also performed to mimic the conditions of ragweed development on the margins of highway. The trial setup was the same like in trial one. 5 ragweed plants were competing with 5 lamb's quarters plants (Chenopodium album), or with 5 ryegrass plants (Lolium perenne). Seeds of all plant species were sown together and thinning of seedlings in the cotyledon stage was performed.

Both ragweed and competitor plants were mowed by scissors at different ragweed plant heights (20, 40 and 60 cm high plants) at level of 3 cm above ground. At the end of season (end of October) plants were weighed, number of seeds produced per plant was determined and the portion of plants
that developed seeds was calculated. Percentage of plants that producing flowers, Percentage of plants developing fertile seeds, amount of seeds produced per plant (pot) and fresh plant mass per pot were measured at the end of October.

Results

- The greatest dry matter reduction after cutting was determined, when ragweed was grown in the mixture with ryegrass
- The regeneration capacity of ragweed exposed to competition to other weeds after mowing is significantly lower when compared development to environment without competition with other plants
- Cutting height (3 and 6 cm) influenced ragweed dry matter and seed production only when ragweed in monoculture was grown in the pots; it increased at lower mowing height
- Dry matter and seed production of ragweed significantly decreased with ragweed first cut at later growth stages and increased period between two cuts
- Our results indicate that pollen and seed production can be completely prevented with two optimal cuts at proper development stage (40-60 cm and 10 week time interval).

Mechanical control: Mowing

1a. Improving efficiency of mechanical ragweed control of urban areas based on mowing in the most vulnerable phonological stages of the plant
1b. Identification the optimal time of mowing that most effectively decreases the biomass, number of male inflorescences, pollen release and seed production of ragweed.

Material and methods

2. Material and methods

2.1. Ragweed mowing experiment was carried out in the experimental field of the Plant Protection Institute of Hungarian Academy of Sciences at Nagykovácsi (47° 32’ N, 18° 56’ E). The experiment was set up on a land, which was abandoned for three years with the only disturbance of autumn ploughing and seed bed preparation in April. Prior to set up the mowing experiment seed bed preparation was done in the middle of April; secondary tillage was carried out with harrow and cultivator. After emergence of ragweed plants, on 5 May 10x10 m plots were stacked out. Plots were separated with 1 m wide land stripes of boundaries. The stripes were kept weed free by regular cultivator treatments. Number of ragweed plants was counted on randomly selected 10x1 m² areas.
2.2. Experimental treatments included: in 2011 none-mowed control, early mowed treatment BBCH 33, late mowed BBCH 51 twice mowed treatment BBCH 33 and 51. In course of the mowing the plants were cut at the height of 5-7 cm in 2011 by Husqvarna, 128 R loan mower.

In 2012 and 2013 treatment included none-mowed control, early mowed treatment BBCH 33, late mowed BBCH 51 twice mowed treatment BBCH 33 and 51 and mowing 3 times BBCH 33, 51 and 51 treatments. The cutting height of the plants was 2-3 cm in 2012 and 2013 due to changing the mowing equipment into Husqvarna hedge trimmer. In the second and third year of the study 327HE4X Husqvarna hedge trimmer was used for mowing the plants.

During the study plots in 4 replicates were randomly designed. Plants were sampled at weekly intervals 5 randomly selected plants were cut off at soil surface level from each plot (20 plants/treatment altogether). Plants were transferred into the laboratory, where the above ground fresh biomass and the plant height were measured, further male inflorescences and female flowers were counted.

2.3. For pollen production studies two plants on each plot were selected (4x2 plants/treatment) to collect pollen. Transparent polyethylene bags for pollen collection were placed on the plants at BBCH 60 (Hess et al., 1997). Each plant was covered with a plastic bag that gave sufficient room for the growth. The non-mowed and early mowed plants were covered by 120x40 cm polyethylene bags. Plants of the late mowed, twice mowed treatments were covered with 80×40 cm polyethylene bags. Plants of mowing three times treatment were covered with 50×40 cm polyethylene bags. For ventilation purposes the bottom corners of the bags were opened on a 5 mm wide and 15 mm long surfaces, which served as ventilation holes just like the 10 randomly pricked 1.0-1.5 mm holes on each bag. The bigger holes served to fix the bags with a pulled trough string to the wire frame. The opening of the polyethylene bags were fixed to the wire frame and closed on the main stems of the ragweed plants under the lowest side shoots with the aid of an adhesive rubber. The polyethylene bags were replaced by new ones weekly, when the pollen content of the bags were washed off in 250 ml of 0.02 % Tween 20 detergent solution. The pollen containing solution was stirred by a glass rod than 5×1 ml samples were collected into Eppendorf tubes. Eppendorf tubes were labeled and stored in refrigerator until pollen counting. After thorough shaking from each Eppendorf tube 2.5µl samples were taken and individually transferred into a glass hemacytometer (MOM Budapest). Pollen grains were counted on 160 × magnification by means of a light microscope. Based on the numbers of 5 counts the number of pollen grains in 250 ml water was calculated.

2.4. Pollen production study was carried out in 2011 and 2012, because counting the pollen grains is a labour-consuming activity. We spent 5 months with counting the pollen grains during the first two years of the study.
**Statistical analyses.** Data were analyzed by ANOVA using STATISTCA, StatSoft, Inc., 2007 program package. The effect of the mowing treatments on the plant above ground fresh biomass, plant height, number of male inflorescences and number of female flowers during the whole season was evaluated by Tukey HSD test.

**Results 2011**

In the first year of the study the height of the mowing was 5-7 cm. Using Husqvarna, 128 R loan mower it was not possible to decrease the cutting height.

![Image showing ragweed plants](image_url)

**Fig. 1.** Due to the 5-7 cm cutting height ragweed plants produced intensive side shoot formation. The higher the cutted stem more internodes’ are situated on it. The side shoots develop from the buds of the internodes.

The ANOVA revealed significant effect of mowing treatments on the plant above ground fresh biomass, plant height, number of female flowers, number of male inflorescences in 2011. $F$ values are: 273, 687, 107, 1643, respectively (n=640). The $P$ values are <0.000. Mowing treatments significantly influenced the number of released pollen grains as well $F=72$, n=32 $P<0.000$. 
The Tukey HSD test revealed the significant difference between the above ground biomass, plant height and the number of male flowers of non-mowed control plants and those of the early mowed plants (Table 1.). However, the number of female flowers and number of pollen grains did not decrease significantly due to early mowing. Due to late and twice mowing there was no significant difference between mowing treatments at the above ground fresh biomass, plant height, number of female flowers and number of male inflorescences. However, the number of pollen grains decreased in a greater extent due to double mowing compared to late mowing. The decreasing effect of twice mowed treatment reached 80 percent at the measured plant parameters (Figs. 3-6).

Non-mowed control plants released 59 million pollen grains during pollination. Although, the pollen reducing effect of the best mowing twice treatment was only 85 % mowing treatments shipped the beginning of pollen releasing period. The flowering of male inflorescences started on non-mowed control plants started on 25 August and lasted for six weeks. Early mowing postponed pollination by tree weeks. However, due to late and twice mowing the pollen production started 6 weeks later and it lasted for 4 weeks. Early and late mowing not only postponed the beginning of pollination, but the intensity of pollen production also decreased significantly (Fig. 7, 8).
Table 1. The effect of mowing treatments on the above ground biomass, plant height, number of female flowers, male inflorescences, number of released pollen grains of ragweed plants and the percent reduction due to mowing treatments. Juliannamajor, Budapest 2011.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Valid No</th>
<th>Mean± S. E.</th>
<th>Min</th>
<th>Max</th>
<th>% reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Above ground biomass (g)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None-mowed</td>
<td>220</td>
<td>28.33±1.37  a</td>
<td>4.00</td>
<td>275</td>
<td>0.00</td>
</tr>
<tr>
<td>Early mowed</td>
<td>200</td>
<td>18.41±0.90  b</td>
<td>0.40</td>
<td>99</td>
<td>35.02</td>
</tr>
<tr>
<td>Late mowed</td>
<td>120</td>
<td>5.52±0.34   c</td>
<td>0.30</td>
<td>26</td>
<td>73.64</td>
</tr>
<tr>
<td>Twice mowed</td>
<td>140</td>
<td>7.47±0.38   c</td>
<td>0.60</td>
<td>34</td>
<td>80.64</td>
</tr>
<tr>
<td><strong>Plant height (cm)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None-mowed</td>
<td>220</td>
<td>100.60±1.13 a</td>
<td>47.00</td>
<td>146</td>
<td>0.00</td>
</tr>
<tr>
<td>Early mowed</td>
<td>200</td>
<td>47.36±1.10  b</td>
<td>4.70</td>
<td>103</td>
<td>53.03</td>
</tr>
<tr>
<td>Late mowed</td>
<td>120</td>
<td>25.45±0.68  c</td>
<td>0.70</td>
<td>47</td>
<td>74.80</td>
</tr>
<tr>
<td>Twice mowed</td>
<td>140</td>
<td>20.84±0.67  c</td>
<td>5.50</td>
<td>55</td>
<td>80.28</td>
</tr>
<tr>
<td><strong>Number of female flowers</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None-mowed</td>
<td>220</td>
<td>636.76±12.90 a</td>
<td>0</td>
<td>6456</td>
<td>0.00</td>
</tr>
<tr>
<td>Early mowed</td>
<td>200</td>
<td>413.70±10.34 ab</td>
<td>0</td>
<td>1582</td>
<td>35.04</td>
</tr>
<tr>
<td>Late mowed</td>
<td>120</td>
<td>170.01±5.90 bc</td>
<td>0</td>
<td>687</td>
<td>73.30</td>
</tr>
<tr>
<td>Twice mowed</td>
<td>140</td>
<td>107.22±6.78 c</td>
<td>0</td>
<td>714</td>
<td>83.16</td>
</tr>
<tr>
<td><strong>Number of male inflorescences</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None-mowed</td>
<td>220</td>
<td>2753.72±121.80 a</td>
<td>0</td>
<td>18580</td>
<td>0.00</td>
</tr>
<tr>
<td>Early mowed</td>
<td>200</td>
<td>1292.93±68.65 b</td>
<td>0</td>
<td>5860</td>
<td>53.05</td>
</tr>
<tr>
<td>Late mowed</td>
<td>120</td>
<td>328.36±16.64 c</td>
<td>0</td>
<td>1700</td>
<td>88.08</td>
</tr>
<tr>
<td>Twice mowed</td>
<td>140</td>
<td>181.41±19.67 c</td>
<td>0</td>
<td>595</td>
<td>93.12</td>
</tr>
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<td><strong>Number of released pollen grains (millions)</strong></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None-mowed</td>
<td>48</td>
<td>59.43±7.67a</td>
<td>39.32</td>
<td>109.47</td>
<td>0.00</td>
</tr>
<tr>
<td>Early mowed</td>
<td>32</td>
<td>43.46±1.13a</td>
<td>31.68</td>
<td>58.13</td>
<td>26.88</td>
</tr>
<tr>
<td>Late mowed</td>
<td>32</td>
<td>24.30±3.02b</td>
<td>14.12</td>
<td>35.88</td>
<td>51.10</td>
</tr>
<tr>
<td>Twice mowed</td>
<td>32</td>
<td>8.66±1.56c</td>
<td>2.91</td>
<td>17.59</td>
<td>85.42</td>
</tr>
</tbody>
</table>

Means with different letters are significantly different \( p<0.05 \) (Tukey HSD test).

Fig. 3. The effect of mowing treatments on the development of above ground plant biomass. Budapest 2011.
Fig. 4. The effect of mowing treatments on the plant height. Budapest, 2011.

Fig. 5. The effect of mowing treatments on the number of male inflorescences. 2011.
Fig. 6. The effect of mowing treatments on the number of female flowers. Budapest, 2011.

Fig. 7. The effect of mowing treatment on the number of released pollen grains and the length of the pollen production period. Budapest 2011.
Fig. 8. Effect of mowing treatments on the number of the released pollen grains. Budapest, 2011.

**Results 2012**

In the second year of the study the loan mower was replaced by 327HE4X Husqvarna hedge trimmer. With the hedge trimmer the cutting height of the plans could be reduced up to 2-3 cm.

Due to the excellent mowing, the mowing treatments significantly affected above ground plant biomass, plant height, number of female flowers, number of male inflorescences ANOVA. The $F$
values are: 281, 163, 68, 129, respectively, n=1220 $P<0.000$. The mowing treatments significantly affected the number of released pollen grains as well $F=82$, $n=40$, $P<0.000$.

Fig. 10. The late mowed plants in 2012

Fig. 11. The twice mowed plants in 2012
Fig. 12. The three times mowed plants in 2012

Fig. 13. The non-mowed control plants
Table 2. The effect of mowing treatments on the above ground biomass, plant height, number of female flowers, male inflorescences, number of released pollen grains of ragweed plants and the percent reduction due to mowing treatments. Juliannamajor, Budapest 2012.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Valid No</th>
<th>Mean± S. E.</th>
<th>Min</th>
<th>Max</th>
<th>% reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Above ground biomass (g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None-mowed</td>
<td>220</td>
<td>84.89±4.85a</td>
<td>2</td>
<td>303</td>
<td>0.00</td>
</tr>
<tr>
<td>Early mowed</td>
<td>240</td>
<td>15.51±0.93b</td>
<td>1</td>
<td>88</td>
<td>81.23</td>
</tr>
<tr>
<td>Late mowed</td>
<td>180</td>
<td>4.26±0.24c</td>
<td>0.2</td>
<td>25</td>
<td>94.08</td>
</tr>
<tr>
<td>Twice mowed</td>
<td>280</td>
<td>4.75±0.33c</td>
<td>0.2</td>
<td>37</td>
<td>94.41</td>
</tr>
<tr>
<td>Mowing 3 times</td>
<td>300</td>
<td>3.81±0.34c</td>
<td>0.2</td>
<td>65</td>
<td>96.52</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plant height (cm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None-mowed</td>
<td>220</td>
<td>82.77±1.64a</td>
<td>19</td>
<td>150</td>
<td>0.00</td>
</tr>
<tr>
<td>Early mowed</td>
<td>240</td>
<td>43.56±1.46b</td>
<td>5</td>
<td>93</td>
<td>43.38</td>
</tr>
<tr>
<td>Late mowed</td>
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<td>22.66±0.72c</td>
<td>5</td>
<td>44</td>
<td>72.63</td>
</tr>
<tr>
<td>Twice mowed</td>
<td>280</td>
<td>19.05±0.57c</td>
<td>4</td>
<td>56</td>
<td>76.45</td>
</tr>
<tr>
<td>Mowing 3 times</td>
<td>300</td>
<td>17.24±0.58d</td>
<td>3</td>
<td>65</td>
<td>70.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of female flowers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-mowed</td>
<td>220</td>
<td>663.16±75.51a</td>
<td>18</td>
<td>2550</td>
<td>0.00</td>
</tr>
<tr>
<td>Early mowed</td>
<td>240</td>
<td>171.11±19.49b</td>
<td>20</td>
<td>1430</td>
<td>74.20</td>
</tr>
<tr>
<td>Late mowed</td>
<td>180</td>
<td>68.14±6.37bc</td>
<td>6</td>
<td>480</td>
<td>89.75</td>
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<tr>
<td>Twice mowed</td>
<td>280</td>
<td>33.82±3.38c</td>
<td>2</td>
<td>288</td>
<td>95.03</td>
</tr>
<tr>
<td>Mowing 3 times</td>
<td>300</td>
<td>13.35±1.41c</td>
<td>2</td>
<td>194</td>
<td>97.44</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of male inflorescences</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-mowed</td>
<td>220</td>
<td>4638±406.91a</td>
<td>26</td>
<td>36.443</td>
<td>0.00</td>
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<tr>
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<td>874±80.18b</td>
<td>25</td>
<td>6877</td>
<td>81.16</td>
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<td>180</td>
<td>186±18.09bc</td>
<td>18</td>
<td>1321</td>
<td>96.00</td>
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<tr>
<td>Twice mowed</td>
<td>280</td>
<td>55±4.97</td>
<td>14</td>
<td>530</td>
<td>98.82</td>
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<td>Mowing 3 times</td>
<td>300</td>
<td>32±4.62</td>
<td>3</td>
<td>626</td>
<td>99.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of released pollen grains (millions)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-mowed</td>
<td>8</td>
<td>155.295±134.492a</td>
<td>103.860</td>
<td>196.720</td>
<td>0.00</td>
</tr>
<tr>
<td>Early mowed</td>
<td>8</td>
<td>44.452±3.870 b</td>
<td>24.860</td>
<td>62.640</td>
<td>71.38</td>
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<tr>
<td>Late mowed</td>
<td>8</td>
<td>35.342±4.711 bc</td>
<td>61.340</td>
<td>22.700</td>
<td>73.25</td>
</tr>
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<td>Twice mowed</td>
<td>8</td>
<td>8.905±1.382 cd</td>
<td>17.020</td>
<td>4.840</td>
<td>94.27</td>
</tr>
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<td>Mowing 3 times</td>
<td>8</td>
<td>2.272±378 d</td>
<td>4.020</td>
<td>680</td>
<td>98.54</td>
</tr>
</tbody>
</table>

Means with different letters are significantly different p<0.05 (Tukey HSD test)

Due to mowing treatments the above ground biomass, plant height, number of female flowers, number of male inflorescences and number of released pollen grains significantly decreased (Table 2.). There was significant difference between early and late mowed treatments. However, there was no significant difference between twice and three times mowed plants (Figs. 14-19).
Fig. 14. The effect of mowing treatments on the development of above ground plant biomass. Budapest 2012.

Fig. 15. The effect of mowing treatments on the plant height. Budapest, 2012.
Fig. 16. The effect of mowing treatments on the number of male inflorescences. 2012.

Fig. 17. The effect of mowing treatments on the number of female flowers. Budapest, 2012.
Fig. 18. The effect of mowing treatments on the number of released pollen grains. Budapest, 2012

Fig. 19. The effect of mowing treatment on the number of released pollen grains and the length of the pollen production period. Budapest 2012.
Results 2013

The mowing treatments significantly affected above ground plant biomass, plant height, number of female flowers, number of male inflorescences ANOVA. The $F$ values are: 238, 742, 267, 68, respectively, $n=1460 \ P<0.000$. 

Table 3. The effect of mowing treatments on the above ground biomass, plant height, number of female flowers, male inflorescences, number of released pollen grains of ragweed plants and the percent reduction due to mowing treatments. Juliannamajor, Budapest 2013.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Valid No</th>
<th>Mean± S. E.</th>
<th>% reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Above ground biomass (g)</td>
<td></td>
</tr>
<tr>
<td>None-mowed</td>
<td>300</td>
<td>44.48±1.71a</td>
<td>0.00</td>
</tr>
<tr>
<td>Early mowed</td>
<td>300</td>
<td>19.12±0.71b</td>
<td>57.02</td>
</tr>
<tr>
<td>Late mowed</td>
<td>260</td>
<td>13.31±0.67c</td>
<td>70.08</td>
</tr>
<tr>
<td>Twice mowed</td>
<td>300</td>
<td>11.72±0.56c</td>
<td>73.66</td>
</tr>
<tr>
<td>Mowing 3 times</td>
<td>300</td>
<td>7.92±0.49d</td>
<td>82.20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plant height (cm)</td>
<td></td>
</tr>
<tr>
<td>None-mowed</td>
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<td>90.84±1.19a</td>
<td>0.00</td>
</tr>
<tr>
<td>Early mowed</td>
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<td>55.44±1.08b</td>
<td>38.07</td>
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<tr>
<td>Late mowed</td>
<td>260</td>
<td>36.93±0.99c</td>
<td>59.35</td>
</tr>
<tr>
<td>Twice mowed</td>
<td>300</td>
<td>30.72±0.80d</td>
<td>67.19</td>
</tr>
<tr>
<td>Mowing 3 times</td>
<td>300</td>
<td>23.35±0.87e</td>
<td>74.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of female flowers</td>
<td></td>
</tr>
<tr>
<td>Non-mowed</td>
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<td>445.43±36.15a</td>
<td>0.00</td>
</tr>
<tr>
<td>Early mowed</td>
<td>300</td>
<td>187.97±12.39b</td>
<td>57.08</td>
</tr>
<tr>
<td>Late mowed</td>
<td>260</td>
<td>268.93±19.37c</td>
<td>39.96</td>
</tr>
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<td>Twice mowed</td>
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<td>107.58±10.55d</td>
<td>75.96</td>
</tr>
<tr>
<td>Mowing 3 times</td>
<td>300</td>
<td>22.32±3.50e</td>
<td>95.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number of male inflorescences</td>
<td></td>
</tr>
<tr>
<td>Non-mowed</td>
<td>300</td>
<td>2099.45±11.12a</td>
<td>0.00</td>
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<td>Early mowed</td>
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<td>783.19±40.25b</td>
<td>62.70</td>
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<td>Late mowed</td>
<td>260</td>
<td>594.90±41.74b</td>
<td>71.71</td>
</tr>
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<td>Twice mowed</td>
<td>300</td>
<td>207.88±20.16c</td>
<td>90.10</td>
</tr>
<tr>
<td>Mowing 3 times</td>
<td>300</td>
<td>72.91±11.97c</td>
<td>96.53</td>
</tr>
</tbody>
</table>

Means with different letters are significantly different $p<0.05$ (Tukey HSD test)

Due to mowing treatments the above ground biomass, plant height, number of female flowers, number of male inflorescences (Table 3.). Apart from the number of male inflorescences there was significant difference between early and late mowed treatments. In 2013 there was significant difference between twice and three times mowed plants except the number of male inflorescences (Figs. 20-21).
Fig. 20. The effect of mowing treatments on the development of above ground plant biomass. Budapest, 2012

Fig. 21. The effect of mowing treatments on the plant height. Budapest, 2013.
Conclusions

The high efficiency of multiple mowing has great importance. The high seed production decreasing efficiency (female flowers) of multiple mowing treatments is especially important.

Mowing is considered to efficiently decrease male inflorescences and above ground biomass, however, it is general opinion of the researchers that the soil seed bank cannot be depleted by mowing. The results of our mowing experiments show that the lower cutting height can efficiently improve seed decreasing effect of mowing. The efficiently of mowing can be increased by mowing plants in generative stage. Early mowing of the vigorously growing plants increases ramification.

However, plants in generative stage invested energy to develop male inflorescences and female flowers. Therefore, late mowing more efficiently decreases pollen and seed production, than early one. Based on our results the seed and pollen production efficiency of mowing can be increased.

References


Conclusions

After the second mowing there was hardly any rain in 2012.

We managed to decrease the cutting height up to 2-5cm by using the Husqvarna hedge trimmer.

The low cutting height resulted in increased efficiency.

Number of female flowers, male inflorescences and pollen grains decreased more than 70 % even due to one early mowing.

Late mowed treatment decreased the flowers by 90 %, but pollen grains only 77 %.

Twice mowed treatment resulted in 94 % reduction of the reproductive parts.

Three times mowed plants reduced seed, male inflorescence and pollen production between 97.7-98.5 %.

The seed production decreasing effect has GREAT IMPORTANCE! Up to now results of the mowing experiments showed efficient pollen decreasing effect, however, mowing was not considered efficient method to decrease seed production. The seed decreasing effect of present study prove that decreased cutting height results in proper seed production reduction.