



Original article

Efficient reduction of biomass, seed and season long pollen production of common ragweed (*Ambrosia artemisiifolia* L.)Zsuzsa Basky^{a,*}, Márta Ladányi^b, Andrej Simončič^c^a Plant Protection Institute, Centre for Agricultural Research, Hungarian Academy of Sciences, 1022 Budapest, Herman Ottó u. 15., Hungary^b Corvinus University of Budapest, Dpt. of Biometrics and Agricultural – Informatics H-1118 Budapest, Villányi út 29., Hungary^c Agricultural Institute of Slovenia, SI-1000 Ljubljana, Hacquetova ulica 17., Slovenia

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ABSTRACT

Ragweed (*Ambrosia artemisiifolia* L.) is a noxious plant that not only is a troublesome agronomic weed that causes economic damage to agricultural crops but also – and even more importantly – causes severe health problems due to its severe allergenicity. The pollen of invasive ragweed has become a major allergenic risk factor in urban areas in newly occupied regions. Many urban areas prohibit herbicide application; thus, mowing is the most widely used control measure. Counting pollen is labour intensive; therefore, pollen production data are mainly based on estimations. Field experiments were conducted to determine the effects of different mowing scenarios, plant density and cutting height on the biomass, pollen production and seed production of common ragweed plants. Ragweed plants were mown twice: just before the flowering of terminal racemes (BBCH 59) and when the flowers of the re-sprouting lateral shoots reached BBCH 59. A 1- to 3-cm cutting height produced the greatest pollen reduction compared to that of intact control plants (94%) based on a season-long pollen collection. The number of female flowers also significantly decreased (97%). Compared to the control, the onset of pollen discharge was delayed by 5 weeks and the length of the pollen discharge period decreased from 9 to 4 weeks. The season-long unique and reproducible pollen production data can be integrated with airborne pollen modelling and population management strategies.

1. Introduction

Common ragweed, (*Ambrosia artemisiifolia* L.), hereafter referred to as ‘ragweed’, is a wind-pollinated annual plant that is native to North America. Ragweed pollen has been detected in Canadian interglacial deposits that are more than 60,000 years old (Bassett and Teresmae, 1962). The massive spread of ragweed in different parts of the world has coincided with major socio-economic transitions that increased disturbed land areas. In 18th and 19th century Canada, European settlement led to increased agricultural activity. Large-scale deforestation and soil disturbance resulted in a hundredfold increase of ragweed pollen in these regions (Bassett and Crompton, 1975).

Ragweed was introduced to Europe at the end of the 19th century. Since then, this species has spread and naturalised across Europe (Kiss and Béres, 2006). The key factor in the introduction of ragweed in Europe was anthropogenic (Chauvel et al., 2006). Commercial trade between North America and Europe, as well as American troops transporting food products and war equipment during the First World War, contributed to the spread of ragweed (Kiss and Béres, 2006). Smith et al. (2013) summarised most existing knowledge about rag-

weed ecology, its distribution and phenological characters of flowering and its environmental health risk. The authors demonstrated that invasive ragweed is an environmental health threat both in its native range and in the regions in which it has been introduced.

Ragweed was first recorded in Hungary in 1908 (Jávorka, 1910). Regular weed surveys since the 1950s have revealed an extension of the species’ distribution in Hungary. However, in the 1950s, ragweed was not a problematic weed; therefore, no attention was paid to its control. By 1997, under favourable environmental conditions and due to the excellent adaptation ability of this species, ragweed had become the dominant weed species, covering 4.7% of the arable crop area (Béres, 2004). In the most recent weed survey in 2007–2008, ragweed maintained its dominant position, covering 5.33% of Hungary’s arable crop area (Novák et al., 2009).

In Europe, the Carpathian Basin, the Rhone Valley and the Po Valley are the most heavily infested regions (Fumanal et al., 2007). Due to the very rapid spreading of ragweed, Essl et al. (2011) developed and tested a risk assessment tool for invasive alien species (IAS) in Germany and in Austria: the “German-Austrian Black List Information System” (G-ABLIS). GABLIS evaluates the impact of alien species on native

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biodiversity; however, socio-economic impacts are not considered in this assessment. Similarly, Pergl et al. (2016) published their Black, Grey and Watch Lists of alien species in the Czech Republic based on environmental impacts and management strategy. These authors considered the invasion dynamics and the environmental and socio-economic impact of alien species; therefore, in their Black List in List category BL1, the first species for risk is ragweed.

The yield-decreasing effect of ragweed depends on its density and crop competitiveness. This effect does not usually occur in dense autumn-sown crops (cereals and winter rape). Ragweed control in these crops is therefore not necessary due to crop competition. However, after harvest when crop competition ends, the emerged ragweed plants must be controlled by stubble turning (cf. Kazinczi et al., 2008).

Ragweed is not only a noxious and troublesome agronomic weed causing economic damage to agricultural crops, it also influences biodiversity (Skj  th et al., 2010) and, even more importantly, causes severe health problems. Pollen grains of *A. artemisiifolia* L. are very potent aeroallergens. Therefore, ragweed is considered the most dangerous allergy-related plant (  koparija et al., 2009). Its highly allergenic pollen induces allergic rhinitis in sensitised patients and induces asthma approximately twice as often as does the pollen of other allergic species (J  ger, 2000; Taramarc  z et al., 2005). Therefore, ragweed control is not only an agricultural task but also a serious public health benefit (Simard and Benoit, 2011).

In the United States, ragweed pollen allergy is one of the most common health problems; the sensitisation rate is greater than 20% (Katz and Carey, 2014). One-third of Hungary's inhabitants suffer from this allergy; two-thirds of these inhabitants have pollen sensitivity, and at least 60% of this pollen sensitivity is caused by ragweed. From 50–70% of allergic people are sensitive to ragweed pollen. Ragweed is the main aero-allergenic plant in Hungary. Approximately half of the total pollen production (PP), 35.9–66.9%, is made up of ragweed pollen (Makra et al., 2005).

Airborne pollen concentration is influenced by the number of plants, PP and release and atmospheric dispersion changes (Makra et al., 2005). Recently, Katz et al. (2014) reported that in urban environments, the local ragweed populations are the most important sources of allergenic pollen. Katz and Carey (2014) proved that in urban environments airborne ragweed pollen concentrations are strongly correlated with ragweed population abundance at spatial scales ranging from 10 m to 1 km.

The main purpose of ragweed control is to reduce the production of allergenic pollen and seeds. Different means of control can be applied in wastelands, natural conservation areas, and agricultural fields; along roads and ditches; and in human-impacted areas in towns. Mowing is a widely used mechanical method to control ragweed, as the application of herbicides is not desirable (Milakovic et al., 2014). Katz et al. (2014) revealed the presence of ragweed significantly more often in lots that were mowed annually or once every second year. Therefore they recommended: “either mow them frequently or do not mow them at all.” Besides there are usually no specific regulations on ragweed control in urban areas, that is why ragweed could be mown up to three – four times a year according to the height of all other vegetation, nevertheless such control management based only on calendar dates makes ragweed control unfortunately most often not enough efficient.

Pollen collection is very time and labour intensive. Therefore, the male reproductive output of ragweed is estimated based on measurements of the biomass (BM) of crushed male inflorescences (MF) (cf. McKone and Tonkyn, 1986; Ackerly and Jasie  ski, 1990; Ziska and Caulfield, 2000; Leiblein and L  sch, 2011;   aulien   et al., 2012; Paquin and Aarssen, 2004). Wayne et al. (2002) collected pollen during the peak of the flowering season and counted it using a particle count and size analyser. Rogers et al. (2006) and Simard and Benoit (2011) collected pollen from randomly selected isolated male flower spikes in a greenhouse. The washed pollen was counted using a haemocytometer.

Fumanal et al. (2007) reported a close relationship between the BM, PP and seed production of ragweed plants grown in different habitats but also noted that little is known about the PP of individual plants growing in natural environments and about the ragweed seed production per plant in Europe. In addition, Patracchini et al. (2011) and Leskovsek et al. (2012) confirmed in their experiments that the generative and reproductive production of ragweed decreased due to intraspecific competition. While there are numerous ragweed studies, no data are available for the season-long PP of ragweed despite the fact that the increased risk to human health has resulted in numerous research activities and publications (Fumanal et al., 2007).

The aim of the recent study was to examine the effects of the widely used mowing date and cutting height compared to the biologically justified ones on the ability to reduce ragweed PP and seed production and BM in field experiments with ragweed plants grown at high and moderate plant densities based on field samples collected weekly.

2. Materials and methods

2.1. Biomass and reproduction

The ragweed mowing experiment was conducted on the experimental field of the Plant Protection Institute of the Hungarian Academy of Sciences in Nagykov  csi (47   32' N, 18   56' E). The 2011 experiment was set up on unplanted land in which the soil disturbance had been limited in the previous 3 years to autumn ploughing and seedbed preparation in April. Before setting up the mowing experiment, autumn ploughing was performed in mid-October 2010, and seedbed preparation was completed in mid-April 2011; secondary tillage was undertaken with a harrow and cultivator. For the 2012 experiment, a five-year-old alfalfa field immediately adjacent to the experimental area was ploughed in October 2011. In mid-April 2012, seedbed preparation similar to that performed in 2011 was completed. On 5 May, when the majority (at least 95%) of ragweed plants had emerged (Kazinczi et al., 2008) in both years, the number of ragweed plants/m² was counted in ten 1-m² sampling areas. Ragweed dominated the experimental area. The mean density of ragweed plants in 2011 was 91 plants/m² and in 2012 was 48 plants/m². At the same time, sixteen 10 × 10-m plots were staked out. These plots were separated by 1-m-wide roads. The roads were kept weed free with regular cultivator treatment.

The experiment was set up as a randomised complete block (randomised) with 4 replicates. Experimental treatments included an unmown control (NM), mowing early (EM) at growth stage BBCH 51 (inflorescences or flower buds visible) (Hess et al., 1997), and mowing late (LM) at BBCH 59 (first flower petals visible). Twice-mown (2 M) plants were mown when the plants reached BBCH 59 before and after the first mowing. The mowing dates were as follows: EM, LM or 2 M (in 2011, 12 June, 25 July, or both 12 June and 25 July; in 2012, 18 June, 28 July, or both 18 June and 28 July, respectively).

In 2011, mowing was performed using traditional scythes; the height of the mowing was 5–7 cm. To improve the mowing efficiency in 2012, mowing was undertaken with a Husqvarna 128 R lawnmower; using this equipment, the cutting height could be decreased to 1–3 cm. Plants were sampled at weekly intervals for 4 weeks from the period when seeds began to develop (BBCH 71) until nearly all the fruits reached the final size expected for the species and location (BBCH 79). Five randomly selected plants were cut at the soil surface in each plot (20 plants/treatment). The sample collection period in 2011 lasted from 8 September until 29 September and in 2012 from 3 September until 24 September. The plants were transferred to the laboratory. The plant height (pH) and aboveground fresh BM were measured and male flowering heads (hereafter referred to as ‘male inflorescences’ [MF]) and female flowers (FF) were counted.

2.2. Pollen production

For PP studies, two plants in each plot were selected (8 plants/treatment) for pollen collection. Polyethylene bags for pollen collection were placed on the plants at BBCH 59 (first flower petals visible – in petalled form) and changed weekly during the PP period until BBCH 69 (end of flowering: fruit set visible). The size of the polyethylene bags placed over NM and EM plants was 120×40 cm, whereas that in the LM and 2 M treatment was 80×40 cm.

For ventilation purposes, the bottom corners of the bags were opened with 5-mm-wide and 15-mm-long holes. The holes served to fix the bags with a pulled-through string to a wire frame. At the same time, the holes served as ventilation together with the pricked 1- to 1.5-mm holes, of which there were 10 on each wall of the bag. The bottoms of the polyethylene bags were fixed to a wire frame and closed under the lowest side shoots using adhesive rubber on the main stems of the ragweed plants. Special attention was paid to perfectly closing the bags on the main stems of the plants.

The polyethylene bags were replaced with new bags weekly. Before removing the adhesive rubbers from the main stems, 30-cm-diameter round polyethylene sheets were laid on the soil surface to collect any fallen pollen grains (a 15-cm incision allowed for the main stem to pass). First, the surface-covering sheets were washed off into the pollen-containing polyethylene bags in 250 ml of water containing 0.02% Tween 20, a mild non-ionic surfactant that acts as a wetting agent, dispersant and solubiliser. The pollen-containing solution was stirred with a glass rod, and then five 1-ml samples were collected in Eppendorf tubes. The Eppendorf tubes were labelled and stored in a refrigerator until pollen counting. After thorough shaking, 2.5- μ l samples were taken from each Eppendorf tube and individually transferred to a glass haemocytometer (MOM Budapest). Pollen grains were counted at 160X magnification under a light microscope. Based on the mean of 5 counts, the number of pollen grains in 250 ml of water was calculated.

At the end of flowering, fruit-set-visible (BBCH 69) pollen-collection plants were labelled, cut at the soil surface and transferred to the laboratory. The pollen collection bags were carefully removed, and the pollen was collected according to standard protocol. Individually labelled plants were washed in 250 ml of water containing 0.02% Tween 20. The pollen of these samples was counted according to the standard protocol. The number of washed pollen grains was divided according to percentage of pollen grains collected weekly during the PP period of the given plant. The number of pollen grains coming from the washed pollen was added to the weekly collected pollen number of each individual plant.

The dates of isolation of the pollen-producing ragweed plants in 2011 were as follows: NM on 28 July, EM on 18 August, LM and 2 M on 4 September. In 2012, NM plants were covered on 24 July, EM plants on 14 August, and LM plants on 21 August and 2 M plants on 4 September, respectively.

2.2.1. Statistical analysis

First, we compared the two-year experimental control (NM) results of BM (g), number of FF and number of MF using Student's *t*-test to show the significant differences between the two years. We also compared the daily mean temperature (DMT [$^{\circ}$ C]) and the monthly precipitation sum (MPS [mm]) (between 15 April and 15 September) to ensure that the meteorological parameters did not differ significantly in these two years. Then, we calculated Pearson's correlation between BM and seed production and PP to check whether, based on the BM, seed production and PP could be estimated.

Comparisons of the following plant-related response variables were made: aboveground BM (g), pH (cm), number of FF and number of MF under four different levels of mowing treatment (NM; EM; LM; and 2 M). Each plant variable was measured in four time intervals of 7 days denoted by their final days: 8, 15, 22, and 29 September 2011 and 3,

10, 17, and 24 September 2012. These comparisons were based on the measurements of 20 plants in each case. Because the variables were not independent, three-way MANOVA models were run with dependent variables (BM, pH, FF and MF) and with factors ('treatment', 'date' and 'year (year includes a combination of plant density and mowing height)'). Given the significance of the overall test, the univariate main effects were examined. As the normality assumption was violated, an *ln* transformation was executed, and the normality of the residuals of the transformed data was proven by D'Agostino's test based on skewness and kurtosis ($p > 0.05$). The homogeneity of variances was checked by Levene's test ($p > 0.05$). The variable means were separated by Games-Howell's post hoc test (Games and Howell, 1976; Jaccard et al., 1984).

The comparison of PP rates under four different levels of mowing treatment (same treatments as in the BM comparison) was based on measurements on different dates, as indicated in Table 2, and involved eight plants per treatment on each date. The number of polyethylene bags collected on different sampling dates varied between 8 and 32.

To compare the PP per plant under different mowing treatments, a two-way mixed-design ANOVA with the factors 'years' and 'treatment' embedded into different observation date-blocks was performed. Because the normality assumption was violated, an *ln* transformation was executed, and the normality of the residuals of the transformed data was proven by D'Agostino's test based on skewness and kurtosis ($p > 0.05$). The assumption of homogeneity of variances was slightly violated (Levene's test was significant at $p < 0.05$); therefore, variable means under different treatments were separated by Games-Howell's post hoc test. We also compared the total PP per plant during the whole PP period by applying a two-way ANOVA model with the factors 'year' and 'treatment'. The normality of the residuals and the homogeneity of variances were checked by D'Agostino's and Levene's tests ($p > 0.05$), respectively. The variable means were separated by Games-Howell's post hoc test. We compared all of the measurements to the highest value of the most effective treatment (2 M), which occurred on 9 September 2011 and 11 September 2012, with a one-sample *t*-test. All of the statistical procedures were conducted using the software IBM SPSS20.

3. Results

3.1. Biomass and reproduction

The results of the comparison of BM production, pH, number of FF and number of MF under different mowing treatments based on weekly measurements during the sampling period are presented in Table 1.

Based on the two-year experimental data, we showed by Student's *t*-test that the control (NM) BM (g), number of FF and number of MF were significantly higher in 2012 ($t_{BM(638)} = 4.69$, $t_{FF(638)} = 5.05$, and $t_{MF(638)} = 6.46$; $p < 0.001$). However, these highly significant differences were not due to significant differences in the DMT or MPS between 15 April and 15 September ($t_{DMT(300)} = 1.95$ and $t_{DMT(4)} = 0.92$; $p > 0.05$). The differences in BM, number of FF and number of MF in 2011 and 2012 were evaluated compared to the NM control, and only the plant density was different between the two years. There was no significant difference between DMT and MPS. Therefore, we can conclude that significant differences are caused mainly by plant density.

Pearson's correlation between BM (g), number of FF, number of MF and PP were all highly significant ($R_{BM,FF} = 0.985$, $R_{BM,MF} = 0.991$, $R_{BM,PP} = 0.920$, $R_{FF,MF} = 0.988$, $R_{FF,PP} = 0.896$, and $R_{MF,PP} = 0.924$; $p < 0.001$; $N = 72$).

Based on the highly significant linear correlation between BM, number of FF, number of MF and number of released pollen grains, we can conclude that the decreased seed production and PP efficiency in mechanical ragweed control can be estimated by measuring the above-ground BM reduction.

The three-way MANOVA (with dependent variables BM, pH, FF and

Table 1

Means and standard deviations of BM (g), pH (cm), number of FF and MF measured weekly during the PP period (8, 15, 22 and 29 of September 2011 and 3, 10, 17, and 24 of September 2012) under the NM, EM, LM and 2 M treatments and the percent reduction of the means compared to those of the NM.

Year	Variables	Treatments	Mean $\pm$ St. Dev of the measurements 8, 15, 22 and 29 September*	Percent reduction of the means, compared to control 'NM'
2011	Biomass (g)	NM	36.24 $\pm$ 16.91a	
		EM	24.87 $\pm$ 19.32b	31.4
		LM	8.13 $\pm$ 4.45c	77.6
		2M	6.28 $\pm$ 4.61d	82.7
	Plant height (cm)	NM	106.45 $\pm$ 13.24a	
		EM	67.43 $\pm$ 14.09b	36.7
		LM	35.86 $\pm$ 5.82c	66.3
		2M	21.32 $\pm$ 5.62d	80.1
	No. of female flowers	NM	654.35 $\pm$ 352.80a	
		EM	523.60 $\pm$ 396.83b	19.1
		LM	202.70 $\pm$ 127.39c	69.0
		2M	116.54 $\pm$ 99.49d	82.2
	No. of male inflorescences	NM	2404.61 $\pm$ 1154.70a	
		EM	1248.07 $\pm$ 986.28b	48.1
		LM	297.44 $\pm$ 231.57c	87.6
		2M	113.40 $\pm$ 110.69d	95.3
2012	Biomass (g)	NM	105.73 $\pm$ 63.02a	
		EM	23.24 $\pm$ 16.68b	78.0
		LM	5.33 $\pm$ 2.57c	94.6
		2M	3.01 $\pm$ 1.58d	97.2
	Plant height (cm)	NM	95.11 $\pm$ 16.00a	
		EM	62.93 $\pm$ 12.30b	33.8
		LM	29.23 $\pm$ 5.78c	69.3
		2M	18.10 $\pm$ 4.81d	81.0
	No. of female flowers	NM	2293.21 $\pm$ 1554.07a	
		EM	476.44 $\pm$ 357.42b	79.2
		LM	145.91 $\pm$ 103.35c	93.6
		2M	63.99 $\pm$ 55.80d	97.2
	No. of male inflorescences	NM	9144.95 $\pm$ 6059.89a	
		EM	1973.20 $\pm$ 1406.91b	78.4
		LM	338.53 $\pm$ 249.07c	96.3
		2M	94.09 $\pm$ 84.15d	99.0

* Means with different letters are significantly different according to Games-Howell's post hoc test ($p < 0.05$).

MF) overall test was highly significant for 'treatment' (Wilk's lambda = 0.07; $p < 0.001$), 'year' (Wilk's lambda = 0.72; $p < 0.001$), and 'date' (Wilk's lambda = 0.68; $p < 0.001$) together with their two-way interaction terms ($p < 0.05$). The main effect ANOVA was highly significant for all of the response variables regarding mowing treatment effect ($F_{BM}[3;9] = 538.26$, $F_{pH}[3;9] = 442.96$, $F_{FF}[3;9] = 20.32$, and $F_{MF}[3;9] = 229.57$; $p < 0.001$; Table 1). The effect of 'year' (including cutting height and plant density differences as well) was significant for the variables and number of MF ($F_{pH}[1;617] = 73.80$ and $F_{MF}[1;617] = 34.14$; $p < 0.001$), whereas it was not significant for BM or number of FF ($F_{BM}[1;617] = 0.39$ and $F_{FF}[1;617] = 0.80$; $p > 0.05$). The effect of dates was significant for pH, BM and number of FF ($F_{pH}[3;617] = 6.13$, $F_{BM}[3;617] = 4.42$, and $F_{FF}[3;617] = 45.97$; $p < 0.01$), but it was not significant for number of MF ($F_{MF}[3;617] = 1.79$; $p > 0.05$). For the results of the post hoc test according to Games-Howell's method, see Table 1.

3.2. Pollen production

The results of the comparison of PP rates under different mowing treatments based on weekly measurements during the PP period are presented in Table 2.

The one-way ANOVA on 'mowing treatment' embedded into different observation date-blocks (Table 2) showed a highly significant treatment effect ($F[3;344] = 26.32$; $p < 0.001$) with a significant year (including mowing height and plant density differences) effect ($F[1;344] = 6.68$; $p < 0.01$) and no significant treatment $\times$ year interaction ($F[3;344] = 1.12$; $p = 0.34$). Games-Howell's post hoc test revealed that the NM produced a significantly higher number of pollen grains, whereas 2 M plants released significantly fewer pollen grains

compared to those produced in the LM treatment in both years (Table 2).

The total PP per plant during the whole PP period was significantly different among mowing treatments ($F[3;56] = 134.61$; $p < 0.001$) and between the two years ($F[1;56] = 16.23$; $p < 0.001$). The result of Games-Howell's post hoc test is presented in Table 2.

Given that mowing twice (2 M) resulted in the lowest overall pollen production, i.e., proved to be the most efficient treatment, we used the highest pollen production value of this treatment as a reference value. For treatment 2 M, the highest pollen production rate of per plant was 4.001 million and 4.4579 million on the 9th of September, 2011 and on the 11th of September, 2012, respectively. We compared the pollen production of all other treatments to this reference value. All of the later pollen production values originating from the twice-mown treatment were significantly lower than the reference (Table 2). All measured values from other treatments were significantly higher or did not differ significantly from the values of 2 M (Student's t ; $p < 0.05$). This result clearly demonstrates the extraordinary success of the twice-mown treatment.

Mowing treatments not only reduced the total PP but also shortened the length of the pollen discharge period in 2011 from 6 to 4 weeks regardless of the treatment. Additionally, the onset of pollen discharge was postponed. Dehiscence in the EM plants started 4 weeks later than in the NM control, whereas the LM and 2 M treatments postponed pollen discharge by 6 weeks (Table 2). The length of the pollen discharge period of the vigorously growing intact plants in 2012 was 9 weeks; that of the EM plants was 7 weeks, and the onset of pollination was postponed by 4 weeks. LM and 2 M reduced the length of the pollen discharge period to 6 and 4 weeks and postponed the onset of pollination by 5 and 6 weeks, respectively (Table 2).

Table 2

Means and standard deviations of the number of pollen grains (million) per plant measured weekly during the PP period (8, 15, 22 and 29 of September 2011 and 3, 10, 17, and 24 of September 2012) in NM, EM, LM and 2 M plants together with the means and standard deviations of the total PP per plant during the whole PP period and the percent reduction of the means compared to those of the NM.

Year	Treatments	Dates	Weekly pollen production per plant		Total pollen production per plant	
			Mean (million)	Std. Dev. (million)	Mean (million) $\pm$ Std. Dev.*	Percent reduction of the means, compared to control 'NM'
2011	NM	4th Aug	4.17	4.28	59.43 $\pm$ 21.76c	
		11th Aug	8.58	2.64		
		19th Aug	16.25	9.39		
		25th Aug	14.19	7.52		
		1st Sep	10.31	5.63		
	EM	9th Sep	5.94	2.64	43.46 $\pm$ 8.33c	26.9
		25th Aug	13.83	3.26		
		1st Sep	15.11	5.01		
		9th Sep	10.64	4.80		
		16th Sep	3.88	2.18		
	LM	11th Sep	14.10	8.97	24.31 $\pm$ 8.59 b	59.1
		18th Sep	4.46	2.43		
		25th Sep	4.31	5.97		
		2nd Oct	1.45	1.60		
	2 M	11th Sep	4.00	4.23	8.67 $\pm$ 4.38 a	85.4
		18th Sep	1.94	0.77		
		25th Sep	1.78	1.19		
		2nd Oct	0.95	0.79		
2012	NM	31st July	0.18	0.17	151.19 $\pm$ 38.08c	
		7th Aug	0.49	0.43		
		14th Aug	8.35	9.56		
		21st Aug	18.46	8.11		
		28th Aug	23.61	11.91		
		4th Sep	37.15	12.77		
		11th Sep	30.04	9.14		
		18th Sep	21.17	8.33		
		25th Sep	11.73	5.43		
		21st Aug	3.03	3.09	44.54 $\pm$ 11.00b	70.5
	EM	28th Aug	5.44	3.84		
		4th Sep	15.93	5.09		
		11th Sep	10.79	5.43		
		18th Sep	4.96	1.76		
	LM	25th Sep	3.52	2.48	35.39 $\pm$ 13.40b	76.6
		2nd Oct	0.86	0.58		
		28th Aug	4.94	2.92		
		4th Sep	14.03	8.00		
		11th Sep	11.83	3.91		
	2 M	18th Sep	2.66	1.04	8.95 $\pm$ 3.93a	94.1
		25th Sep	0.88	0.86		
		2nd Oct	1.05	0.54		
		11th Sep	4.46	3.30		
		18th Sep	2.15	1.15		
		25th Sep	1.38	0.65		
		2nd Oct	0.83	0.34		
		9th Oct	0.13	0.08		

* Means with different letters are significantly different according to Games-Howell's post hoc test ($p < 0.05$).

4. Discussion

In the NM control treatment, the approximately 50% lower plant density in 2012 due to decreased intraspecific competition resulted in a nearly 3 times higher BM, 3.5 times higher seed production and 2.5 times higher PP compared to those in 2011. Our results agree with those of [Patraccchini et al. \(2011\)](#) and [Leskovsek et al. \(2012\)](#). These authors reported lower BM production under high ragweed density compared to that under lower ragweed density due to intraspecific competition. [Paquin and Aarssen 2004](#) also reported BM and pH reductions due to intraspecific competition.

In 2011, the mean total PP of the NM control plants grown at 91 plants/m² was 59.430 million pollen grains/plant. In 2012 at 48 plant/m², the NM control plants released 151.190 million pollen grains/plant. Our PP results agree with the data of [Simard and Benoit \(2011\)](#), who conducted a greenhouse experiment in which the ragweed plants in high-density plots produced approximately half as much pollen as the

single plants.

In 2011, using traditional scythes, the mowing height was 5–7 cm. The decrease in BM and number of FF even under the best 2 M treatment was not much greater than 80%; however, the decrease in the number of MF reached 95%.

To improve mowing efficiency in the second year, a Husqvarna 128 R lawnmower was used to decrease the cutting height to 1–3 cm. The lower cutting height resulted in a 97–99% aboveground BM, FF and MF reduction compared to those of the NM control in 2012. [Mutch et al. \(2003\)](#) also reported significant ragweed BM reduction due to mowing in wheat stubble despite the variation among years and mowing treatments.

The most effective 2 M treatment resulted in 94% PP reduction and 97% seed production reduction compared to those of the control in 2012. [Simard and Benoit \(2011\)](#) reported a 9.16 times lower PP of mowed plants than intact plants in a pot experiment. In our study in 2012, not only did the number of released pollen grains decrease, but

the pollen-discharging period was postponed by 6 weeks and its length decreased from 9 to 4 weeks.

Our decreased seed production results are consistent with the data of Milakovic et al. (2014). The best seed-decreasing efficiency reported in Milakovic et al. (2014) occurred when mowing was conducted at the end of June, the end of August, and mid-September. This similarity is due to the coincidence of the phenological stages at which their first two mowings and our two mowings were conducted. Mowing just before the onset of pollination affects the most vulnerable phenological stage of ragweed because the development of millions of pollen grains in the MF requires the highest energy in the life cycle of the plant (Béres, 2004).

In our experiment, we achieved a very efficient seed reduction with two mowings but only in the second year, when the cutting height varied from 1 to 3 cm, as suggested by Vincent et al. (1992). The low-cut, shorter main stem can accommodate fewer buds; therefore, due to the lower cutting height, the number of newly sprouting shoots is lower (Milakovic et al., 2014).

Our seed production and PP results agree with those of Fumanal et al. (2007). In a wasteland area, these authors found a lower seed production and PP of ragweed than those of field crops due to growing conditions and competition.

In Canada, Vincent et al. (1992) reported an 88% pollen-decreasing efficiency of mown plants. However, in our experiment at a cutting height of 1–3 cm, the most efficient 2 M treatment resulted in a 94% reduction of the released pollen grains.

The unique reproducible methods of this experiment are recommended for use in field experiments, where the efficiency of the treatments must be evaluated based on the PP and seed production of ragweed. Due to the close relationship between the aboveground BM and the PP and seed production of ragweed plants, as confirmed by our reliable pollen and seed count data, it can be concluded that precisely measured BM data are suitable for use in modelling air pollutant ragweed PP and seed production.

5. Conclusion

This paper reports season-long PP and seed production data of ragweed based on a field experiment carried out on abandoned land at high and moderate plant densities under different mowing regimes compared to an NM control. The efficiency of mowing can be increased if the first mowing is conducted just before flowering at BBCH 59, typically at the end of July, and if the second mowing is conducted at the end of August or beginning of September, when the re-sprouting lateral shoots reach the growth stage at BBCH 59. By decreasing the mowing height to 1–3 cm, the number of re-sprouting lateral shoots decreased, leading to a further increase in mowing efficiency. Based on the results of this study, both the intensity and the length of the ragweed pollen emission period can be efficiently decreased. This decrease results in a delay in the actual day of *Ambrosia* pollen emission, which is the most important variable related to the atmospheric concentration of this harmful pollutant (Makra et al., 2005; Katz et al., 2014). The BM, seed production and PP results of this study are based on season-long correct measurements and are therefore unique and thus suitable for application in other biological and ecological studies of ragweed. Urban environment and greening policy should consider these results and ragweed control much more seriously. Our study clearly indicates the most vulnerable growth stages when mowing is most efficiently reducing pollen and seed production of ragweed. But the management should not be planned by fix dates, since the growing and climatic conditions vary from year to year and influence phenological stages of ragweed.

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