Strategies for Ambrosia control

Euphresco project AMBROSIA 2008-09

Scientific Report

Edited by

Niels Holst

Abstract

Ambrosia artemisiifolia (‘ambrosia’) is an invasive weed in Europe, important not only for its detrimental effects on agriculture and nature but, even more, on human health. Ambrosia pollen is highly allergenic. To provide European countries with a scientific basis to implement national strategies for ambrosia prevention and control, this project set out to carry out trials in greenhouses and fields to find the best possible control options fitting different scenarios. The control options focused upon were herbicide and mechanical treatments and the effect of competition with other plants.

Any strategy must aim to prevent not only pollen production but also production of fertile seeds. Ambrosia can only be eradicated, with reasonable means, from sites where it has not yet infested the soil seed bank.

Different habitats give different opportunities for control:

- Agricultural fields: Herbicide treatments can be split for improved efficacy. Some herbicides are less effective with increasing plant size. Herbicide efficacy will also be enhanced by competitive crops or mechanical weed treatments. Organic farmers should explore these non-chemical options.
- Construction sites: Bare soil should be avoided by establishing a dense plant cover. This will prevent mass invasion of ambrosia and thus make manual eradication of single invaders possible (plants to be uprooted and destroyed before flowering).
- Roadsides: Sites heavily infested by ambrosia should be herbicide-treated after mowing to achieve the best control of plant re-growth.
- Gardens and parks: Bare soil should be avoided by establishing a dense plant cover. Single plant stands should be eradicated by hand.
- Natural habitats: Disturbed soil should immediately be covered by a dense population of native plants in case of an advanced infestation. Single plant stands in areas where infestation is beginning, should be uprooted and destroyed. If ambrosia is growing in competition with other plants, mowing can be tried as a control method.

Ambrosia has exceptional potential for regrowth after cutting: side-shoots grow vigorously to flower and produce seeds if not controlled. This limits the effectiveness of mowing in general. Special attention must be given to infested stubble fields.

The project established an informal network of researchers working with invasive weeds. This network will be kept alive in the short run through the writing of the planned papers, and in the longer run through the newly formed International Ragweed Society.

An illustrated brochure with suggested practical guidelines for ambrosia control was prepared in several languages (Danish, English, French, German and Slovene). Thus we hope to facilitate swift accommodation and implementation of guidelines for

ambrosia control and prevention all over Europe, according to national policies and priorities, and guided by scientific knowledge.

Contents

Foreword

This document reports the result of the project *Strategies for Ambrosia control (*AMBROSIA*)* funded by Euphresco, 1 November 2008 – 31 October 2009.

The project team incorporated researchers from six institutes and four countries:

- Aarhus University (Denmark): Preben K. Hansen, Niels Holst, Per Kudsk, Solvejg K. Mathiassen.
- Agricultural Institute of Slovenia (Slovenia): Andrej Simoncic.
- University of Maribor (Slovenia): Mario Lesnik,
- Agroscope (Switzerland): Christian Bohren, Stephanie Waldispühl.
- Julius Kühn Institute (Germany): Arnd Verschwele, Birte Wassmuth, Uwe Starfinger.
- University of Copenhagen (Denmark): Rita Buttenschøn, Hans Peter Ravn.

Chapters and sub-chapters were written by the authors indicated.

1 Introduction

By Niels Holst

1.1. The Ambrosia problem in Europe

Ambrosia artemisiifolia (‘ambrosia’ in this report) is native to USA but has been spreading in Central European during the second half of the 20th century with an escalation in the 1990s. This has caused general concern because of the highly allergenic pollen produced by this plant (Rybnicek & Jäger, 2001, D'Amato et al., 2007).

The two important components of ambrosia management are (i) to keep ambrosia under control where it has already infested the seed bank, every year eliminating as far as possible both pollen and seed production of emerging plants, and (ii) preventing spread of seeds from infested to non-infested sites (Bohren et al., 2008).

This short-term project was focused at research that will increase our knowledge on the first component, i.e. the direct control of ambrosia at infested sites.

1.1.1. Habitats and control options

Ambrosia most easily invades disturbed areas, such as agricultural fields, construction sites, road sides and gardens but natural habitats are also at risk, e.g. riverine ecosystems that are naturally disturbed by floods. Together these areas form a gradient from the most to the least managed:

- agricultural fields
- construction sites
- road sides
- gardens and parks
- natural habitats

This gradient is also reflected in the control options available. Herbicides, for instance, are most relevant in agriculture and least in nature.

In agriculture, ambrosia can be controlled by the same measures as other spring-germinating annual weeds. In conventional agriculture this means through herbicides and crop rotation. What sets ambrosia apart from other weeds is its potential impact on yield quality. Harvested crops that are not completely processed, e.g. used for fodder, bird feed or seed production, may be infected with ambrosia seeds and thus pose a risk for dispersal of ambrosia.

From an environmental point of view, construction sites are open for all control methods but herbicides may be prohibited, by principle, in some countries. The road side flora is a component of landscape biodiversity that puts restrictions on the available control options. Private gardens and public parks are intensively managed sites which makes prevention a viable option. In these areas it might be possible to eradicate every invading ambrosia plant at first sight and thus quell a pending infestation.

1.1.2. Scenarios under study

Depending on country and habitat, different control methods options are available and practical. The relevant combinations of country, habitat and control methods thus define the scenarios for which ambrosia control must be optimised.

Herbicides are applicable in most crops and growing systems in Europe and, to a varying degree, also to non-cultivated areas. To provide better knowledge for the rational use of herbicides, we carried out experiments in greenhouse and field to determine herbicide efficacy according to choice of

- active ingredients
- ambrosia plant size at application time
- single vs. sequential application

The active ingredients were chosen to cover different modes of action and varying efficacy against ambrosia according to earlier work (Bohren et al. 2008).

These choices were tested under contrasting conditions of the infested habitat:

- in a more or less competitive environment
- in combination with mowing
- in combination with hoeing (in a maize crop)

To investigate control options in habitats where herbicides are not applicable, we also tested

- repeated mowing without herbicides
- repeated hoeing in maize without herbicides

To facilitate better planning and timing of control, we investigated the basic biology of ambrosia, in terms of plant emergence and plant phenology (i.e. development).

1.2. Project objectives

1.2.1. List of objectives

The project was divided into seven work packages, each with its own main objective and set of sub-objectives. The sub-objectives were either fulfilled (√) or not (÷). The latter are commented in the next section

1. To strengthen trans-national collaboration on ambrosia research and control.
    a. √ Project information has been kept updated and communicated to projects partners throughout project execution.
    b. √ Three project workshops have been carried out.

   c. √ A joint research strategy has been formulated among the project partners on future ambrosia research.
   d. √ Project outputs have been collected and published in the Scientific Report.
2. To delineate the scenarios for ambrosia control in the partner countries, according to habitat and possible control options.
   a. √ Scenarios for control have been selected, encompassing the major ambrosia problems, current and anticipated, in all partner countries.
   b. √ The treatment options to be explored have been defined.
   c. √ The end-users of the national guidelines have been identified.
3. To quantify the control achieved by different herbicides, depending on application timing and mode of action, against ambrosia.
   a. √ Common experimental protocols have been formulated in the Scientific Report.
   b. √ **(÷)**Herbicide dose-response experiments under controlled conditions have been carried out.
   c. √ **(÷)**Herbicide efficacy experiments under field conditions have been carried out.
   d. √ **(÷)**Experimental data have been analysed and the results written up in the Scientific Report.
4. To quantify the control achieved by different physical methods with or without herbicides, depending on application timing and mode of action, against ambrosia.
   a. √ Common experimental protocols have been formulated in the Scientific Report.
   b. √ Physical/chemical experiments under ruderal field conditions have been carried out.
   c. √ **(÷)**Experimental data have been analysed and the results written up in the Scientific Report.
5. To increase knowledge on the management options for the ambrosia seed bank.
   a. √ Common experimental protocols have been formulated in the Scientific Report.
   b. ÷The effect of composting on the viability of seeds has been quantified.
   c. ÷ The germination biology of ambrosia seeds of different origin been characterized.

    d. ÷ The suppression of ambrosia emergence from the seed bank has been quantified for different scenarios.
    e. √ Experimental data have been analysed and the results written up in the Scientific Report.
6. To formulate the best-bet strategies, based on current knowledge and project results, for the control of ambrosia in different scenarios.
    a. √ The phenological development of ambrosia, growing undisturbed or controlled, have been modelled.
    b. √ Best-bet strategies have been formulated for different scenarios and written up in the Scientific Report.
7. To publish the scientific basis for national guidelines, aimed at the partner countries, for the control and prevention of ambrosia in different scenarios.
    a. √ Structural framework for ambrosia National Guidelines has been consented by the partners.
    b. √ Scientific basis for National Guidelines, version 1 based on current knowledge finished.
    c. √ Scientific basis for National Guidelines, final version, incorporating project results, finished.
    d. √ Scientific basis for National Guidelines translated from English into Danish, French, German and Slovene and published on appropriate national web sites.

1.2.2. Unfulfilled objectives

Two sub-objectives were partly fulfilled:

- Herbicide experiments were carried out but not including other active substances, such as pelargonic acid, acetic acid and citronella oil (objectives 3b-c). – In the final experimental design, conventional herbicides were favoured to allow for more variations in application strategy. We found it more promising to explore combinations, timing and split applications.
- Field experiments were carried out but not all results from Slovenia were included in the report (objectives 3d and 4d). – Not all data were ready for analysis before the end of the project. The results will be included in the planned scientific paper, however.

Three sub-objectives were not fulfilled:

- The effect of composting on the viability of seeds was not quantified (objective 5b). – Despite repeated trials with heat treatments of ambrosia and several other plant species, we never succeeded in getting consistent results. Non-lethal treatments seemed to trigger seed dormancy which added to the complexity of this failed experiment.

- The germination biology of ambrosia seeds of different was not characterized (objective 5d). – The field experiments were more demanding than foreseen. Hence, resources were not locally available to carry out this experiment.
- The suppression of ambrosia emergence from the seed bank was not quantified for different scenarios (objective 5d). – We found no way, even in theory, of integrating this method in a strategy to control ambrosia in any of the habitats we deemed relevant (section 1.1.1 and 1.1.2).

1.3. Format of this report

This report must balance between including the full detail of scientific study, while not precluding the possibility of publication in scientific journals:

- Methods and Materials sections describe all practical procedures and statistical design but are lacking in terms of the description of statistical procedures.
- Results sections highlight main findings through exposition of typical examples and summary tables. The few results, which are not likely to be published later, are given in full detail.

No scientific finding can be considered valid, or even existing, until accepted in a peer-reviewed journal. Two scientific papers are in preparation based on the results of this project. Interested readers are invited to contact the first authors of these papers (section 4.3), in case they need further documentation and elaboration of the results published in this report.

2 Materials and methods

Ambrosia seeds were of local origin in Slovenia and Switzerland, while seeds from Switzerland were used in Denmark and Germany.

2.1. Ambrosia biology

2.1.1. Emergence

By Stéphanie Waldispühl

Localities

Switzerland

Rationale

To plan ambrosia control within the season, the time of emergence must be considered together with the logistics and the best timing of the chosen control strategy.

Objective

Observe emergence pattern on ambrosia-infested land.

Experimental layout

Factor	Level
1. Soil disturbance	1. raking
	2. no soil disturbance

Dimensions: 4 replicates per treatment giving 8 plots.

Experimental procedure

On infested ambrosia land, previously harrowed and free of other weeds at onset of experiment (glyphosate treatment 1800 g ai/ha), 8 plots of 1 x 1m were defined. The experiment began in the beginning of April, when ambrosia started to germinate. Half of the plots were hand raked and half of them not disturbed. Hand raking took place every 14 days on the same 4 plots.

Every 14 days, before hand raking, the number of germinated ambrosia was counted on the surface of $1m^2$. The seedlings were cut to free the surface. Any competitive weed were also cut.

2.1.2. Phenology

By Niels Holst

Localities

Denmark, Germany, Slovenia, Switzerland.

Rationale

The time from emergence until flowering, pollen production and seed-setting sets the time window for successful control, both to avoid immediate health hazards (pollen) and long-term population build-up (seed production). The time needed for ambrosia to complete its development cycle from seed to seed also sets the climatic limit to its invasion. Data from all localities were summarised and compared with an existing model of ambrosia development.

Objective

To validate an existing model of the phenological development of ambrosia growing undisturbed or controlled.

Data analysis

Phenological observations from field experiments 2.3 and 2.4 were used to validate an existing phenology model of ambrosia (Deen et al., 1998a, Deen et al., 1998b). This model divides ambrosia development into five stages A-E. Growth stage C and E corresponds to growth stages 51 and 61, respectively, on the commonly used BBCH scale:

Growth stage	**Beginning**	**End**	**Duration; D (biological days)**
A	germination	juvenile	7
B	juvenile	main stem terminal bud appearance	4.5
C (GS 51)	main stem terminal bud appearance	pistillate flower appearance	4.5
D	pistillate flower appearance	beginning anthesis	4.5
E (GS 61)	beginning anthesis	maturity	14.5

The duration of each stage is measured in 'biological days'. Up to one biological day is accumulated for every chronological day as a product of a day length index (δ) and a temperature index (τ):

$$D(L,T) = \lambda(L)\,\tau(T),$$

where L (hours) is day length and T (^{o}C) is the daily average temperature. The indexes are calculated by

$$\lambda(L) = \begin{cases} 1 & \text{for } L < L_0 \\ \exp\left[(L - L_o)\ln(1-\alpha/100)\right] & \text{for } L \geq L_0 \end{cases}$$

and

$$\tau(T) = \begin{cases} 0 & \text{for T} < T_0 \\ 1 - \dfrac{\mathrm{T}_{\max} - T}{T_{\max} - T_0} & \text{for } \mathrm{T}_0 \leq \mathrm{T} < \mathrm{T}_{\max} \\ 1 & \text{for } \mathrm{T}_{\max} \leq T \end{cases}$$

The model needs two parameters for each index:

- L_0 = 14.5 hours
- α = 60% for stage C and 50% for other stages
- T_0 = 0.9 ^oC
- T_{max} = 31.7 ^oC.

2.2. Chemical control: controlled conditions

By Per Kudsk & Solvejg K. Mathiassen

2.2.1. Effect of treatment timing

Localities

Denmark.

Rationale

To obtain the best result of a single herbicide-spraying, we need to know the response of ambrosia to different active ingredients, depending on the dose and the growth stage of the plant. Control could be achieved possibly, both in terms of reduced growth and thereby reduced output of pollen and seeds and in terms of reduced seed vitality.

Objective

To examine the effect of time of application on growth and seed production of ambrosia.

Experimental layout

Factor	Level
1. Herbicide	1. Glyphosate (N=1440 g ai/ha)
	2. Florasulam (N=7.5 g ai/ha
	3. Clopyralid (N=100 g ai/ha)
	4. Mecoprop (N=1200 g ai/ha)
	5. Mesotrione (N=150 g ai/ha)
2. Dose	1. 1/8 N

	2. 1/4 N 3. 1/2 N 4. 1 N
3. Growth stage	1. 4-leaf stage 2. 8-leaf stage 3. Begin of flowering 4. End of flowering (only seed)

Dimensions:

Effect on seed production: 5 herbicides × 4 doses × 4 growth stages × 5 replications per treatment + 4 growth stages × 10 untreated controls giving 440 pots.

Effects on biomass: 5 herbicides x 4 doses x 3 growth stages x 3 replicates + 3 growth stages x 6 untreated controls giving 198 pots

Experimental procedures

Plants of ambrosia were sown in the beginning of March in 6.5 L pots for seed harvest and 2 L pots for biomass in a potting mixture consisting of field soil, sand and peat (2:1:1 w/w) and grown in a heated glasshouse. Prior to herbicide application the number of plants per pot was reduced to 1 in the pots for seed harvesting and to 4 in the pots for biomass production. Herbicide preparations were applied using a laboratory pot sprayer equipped with a boom fitted with two Hardi ISO F110-02 flat fan nozzles using a volume rate of ca. 150 l/ha. Herbicides were chosen to include a range of effectiveness against ambrosia according to earlier work (Bohren et al. 2008).

In pots for biomass measurements the foliage fresh and dry weights were recorded 3 weeks after herbicide application. In pots for seed harvesting the herbicide efficacy was visually assessed 2, 4 and 6 weeks after treatment. At maturity the seeds were harvested and the number and weight of seeds recorded. Samples of 100 seeds will be placed in Petri dishes and stratified at 4 ^{o}C for 6 weeks and then germinated at 25 ^{o}C in light. Number of germinated seeds will be counted every second day.

Note: Seed germination trials could not be finished before the end of this project and will be reported elsewhere.

2.2.2. Effect of sequential treatments

Localities

Denmark.

Rationale

Split application of one herbicide, or two in combination, can be more efficient than just one spraying with the same total dose. Several variations of split applications must be explored to find the best control solutions.

Objective

To examine the effect of sequential treatment with the same herbicide or different herbicides on amrosia.

Experimental layout

Factor	Level
1. Herbicide	1. Florasulam (T1) (N=3.75 g ai/ha)
	2. Florasulam (T2) (N=7.5 g ai/ha)
	3. Florasulam (T1)+florasulam (T2) (N=1.86+3.75 g ai/ha)
	4. Mecoprop (T1) (N=1200 g ai/ha)
	5. Mecoprop (T2) (N=2400 g ai/ha)
	6. Mecoprop (T1)+mecoprop (T2) (N=600+1200 g ai/ha)
	7. Mesotrion (T1) (N=75 g ai/ha)
	8. Mesotrion (T2) (N=150 g ai/ha)
	9. Mesotrion (T1)+mesotrion (T2) (N=37.5+75 g ai/ha)
	10. Clopyralid (T2) (N=200 g ai/ha)
	11. Glyphosate (T2) (N=720 g ai/ha)
	12. Florasulam (T1)+Clopyralid (T2) (N=1.86 + 100 g ai/ha)
	13. Florasulam (T1)+Glyphosate (T2) (N=1.86 + 360 g ai/ha)
	14. Mecoprop (T1)+Clopyralid (T2) (N=600 + 100 g ai/ha)
	15. Mecoprop (T1)+Glyphosate (T2) (N=600 + 360 g ai/ha)
2. Dose	1. 1/16 N
	2. 1/8 N
	3. ¼ N
	4. ½ N
	5. 1 N

Dimensions: 15 herbicides × 5 doses × 3 replications + 6 untreated controls giving 231 pots.

Experimental procedures

Plants of ambrosia were sown in 2 L pots in a potting mixture consisting of field soil, sand and peat (2:1:1 w/w) and grown in a glasshouse. Prior to herbicide application the number of plants per pot was reduced to a pre-set number. Herbicide preparations were applied using a laboratory pot sprayer equipped with a boom fitted with two Hardi ISO F110-02 flat fan nozzles using a volume rate of ca. 150 l/ha at T1 (=2-4 leaf stage) and T2 (=2 weeks after T1).

Three to four weeks after T2 the plants were harvested and foliage fresh and dry weights are recorded. Dose-response curves were estimated using non-linear regressions and the ED_{50} and ED_{90} doses for each herbicide preparation estimated.

The Additive Dose Model was used to determine whether dose-splitting was additive, i.e. that one herbicide dose applied at a specific time can be replaced by an equivalent dose ratio at another time.

2.2.3. Combined effect of herbicide treatment and crop competition

By Solveig K. Mathiassen, Per Kudsk and Birte Wassmuth

Rationale

When ambrosia is growing in a competitive crop, like spring barley, the plants surviving a herbicide treatment will undergo severe stress due to competition with the crop. To find the best control solution for ambrosia growing in cultivated land, different scenarios for ambrosia-crop competition must be explored. The decisive factors are dose and crop density, and the relative size of ambrosia and crop at the time of spraying (because this sets the stage for the ensuing competitive race between the two plant populations)

Objective

To examine the combined effect of herbicide treatment and crop competition on ambrosia using a target-neighbourhood design.

Localities

Denmark and Germany.

Experimental layout (Germany)

Factor	Level
1. MCPP dose	1. 1/16 N = 75 g/ha
	2. 1/8 N = 150 g/ha
	3. 1/4 N = 300 g/ha
	4. 1/2 N = 600 g/ha
	5. 1/1 N = 1200 g/ha

2. Crop density	1. 0 plants/m^2. 2. 75 plants/m^2 (2 barley plants per pot) 3. 150 plants/m^2 (4 barley plants per pot) 4. 300 plants/m^2 (8 barley plants per pot) 5. 600 plants/m^2 (16 barley plants per pot)
3. Growth stage	1. Crop and weed same growth stage (GS1) 2. Crop with 2 leaves more then the weed (GS2)
4. End points	1. Biomass at anthesis of barley 2. Biomass at maturity of barley

Dimensions: 5 doses × 5 crop densities × 2 growth stages × 2 end points × 3 replications per treatment + 6 untreated per crop density, growth stage and end point, giving 480 pots.

Experimental procedures (Germany)

Pots (Ø 19cm) were filled with a mixture of standard garden soil and sand and were fertilized once (250ml Wuxal/pot, 8:8:6 N:P:K). Spring barley was germinated at room temperature and was transplanted at 2-leaf stage. Ambrosia seeds were put in cold storage in wet sand for 4 weeks to break dormancy (Bohren et al. 2008) before germinating in a climate chamber at 20°C. Ambrosia was transplanted at two different timings (GS1 and GS2) having 2 leaves. One ambrosia plant was planted into the centre of each pot. For GS1, barley and ambrosia were transplanted at the same day, both having 2 leaves. For GS2, ambrosia plants with 2 leaves were transplanted when barley had already developed 4 leaves.

Pots were randomized in a greenhouse cooled to 20°C in the beginning and to 25°C during the course of the experiment. On very hot days higher temperatures could not be avoided. Night temperatures were lower, since the glasshouse was not heated.

Herbicide application took place at the same day for both growth stages, barley had 6 leaves (300 crop plants/m²), 2 shoots (150 crop plants/m²) and 4 shoots (75 crop plants/m²), while ambrosia had 6 leaves (GS1) and 4 leaves (GS2). GS2 ambrosia plants were very small. Herbicide was applied using a laboratory pot sprayer using a volume rate of 300L/ha.

Plant height, growth stage and damage were visually assed 3, 4, 5 and 9 weeks after treatment (WAT). At anthesis (4 WAT) and maturity (9 WAT) of barley, plants were harvested and plant height, growth stage, damage (visual assessment) and dry weight of ambrosia were recorded. Visual plant damage was estimated using a scale according to the former EWRS scale:

(0) – No effect

(1) – Trace effect: generally associated with slight growth stimulation

(2) – Slight effect

(3) – Moderate effect: plants more than 75% of the size of control (decrease by 25%)

(4) – Injury: plants more than 50% of control and with some clear visible injury on leaves and stems

(5) – Definite injury: plants half the size of control, leaf epinasty, plant parts deformed and discoloured

(6) – Herbicidal effect: plants 25% size of control, leaf epinasty, plant parts deformed and discoloured

(7) – Good herbicidal effect: very small plants, leaf epinasty, plant parts deformed and discoloured

(8) – Approaching complete kill, only few green parts left

(9) – Complete kill

Experimental layout (Denmark)

Same as in Germany, except that one extra level of crop density (600 plants/m^2) was included. The temperature in the glasshouse was 20-25 ^oC following fluctations in outdoor temperature. As the experiment was conducted from May to August no additional light was applied.

Experimental procedures (Denmark)

Plants of ambrosia were sown in boxes in a potting mixture consisting of field soil, sand and peat (2:1:1 w/w) and grown in a glasshouse. Spring barley was sown in 6.5 L pots using a template to ensure uniform spacing and an even density over the pot area. One ambrosia plant was transplanted into the centre of each pot at two different timings. Herbicide preparations were applied using a laboratory pot sprayer equipped with a boom fitted with two Hardi ISO F110-02 flat fan nozzles using a volume rate of ca. 150 l/ha.

At anthesis and at maturity plants were harvested and foliage fresh and dry weights were recorded. Dose-response curves were estimated using non-linear regressions and the ED_{50} and ED_{90} doses were calculated for each herbicide preparation.

2.3. Chemical control: field conditions

By Stéphanie Waldispühl and Christian Bohren

2.3.1. Chemical control on non-cultivated land

Localities

Denmark, Germany, Slovenia, Switzerland.

Rationale

To obtain the best results of herbicide control on non-cultivated land, we need to know the response of ambrosia to different active ingredients depending on its growth stage. The aim is to prevent flowering and seed set of ambrosia.

Objective

To examine the effect of five different active ingredients, which already showed good results in previous tests, by applying the authorised maximal dose on two different ambrosia growth stages.

Experimental layout

Factor	Level
1. Herbicide	1. Mecoprop (1200 g ai/ha)
	2. Florasulam (7.5 g ai/ha)
	3. Mesotrione (150 g ai/ha)
	4. Glyphosate (1440 g ai/ha)
	5. Clopyralid (100 g ai/ha)
	6. Untreated control
2. Growth stage	1. 4-leaf stage (GS14)
	2. 8-leaf stage (GS18)

Dimensions: 4 replications × 6 herbicides × 2 growth stages giving 48 field plots.

Experimental procedures

Ambrosia seeds were prepared by cold storage in wet sand for 4 weeks to break dormancy. Once the seedlings reached sufficient size (2-4 leaf stage), the plants were transplanted into the field. The field was previously harrowed and glyphosate-treated (1440 g ai/ha) to have a surface free of weeds at onset of experiment. Five ambrosia plants were transplanted per m^2. Plots (2m x 3m) were randomized through the field. $1m^2$ of each plot was chosen to collect the data. In total 240 ambrosia plants were transplanted.

Competitive weeds were eliminated by hand weeding during the experiment.

The first treatment (GS14) took place when 80% of the ambrosia plants had 4 leaves, and the second treatment (GS18) when 80% of the ambrosia plants had 8 leaves.

At days 14, 21, 28 and 35 after GS14 and GS18, visual assessments, plant height and developmental stage of ambrosia were recorded inside of the $1m^2$ surfaces. At days 35 after GS14, plant height, developmental stage, fresh weight and dry weight of ambrosia were measured. Visual plant damage was estimated using the former EWRS scale (section 2.2.3).

2.3.2. Chemical control in spring barley

Localities

Denmark, Germany, Slovenia, Switzerland.

Rationale

The spread of ambrosia into cultivated land is augmenting and strategies to prevent flowering and seed set of ambrosia have to be ameliorated. Therefore the combined effect of crop competition and herbicide control needs to be studied. For this study we evaluated the effect of crop density on ambrosia development and the additive effect of a herbicide application using, both an active ingredient known to have strong effect on ambrosia (mecoprop) and an active ingredient known to have little effect (tribenuron-methyl).

Objective

To examine the combined effect of herbicide treatment and crop competition on ambrosia in the field.

Experimental layout

Factor	Level
1. Crop density	1. 2 N 2. 1 N 3. 1/2 N 4. 0 N
2. Herbicide	1. Mecoprop (1200 g ai/ha) 2. Tribenuron-methyl (22.5 g ai/ha) 3. Untreated control

(N= 300 plants per m^2)
Dimensions: 4 replications per treatment, i.e. 12 field plots.

Experimental procedures

The field was harrowed and spring barley sown in April according to local conditions. Fertilization was applied as needed. Ambrosia seeds were prepared by cold storage in wet sand for 4 weeks to break dormancy. Once the seedlings reached sufficient size (2-4 leaf stage), the plants were transplanted into the field. Five ambrosia plants were transplanted per m^2. Plots (2m x 1.50m) were randomized through the field. $1m^2$ of each plot was chosen to collect the data.

Ambrosia plants will be transplanted when the barley is at 2-3 leaf stage. Five ambrosia plants will be transplanted per m^2; plots are 2x1.50m in size and $1m^2$ out of this surface will be chosen to collect the data.

Competitive weeds were eliminated by hand weeding during the experiment.

Herbicide treatment took place when 80% of the ambrosia plants had 6-8 leaves, At days 14, 21, 28 and 35 after treatment, visual assessments, plant height and developmental stage of ambrosia were recorded inside of the $1m^2$ surface. At days 35 after treatment, plant height, developmental stage, fresh weight and dry weight of ambrosia were measured. Inside of the $1m^2$ plot, barley was harvested too and fresh and dry weight will be measured. Visual plant damage was estimated using the former EWRS scale (section 2.2.3).

2.4. Physical/Chemical control

By Arnd Verschwele & Birte Waßmuth

2.4.1. On non-cultivated land

Rationale

To prevent flowering and seed set of ambrosia on non-cultivated land, different combinations of cutting and herbicide application may be feasible, depending on the specific area and the available equipment. To choose the best option the efficacy of the different treatments must be known.

Objective

To examine the combined effect of cutting and herbicide application on ambrosia growing on non-cultivated land, either in gravel (e.g. building lot) or in grass-dominated vegetation (e.g. roadside).

Localities

Denmark, Germany, Switzerland.

Experimental layout

Factor	Level
1. Surface	1. Gravel 2. Grass
2. Control strategy	1. Cutting + herbicide after 14 days 2. Cutting + cutting after 14 days 3. Herbicide + cutting after 14 days 4. Cutting + cutting + cutting every 7 days 5. Untreated control
3. Growth stage	1. BBCH 21-25 or plant height of 10-15cm (T1) 2. BBCH 55-59 or plant height of 15-20cm (T2)

Dimensions: 4 replications × 2 surfaces × 5 control strategies × 2 growth stages gives 80 plots, each with 5 transplanted ambrosia plants, giving 400 ambrosia plants total.

Experimental procedures (Changins)

Ambrosia plants were transplanted from an infested field in Geneva to institute in Changins. The plants were transplanted on 11.05 at BBCH stadium 14-18. On 18.05 we transplanted some ambrosia plants a second time because they did not survive the first transplantation. Therefore, gravel plots had less than 5 plants/m² in some cases. The control strategies were initiated once 80% of the plants had developed, either the first side shoot (treatment 1 = T1), or the first inflorescences (treatment 2 = T2). Ambrosia plants were developing very slowly in the grass experiment. Thus, the second treatment was conducted at a plant height of 15-20cm instead of BBCH 55-59 and plants were pretty similar in growth as at the first treatment. Cutting of ambrosia and grass was carried out by hand at 8cm height. Mecoprop-P 600g/L was applied in the herbicide treatments.

At days 14, 21, 28 and 35 after the last treatment of T1 and T2 respectively, visual assessments, plant height and developmental stage of ambrosia were recorded for individual plants of all plots. At day 35 additionally dry weight of ambrosia was measured. Visual plant damage was estimated at all locations using a scale according to the former EWRS scale (section 2.2.3).

Calendar for the experiment in Changins

	Gravel		Grass	
	T1	T2	T1	T2
Establishment				
Planting	11MAY09			
Treatments				
1st cutting	01JUL09	15JUL09	08JUL09	15JUL09
2nd cutting	09JUL09	21JUL09	15JUL09	21JUL09
3rd cutting	15JUL09	29JUL09	21JUL09	29JUL09
1st herbicide application	01JUL09	15JUL09	08JUL09	15JUL09
2nd herbicide application	09JUL09	21JUL09	15JUL09	21JUL09
Assessments				
2WAT	15JUL09	29JUL09	21JUL09	29JUL09
3WAT	21JUL09	04AUG09	29JUL09	04AUG09
4WAT	28JUL09	11AUG09	04AUG09	11AUG09
5WAT	04AUG09	19AUG09	11AUG09	19AUG09
6WAT	12AUG09	27AUG09	18AUG09	27AUG09
7WAT	18AUG09		27AUG09	
8WAT				
Biomass	18AUG09	27AUG09	27AUG09	27AUG09

Experimental procedures (Braunschweig)

Ambrosia seeds were put in cold storage in wet sand for four weeks to break dormancy (Bohren et al. 2008). After germination at 20°C seedlings were transplanted into multipot-trays (grass) or peat pots (gravel) which were transferred into grass or gravel surfaces at 4-leaf stage. Plots were 1m² containing 5 ambrosia plants each. Before the beginning of the experiment the grass was mown and the gravel site was treated with hot water weed control to prevent ambrosia plants from severe light competition.

The control strategies were initiated once 80% of the plants had developed the first side shoot for T1, and the first inflorescences (gravel) or a plant height of 15-20cm (grass) for T2. Cutting of ambrosia and grass was carried out by hand at 8cm height according to mowers which cannot mow lower heights. Herbicide was applied as Duplosan KV (mecoprop-P 600g/L) at a rate of 2L/ha using a manual sprayer. Assessments were conducted following the common protocol (see above).

Calendar for the experiment in Braunschweig

	Gravel		Grass	
	T1	T2	T1	T2
Establishment				
Planting	04JUN09		04JUN09	
Treatments				
1st cutting	02JUL09	16JUL09	16JUL09	
2nd cutting	09JUL09	23JUL09	23JUL09	
3rd cutting	16JUL09	31JUL09	31JUL09	
1st herbicide application	02JUL09	16JUL09	16JUL09	
2nd herbicide application	09JUL09	23JUL09	23JUL09	
Assessments				
2WAT	02JUL09	16JUL09	16JUL09	
3WAT	09JUL09	23JUL09	23JUL09	
4WAT	16JUL09	31JUL09	31JUL09	
5WAT	30JUL09	12AUG09	12AUG09	
6WAT	06AUG09	19AUG09	19AUG09	
7WAT	12AUG09	27AUG09	27AUG09	
8WAT	19AUG09	02SEP09	02SEP09	

Biomass	19AUG09	02SEP09	02SEP09	

Experimental procedures (Flakkebjerg)

The experiments in Flakkebjerg were conducted on agricultural land, where no crop was sown and other weeds was removed by hand, in the part of the experiment where the surface was “gravel.” The “grass”-surface was simulated by spring barley (177 kg/ha approximately 300 plants/m²). The experiment was applied with 100 kg N/ha before establishing the experiment. The first treatment was realized at BBCH 21-25, while the second treatment took place at BBCH 55-59. All ambrosia plants were transplanted and assessments were conducted following the common protocol (see above).

Calendar for the experiment in Flakkebjerg

	Gravel		Grass	
	T1	T2	T1	T2
Establishment				
Planting	10MAY09		10MAY09	
Treatments				
1st cutting	17JUN09	15JUL09	17JUN09	15JUL09
2nd cutting	01JUL09	29JUL09	01JUL09	29JUL09
3rd cutting	15JUL09		15JUL09	
1st herbicide application	17JUN09	15JUL09	17JUN09	15JUL09
2nd herbicide application	01JUL09		01JUL09	
Assessments				
2WAT				
3WAT	08JUL09		08JUL09	
4WAT				
5WAT	22JUL09	22JUL09	22JUL09	22JUL09
6WAT	29JUL09	29JUL09	29JUL09	29JUL09
7WAT				
8WAT	27AUG09	27AUG09	27AUG09	27AUG09
Biomass	27AUG09	27AUG09	27AUG09	27AUG09

2.4.2. In maize fields

By Birte Wassmuth, Preben K. Hansen, Stephanie Waldispühl and Andrej Simoncic

Rationale

To prevent flowering and seed set of ambrosia in maize fields, different combinations of hoeing and herbicide application may be feasible, depending on the specific area and the available equipment. To choose the best option the efficacy of the different treatments must be known.

Objective

To examine the combined effect of hoeing and herbicide application on ambrosia growing in maize fields.

Localities

Denmark, Germany, Slovenia, Switzerland.

Experimental layout

Factor	Level
1. Control strategy	1. Hoeing + herbicide after 14 days
	2. Hoeing + hoeing after 14 days
	3. Herbicide + hoeing after 14 days
	4. Hoeing
	5. Herbicide
	6. Control
2. Ambrosia size	1. Height 5-8cm (H1)
	2. Height 12-15cm (H2)

Dimensions: 4 replications × 6 control strategies × 2 ambrosia sizes gives 48 plots, each with 5 (transplanted) ambrosia plants, giving 240 ambrosia plants total.

Experimental procedures

In a maize field 48 ambrosia plots (1 m², five ambrosia plants) were established. Depending on the location ambrosia plants were sown (D), transplanted (DK) or were naturally occurring (CH, SLO). In Germany 20 seeds per plot were sown after the maize. Thus, ambrosia plants were growing within and in between the maize rows. Germination rate was very low; therefore ambrosia plants had to be transplanted into some plots to reach a density of five ambrosia plants per m². In Denmark ambrosia plants were transplanted solely into the maize rows, while in Switzerland ambrosia plants were naturally growing within and between the rows.

The crop was hoed to local agricultural practice. Herbicide was applied as Callisto (100g/L Mesotrione) at a rate of 1.5L/ha using a pushed agricultural sprayer with airmix no drift 025 nozzles.

At days 14, 21, 28 and 35 after the last treatment of H1 and H2 respectively, visual assessments, plant height and developmental stage of ambrosia were recorded for individual plants of all plots. At day 35 additionally dry weight of ambrosia was measured. Visual plant damage was estimated using a scale according to the former EWRS scale (see 2.2.3)-

Statistics

All locations were analysed separately.

Days after treatment (DAT) were calculated as number of days after the last treatment.

Relative height =height treated/height untreated.

Relative GS = GS treated/GS untreated.

Relative dry matter = DM treated/DM untreated.

Calendar for the experiment in Braunschweig

Operation	**Date**
Establishment	
Sowing	
Ambrosia planting	30APR09
Treatments	
Hoeing 1.1	10JUN09
Hoeing 1.2	24JUN09
Spraying 1.1	10JUN09
Spraying 1.2	24JUN09
Hoeing 2.1	17JUN09
Hoeing 2.2	24JUN09
Spraying 2.1	17JUN09
Spraying 2.2	24JUN09
Measurements	
1.2WAT	23JUN09
1.3WAT	08JUL09
1.4WAT	14JUL09

1.5WAT	21JUL09
1.6WAT	05AUG09
2.2WAT	23JUN09
2.3WAT	08JUL09
2.4WAT	14JUL09
2.5WAT	21JUL09
2.6WAT	05AUG09
Harvest	05AUG09

Calendar for the experiment in Changins

Operation	**Date**
Establishment	
Sowing	05MAY09
Handweeding	12MAY09
Treatments	
Hoeing 1.1	27MAY09
Hoeing 1.2	09JUN09
Spraying 1.1	27MAY09
Spraying 1.2	09JUN09
Hoeing 2.1	04JUN09
Hoeing 2.2	16JUN09
Spraying 2.1	04JUN09
Spraying 2.2	16JUN09
Measurements	
1.2WAT	09JUN09
1.3WAT	16JUN09
1.4WAT	23JUN09
1.5WAT	30JUN09
1.6WAT	08JUL09
1.7WAT	14JUL09
1.2WAT	16JUN09

1.3WAT	23JUN09
1.4WAT	30JUN09
1.5WAT	08JUL09
1.6WAT	14JUL09
1.7WAT	20JUL09

Calendar for the experiment in Flakkebjerg

Operation	**Date**
Establishment	
Sowing	
Treatments	
Hoeing 1.1	17JUN09
Hoeing 1.2	01JUL09
Spraying 1.1	17JUN09
Spraying 1.2	01JUL09
Hoeing 2.1	01JUL09
Hoeing 2.2	15JUL09
Spraying 2.1	01JUL09
Spraying 2.2	15JUL09
Measurements	
4WAT	29JUL09
7WAT	02SEP09
Harvest	02SEP09

Calendar for the experiment in Ljubljana

Operation	**Date**
Establishment	Field natural weed flora at the Rakican experimental station (46°37’N, 16°10’E)
Sowing	
Treatments	

Hoeing 1.1	22MAY09
Hoeing 1.2	02JUN09
Spraying 1.1	22MAY09
Spraying 1.2	02JUN09
Hoeing 2.1	02JUN09
Hoeing 2.2	10JUN09
Spraying 2.1	02JUN09
Spraying 2.2	10JUN09
Measurements	
2WAT	09JUN09
3WAT	16JUN09
4WAT	23JUN09
5WAT	30JUN09
6WAT	08JUL09
7WAT	14JUL09
Harvest	21JUL09

2.5. Composting of seeds

By Preben K. Hansen

Localities

Denmark, Germany.

Rationale

Ambrosia plants with seeds may end in communal composting facilities. The question is whether compost heat will kill the seeds. If seeds survive composing then ambrosia should not be composted but destructed more thoroughly e.g. burned.

Objective

To examine the effect of on seed vitality of extended periods of heating in the reign typical of professionally kept compost heaps.

Experimental layout

Bags with 100 ambrosia seeds were kept at constant temperature for 0, 1, 2, 4, ..., 512 h (ca. 21 d) with three levels of temperature: 55, 70 and 85 ^{0}C.

Experimental procedures

Ambrosia seeds were put into small bags of textile (fibre-tex) together with 0.1 L of soil, 100 seeds in each bag. The bags were put into a mixture of water, peat and straw and are stored in a closed contained in a drying cabinet for up to three weeks. On each sampling occasion one bag was picked at random, and the seeds were transferred to germination trays and placed in greenhouse to monitor germination.

3 Results and Discussion

3.1. Ambrosia biology

3.1.1. <u>Emergence</u>

By Stephanie Waldispühl

The emergence of ambrosia seeds was not affected by soil disturbance. The total emergence of seedlings (per m^2) in undisturbed plots (146±14.62 s.e.) did not differ from that in the raked plots (127±15.46 s.e.). Both kinds of plot showed the same trend in emergence (Fig. 3.1); ambrosia clearly favoured germination in April-May. From July and onwards no additional emergence was observed.

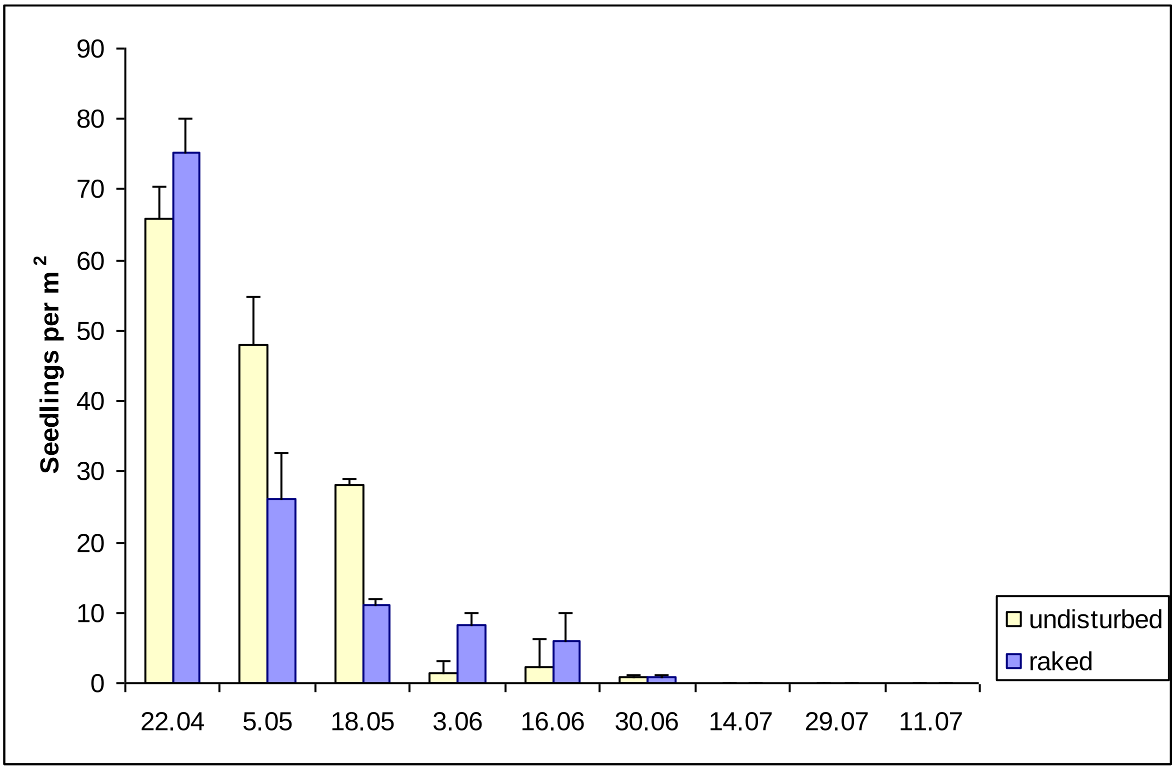


Fig. 3.1. Phenology of ambrosia seedling emergence in undisturbed and raked plots (error bars show s.e.).

3.1.2. Phenology

By Niels Holst

The model

The phenology model was used to estimate expected development times from emergence to GS51 and GS61, based on weather data near the experimental sites and day length calculated from site latitude (Fig. 3.2). According to the model, the time period until first flowering (GS61) should range from between 4-6 months in Denmark (cool summer, long days) to 2-3 months in Switzerland and Slovenia (warm summer, shorter days).

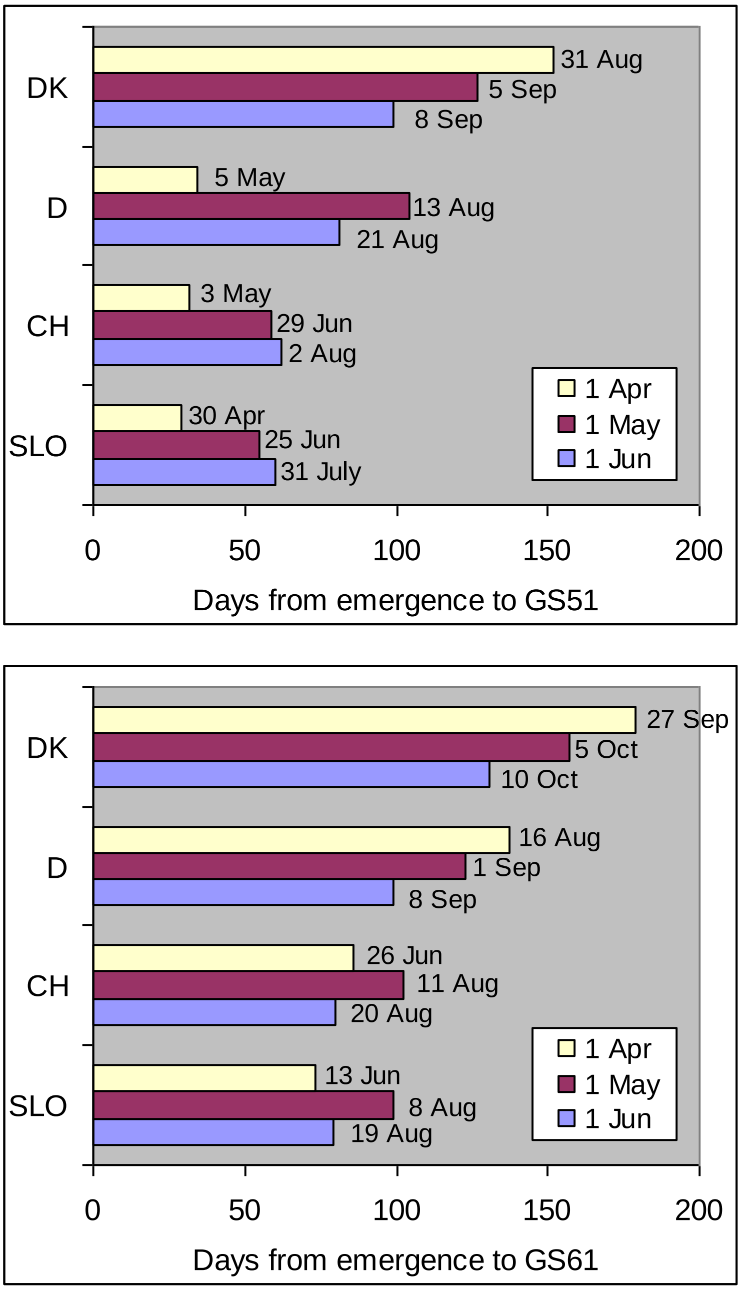


Fig. 3.2. Model prediction of the number of days from emergence (1 April, 1 May or 1 June) to GS 51 (inflorescence visible) and GS 61 (beginning of flowering).

Comparison with observed phenology

The model predictions were compared with the phenology observed for the untreated plants in, either (for Denmark, Germany and Switzerland) the grass/gravel experiment (section 2.4.1), or (for Slovenia) the spring barley competition experiment (section 2.3.2).

Denmark

Plants raised in the greenhouse were planted into the field at the 4-leaf stage on 10 May. On 29 July 31% had reached GS51. On 27 August all were past GS51 and 59% were in GS61. The model predicted GS61 a month later on 27 September (Fig. 3.2), if plants had emerged in the field on 1 April. It is not possible to assess whether seeds in the field would have been able to produce seedlings on 1 April, which again would have grown to the 4-leaf stage by 10 May. Hence the validity of the model under Danish conditions remains uncertain.

Germany

Plants raised in the greenhouse were planted into the field on 4-10 June. The development of these plants fitted well with the model, assuming emergence on 1 May (Fig. 3.2). On 12 August 83% had reached GS51 and on 27 August 36% had reached GS61.

Switzerland

The plants emerged from the natural seed bank in a single flush in mid-April. According to the model (Fig. 3.2) emergence during April would result in GS51 being reached between 3 May and 29 June, and GS61 between 26 June and 11 August. The observed development was at first slower (on 15 July only 55% of the plants were in GS51) but then fit better the prediction (on 4 August 47% were in GS 61).

Slovenia

Fields were sprayed, the first time on 18 May when at least 80% of the plants were in the 4-leaf stage. Assuming that emergence happened on 1 May, the model predicted GS51 on 25 June (Fig. 3.2). In the field 25% of the plants were in GS51 on 3 July. The development was not followed later on; hence, the precision of the model is difficult to assess for Slovenia.

Conclusion

The observations from German and Switzerland suggest that the model is valid for ambrosia phenology Europe. After further validation the model could be a valuable tool to forecast ambrosia pollen and seed production. A phenological network with stations throughout Europe to monitor ambrosia phenology would be useful to perform risk assessment along the northern border of the invasion.

3.2. Chemical control: controlled conditions

3.2.1. Effect of treatment timing

By Solveig K. Mathiassen & Per Kudsk

The dose requirements increased significantly for most of the herbicides when application was carried out at late compared to early development stages of ambrosia. The doses of florasulam and mesotrion had to be increased by a factor 2 to 3 and the dose of MCPP by a factor 3 to 6 if spraying was delayed from the 4-leaf stage to the 8-leaf stage. In contrast there was no need of increasing the doses of glyphosate and clopyralid. If herbicide application was further delayed until the flowering stage the doses of florasulam, mecoprop and mesotrione had to be increased by a factor 14 or more and the dose of clopyralid by a factor 5 compared to the doses at the 4-leaf stage for obtaining a specific efficacy level (Table 3.1)..

Table 3.1. Comparison of the dose needed to obtain the same efficacy level when spraying at late *vs.* early growth stages

Herbicide	Dose multiplication factor when delaying treatment	
	From 4- to 8-leaf stage	From 4-leaf to flowering stage
Glyphosate	0.4	1
Clopyralid	1	>5
Florasulam	2-3	14
Mecoprop	3-6	15
Mesotrione	1-3	>19

Conclusion

The results show that it is possible to control ambrosia - even at late growth stages - with all the tested herbicides. However, glyphosate was the only herbicide that did not require higher doses for controlling ambrosia at later growth stages.

3.2.2. Effect of sequential treatments

By Solveig K. Mathiassen & Per Kudsk

Split or sequential application of herbicides could be a recommendation to ensure effective control of early as well as late cohorts of germinating ambrosia on uncropped areas and in crops with low competitiveness. In this case a low dose should be applied at an early growth stage and followed up by another application when new seedlings emerge. This strategy will also lead to repeated application on plants that have survived the first spraying and the question is if such split applications are as effective as a single application of the same total dose.

The experiments were analysed using a joint-action model as dose-splitting can be considered a special case of joint action of herbicides, not as mixtures, but as staggered applications. The Additive Dose Model (ADM) which is generally accepted as the joint action reference model for mixtures of herbicides has previously been used to evaluate the efficacy of split applications (Mathiassen & Kudsk, 2007). ADM implies that the ED doses of dose-splitting treatments should follow the isobole between the ED doses of the single treatments. If the calculated ED dose of a dose-splitting treatment is located above the isobole, the response to dose splitting is antagonistic and location below the isobole indicate a synergistic response (Fig. 3.3) Most of the split treatments tested yielded a synergetic or synergetic-to-additive response. None were antagonistic (Table 3.2). Thus split applications with the proper herbicides resulted in a higher efficacy than a single treatment, even when the total dose remained the same.

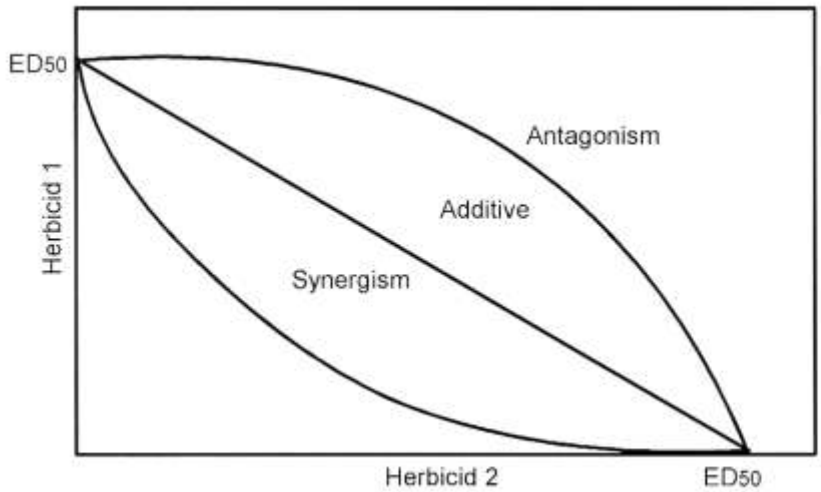


Fig.3.3. Schematic illustration of possible interactions between split applications according to the Additive Dose Model. The x- and y-axes represent relative doses of same or different herbicides at timing 1.

Table 3.2. Classification of sequential treatment efficacy

Synergetic	Additive	Antagonistic
Mesotrione x 2		
Florasulam x 2		
MCPP x 2		
Florasum + Clopyralid	Florasum + Clopyralid	
Florasum + Glyphosat	Florasum + Glyphosat	
	MCPP + Clopyralid	
	MCPP + Glyphosat	

<u>Conclusion</u>

Sequential treatments or split applications showed synergistic or additive effects. Most split applications were more effective than one single application (florasulam, MCPP and mesotrione) while treatments with florasulam and MCPP as the first application followed by clopyralid or glyphosate in the second application were additive.

3.2.2. Combined effect of herbicide treatment and crop competition

By Birte Wassmuth & Solvejg K. Mathiassen

Fig. 3.4. Experimental set-up: Ambrosia in 4-leaf stages, barley in 2- or 5-leaf stages and at varying density.

Results

The visual assessments showed that damage on ambrosia plants differed significantly between doses. Ambrosia plants treated with 75g MCPP/ha were significantly less damaged compared to treatments with higher application doses of damage. The biomass of ambrosia harvested at anthesis differed significantly between doses, crop densities and growth stages (Fig. 3.5). Ambrosia plants treated with 0, 75 and 150 g MCPP/ha produced more dry matter compared to plants treated with 300, 600 and 1200 g MCPP/ha treatments. Crop density had a strong impact on the dry matter of *ambrosia*. The *ambrosia* plants produced more dry matter when grown in pots with 0 or 75 crop plants although barley dry matter did not differ between the three crop densities due to more tillers at low density. Additionally, *ambrosia* plants of GS1 produced more biomass than the ones of GS2. There was a significant interaction between crop density and growth stage and between dose and crop density.

The phenological development of ambrosia was affected by doses, crop densities and growth stages. Ambrosia plants treated with 600g MCPP/ha were less developed compared to plants which had received 75 and 150g MCPP/ha. Crop density was also crucial with less developed plants at densities of 150 and 300 crop plants compared to plants growing at lower barley densities. Finally, ambrosia plants was more developed when growing in combination with barley at the youngest growth stage (GS1) compared to the later (GS2).

The main responses of ambrosia harvested at maturity of the barley plants were more or less similar to the responses of those harvested at anthesis

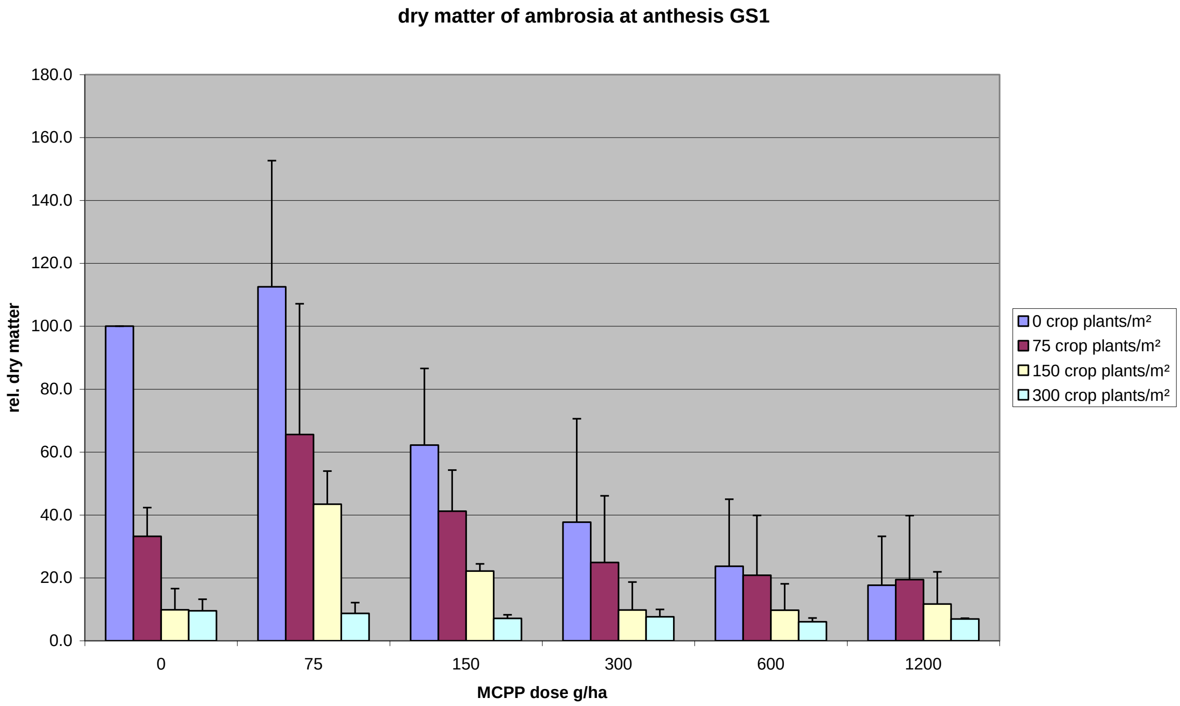


Fig. 3.5. Dry matter of *Ambrosia artemisiifolia* treated with 0, 75, 150, 300, 600 or 1200g MCPP/ha, grown in competition with different barley densities (% relative average ± s.d.). Data collected at anthesis of the barley plants.

Conclusion

Competition is a crucial factor for the development and growth of ambrosia. In the presence of a competing crop the development and dry matter production is reduced. The reduction in biomass production depends on the competitiveness of the crop. However, this growth suppression will persist until the crop is harvested.

In the German trials the dry matter production of ambrosia was highest in treatments of 0 or 75 g MCPP/ha indicating growth stimulation at low MCPP doses (hormesis effect). However, higher doses had an adverse effect and reduced dry matter independent of crop density. Hormesis was not present in the Danish trial.

An application of the highest MCPP dose was not 100% effective in terms of killing all ambrosia plants but development was stopped or slowed down preventing flowering and seed set. This was already the case at doses of 150g MCPP/ha for GS1 ambrosia plants. Thus MCPP can stop build-up the local seed pool and in the long run could help to empty the seed pool.

Dose response curves were estimated using the results from the Danish experiment. It was possible to calculate not only ED doses of MCPP but also ED values for crop densities. Using this method enables a comparison between the effect of crop competition and herbicide efficacy which can be summed up by this example:

The competitive ability of 340 barley plants per m^2 emerging at the same time as the ambrosia was equivalent to the efficacy of225 g/ha MCPP at the 4-leaf stage. If the barley plants emerge 10 days before ambrosia only 51 barley plants are needed to produce the same competition level.

Conclusion

Ambrosia growth is highly affected by crop competition and herbicide doses. Establishment of a dense plant cover is a good first step in a strategy for ambrosia control which may reduce the required herbicide dose. MCPP is effective in stopping the spread of ambrosia.

3.3. Chemical control: field conditions

By Preben K. Hansen, Stephanie Waldispühl and Birte Wassmuth

3.3.1. Chemical control on non-cultivated land

The efficacy of the five herbicides applied at two plant growth stages varied among the three experimental locations (Table 3.3). All together these results suggest that early treatment is the most robust, i.e. is most likely to result in a high efficacy. Among the herbicides, mecoprop and mesotrione did not always result in good control.

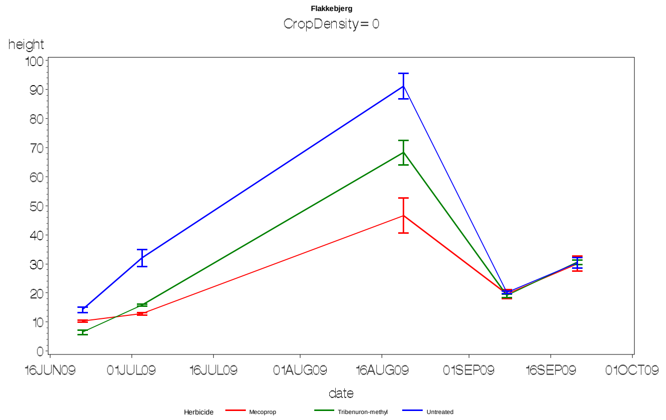
Table 3.3. Percentage effect of five herbicides on *Ambrosia artemisiifolia* at three locations in Europe. Effects >90% shown in grey. GS14: 4-leaf stage; GS18: 8-leaf stage.

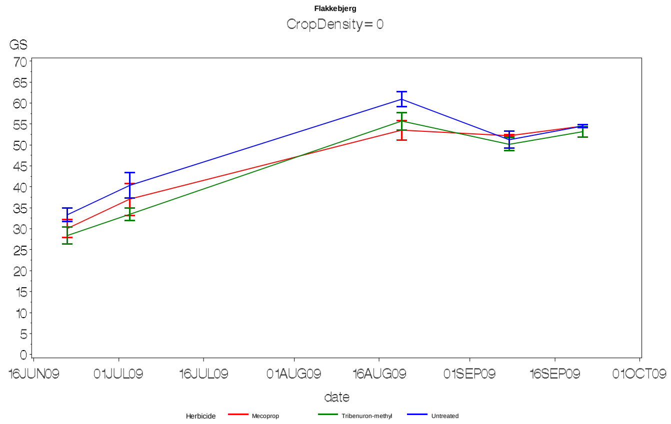
	Braunschweig		Changins		Flakkebjerg	
Active compound	GS14	GS18	GS14	GS18	GS14	GS18
Clopyralid	87	84	91	22	100	61
Florasulam	97	92	97	47	97	89
Glyphosate	100	98	88	98	100	96
Mecoprop	91	85	79	34	78	68
Mesotrione	97	79	76	29	100	77

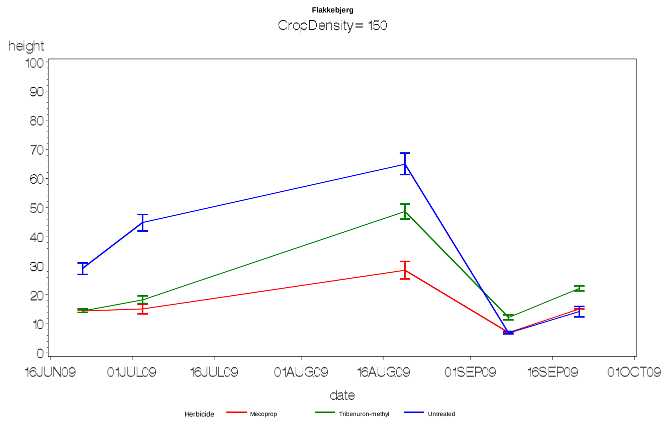
3.3.2. Chemical control in spring barley

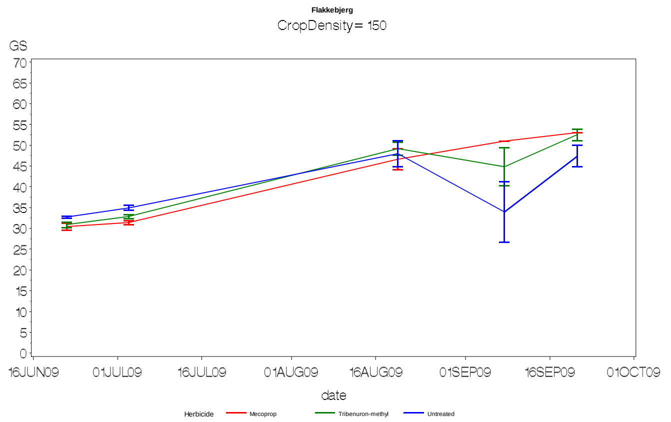
The results are shown for the trial in Flakkebjerg which displayed trends typical of all three locations (Fig. 3.13). Mecoprop had a higher efficacy than tribenuron-methyl and crop competition added to the effect. Herbicides and crop competition retarded both growth and development but after harvest plants showed vigorous regrowth in all treatments. In a practical situation this would necessitate additional control in the stubble to prevent ambrosia setting seeds.

Fig. 3.13 (next page). Herbicide field trial in Flakkebjerg, Denmark with barley density (top to bottom): 0, 150, 300 and 600 plants per m^2. Height (left) and growth stage (right) of ambrosia are shown from June to September for treatments: mecoprop (red), tribenuron-methyl (green) and untreated (blue).


Flakkebjerg
CropDensity= 0
height
16JUN09 01JUL09 16JUL09 01AUG09 16AUG09 01SEP09 16SEP09 01OCT09
date
Herbicide Mecoprop Tribenuron-methyl Untreated


Flakkebjerg
CropDensity= 0
GS
16JUN09 01JUL09 16JUL09 01AUG09 16AUG09 01SEP09 16SEP09 01OCT09
date
Herbicide Mecoprop Tribenuron-methyl Untreated


Flakkebjerg
CropDensity= 150
height
16JUN09 01JUL09 16JUL09 01AUG09 16AUG09 01SEP09 16SEP09 01OCT09
date
Herbicide Mecoprop Tribenuron-methyl Untreated


Flakkebjerg
CropDensity= 150
GS
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date
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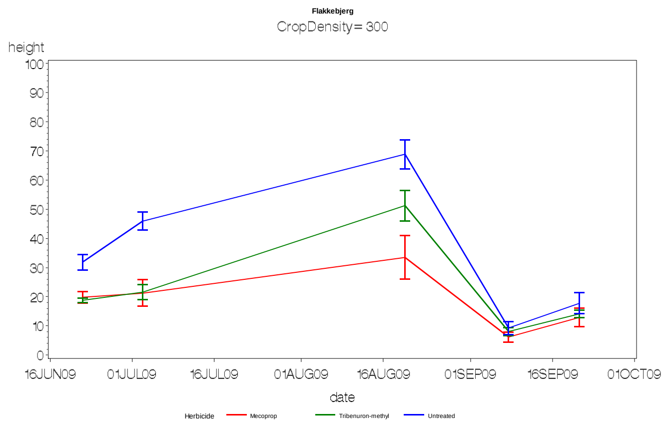
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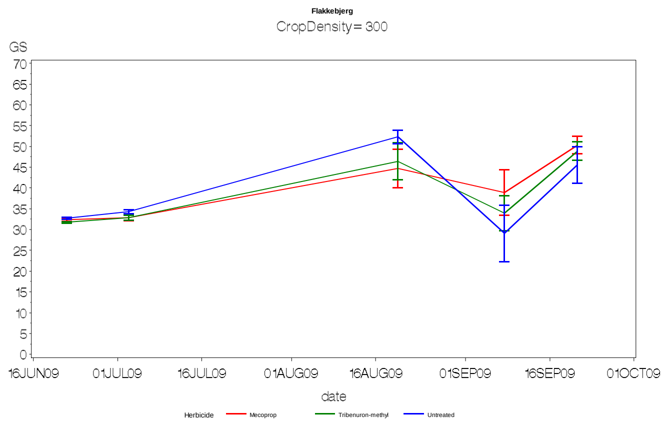
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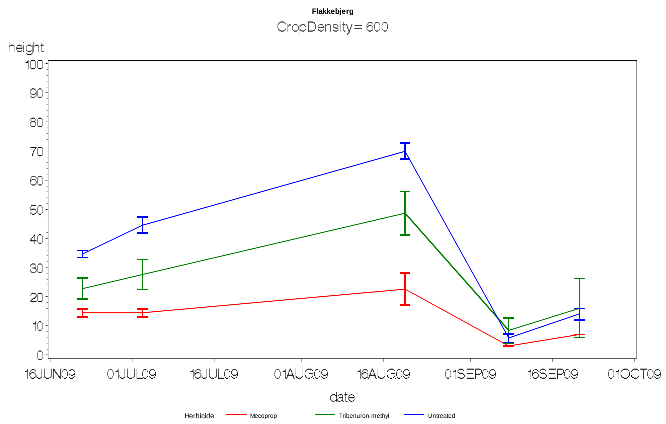
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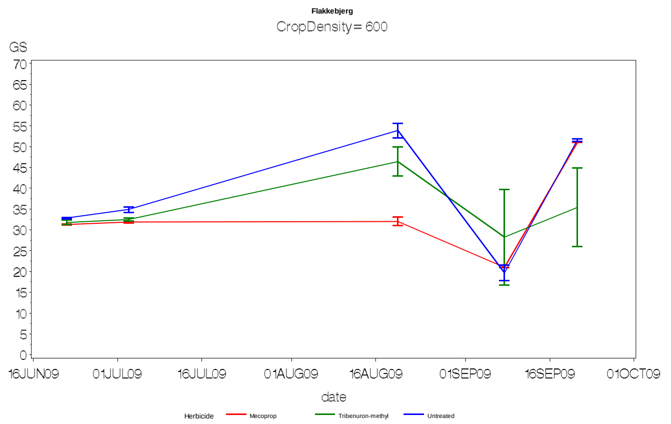
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date
Herbicide Mecoprop Tribenuron-methyl Untreated

3.4. Physical/Chemical control

3.4.1. On non-cultivated land

By Birte Wassmuth, Preben K. Hansen and Stephanie Waldispühl

Table 3.4. Response of plant height of *Ambrosia artemisiifolia* to different control strategies.

Control strategy Surface gravel	% reduction when treated at growth stage BBCH 21-25			BBCH 55-59		
	CH	DK	D	CH	DK	D
untreated control	-	-	-	-	-	-
cutting + herbicide after 14 days	71	59	71	-	51	67
cutting + cutting after 14 days	38	12	27	-	49	16
herbicide + cutting after 14 days	66	47	89	-	25	82
cutting + cutting + cutting every 7 days	32	29	37	-	62	22

Control strategy surface grass	% reduction when treated at growth stage BBCH 21-25 (D, DK) or plant height of 10-15cm (CH)			BBCH 55-59 (DK) or plant height of 15-20cm (CH, D)		
	CH	DK	D	CH	DK	D
untreated control	-	-	-	-	-	-
cutting + herbicide after 14 days	96	71	60	-	72	-
cutting + cutting after 14 days	45	30	49	-	68	-
herbicide + cutting after 14 days	97	58	75	-	6	-
cutting + cutting + cutting every 7 days	55	57	27	-	79	-

Table 3.5. Response of plant development of *Ambrosia artemisiifolia* to different control strategies.

Control strategy Surface gravel	% reduction when treated at growth stage BBCH 21-25			BBCH 55-59		
	CH	DK	D	CH	DK	D
untreated control	-	-	-	-	-	-
cutting + herbicide after 14 days	35	15	62	-	16	62
cutting + cutting after 14 days	3	4	11	-	19	6
herbicide + cutting after 14 days	30	12	80	-	97	66
cutting + cutting + cutting every 7 days	2	10	14	-	23	5

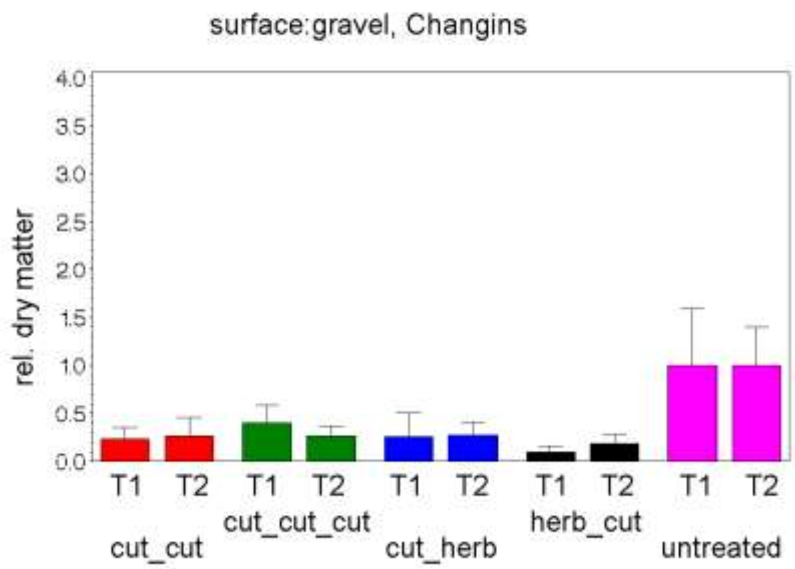
Control strategy Surface grass	% reduction when treated at growth stage BBCH 21-25 (D, DK) or plant height of 10-15cm (CH)			BBCH 55-59 (DK) or plant height of 15-20cm (CH, D)		
	CH	DK	D	CH	DK	D
untreated control	-	-	-	-	-	-
cutting + herbicide after 14 days	95	30	60	-	33	-
cutting + cutting after 14 days	10	7	26	-	33	-
herbicide + cutting after 14 days	98	31	66	-	+1	-
cutting + cutting + cutting every 7 days	32	17	19	-	35	-

Table 3.6. Response of dry matter yield of *Ambrosia artemisiifolia* to different control strategies.

Control strategy Surface gravel	% reduction when treated at growth stage BBCH 21-25			BBCH 55-59		
	CH	DK	D	CH	DK	D
untreated control	-	-	-	-	-	-
cutting + herbicide after 14 days	77	66	81	76	67	48
cutting + cutting after 14 days	66	17	34	79	70	25
herbicide + cutting after 14 days	90	62	96	83	49	84
cutting + cutting + cutting every 7 days	65	58	57	73	85	26

Control strategy Surface grass	% reduction when treated at growth stage BBCH 21-25 (D, DK) or plant height of 10-15cm (CH)			BBCH 55-59 (DK) or plant height of 15-20cm (CH, D)		
	CH	DK	D	CH	DK	D
untreated control	-	-	-	-	-	-
cutting + herbicide after 14 days	99	72	64	90	59	-
cutting + cutting after 14 days	77	+42	79	70	53	-
herbicide + cutting after 14 days	99	63	77	100	49	-
cutting + cutting + cutting every 7 days	72	5	48	72	66	-

Changins



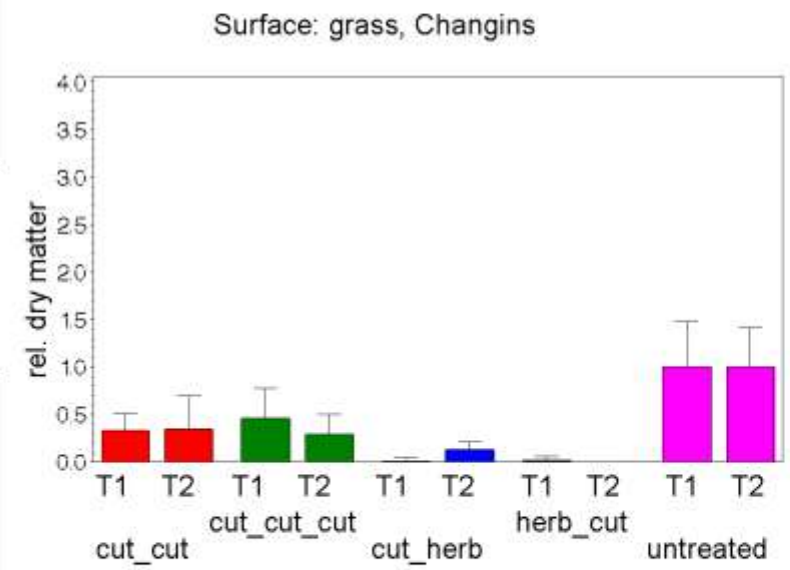


Fig. 3.14. The effect of different treatment strategies on the relative biomass (in relation to the untreated in the same growth stage) of *Ambrosia artemisiifolia* in Changins in gravel and grass. Vertical lines indicate s.e.

The results from Changins showed very great differences between the grass and gravel surface. Grass reduced the size of ambrosia dramatically (for T1 and T2: 1.3 g and 1.3 g per plant in untreated grass compared to 125 g and 148 g per plant in gravel). Height of untreated plants went up to 80-90 cm in gravel compared to 30-40 cm in grass covered surfaces. The treatments that reduced height development most included herbicide applications. In the gravel surface, the treatment with cutting as the initial treatment followed by a herbicide treatment was able to reduce height development the most, followed by the treatment herbicide and then cutting. Cutting reduced plant height as well but only ~ 35 % with no difference between cutting two or three times. On grass covered surface, the treatments with herbicides reduced height growth the most. They were followed by the two different cutting treatments which had significantly taller plants than the herbicide treatments. Still, plant height was lower than in the untreated control. Plant growth stage at the time of treatment was crucial for all treatments. Plants of growth stage 21-25 that were only cut grew taller, while plants were smaller when treated in combination with herbicides.

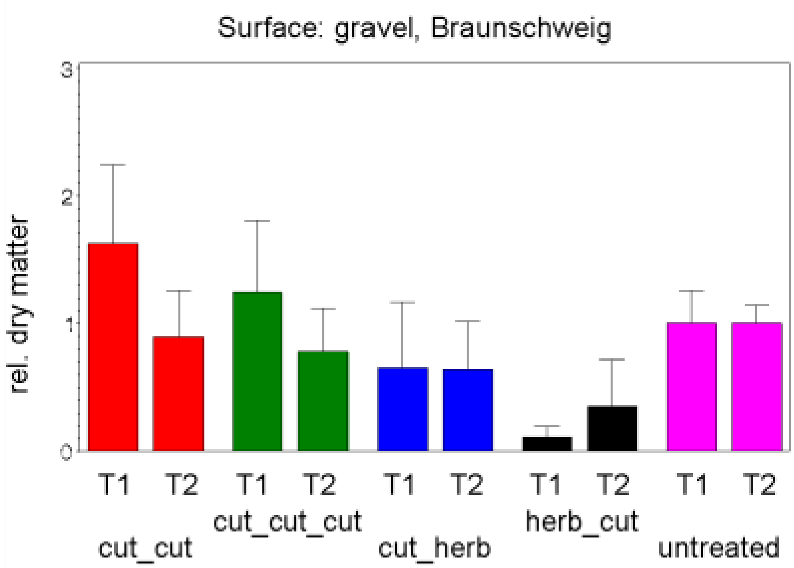
For the phenological development only the treatments which included herbicides retarded development compared to untreated plots in the gravel surface. While, in grass covered plots, all treatments retarded development compared to the untreated control with the treatments including herbicides being the most effective.

Dry matter production on grass was significantly reduced in all treatments except when cut three times. Most effective in dry matter reduction was the combination of early herbicide application followed by cutting which decreased dry matter yield by almost 100% (Fig. 3.14). On gravel all four treatments were equally effective. Ambrosia dry matter was reduced by 70 to 80% (Table 3.6).

Braunschweig

The experiments in Braunschweig showed larger plants in the gravel part of the experiment, however not as marked differences as in Changins and Flakkebjerg. The height development in the gravel experiment was reduced by all experiments, especially when ambrosia was treated with herbicides. Ambrosia plants that were treated at growth stage 21-25 were significantly smaller in all treatments (Table 3.4). Similarly, in the grass covered part of the experiment, all treatments were able to reduce height development compared to untreated plots.

The phenological development was delayed compared to untreated controls in all the grass covered plots, but mostly where herbicides were applied. In the gravel plots only the treatments with herbicides were able to delay the phenological development. Growth stage at the time of treatment was crucial with less developed plants when treated at growth stage 21-25.



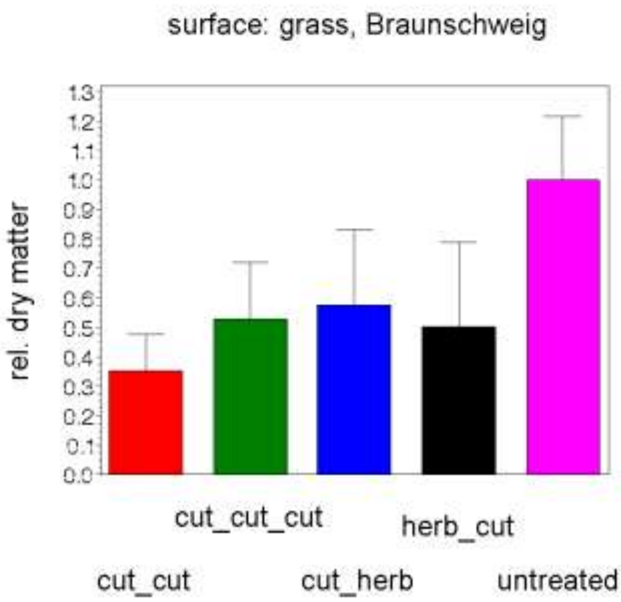
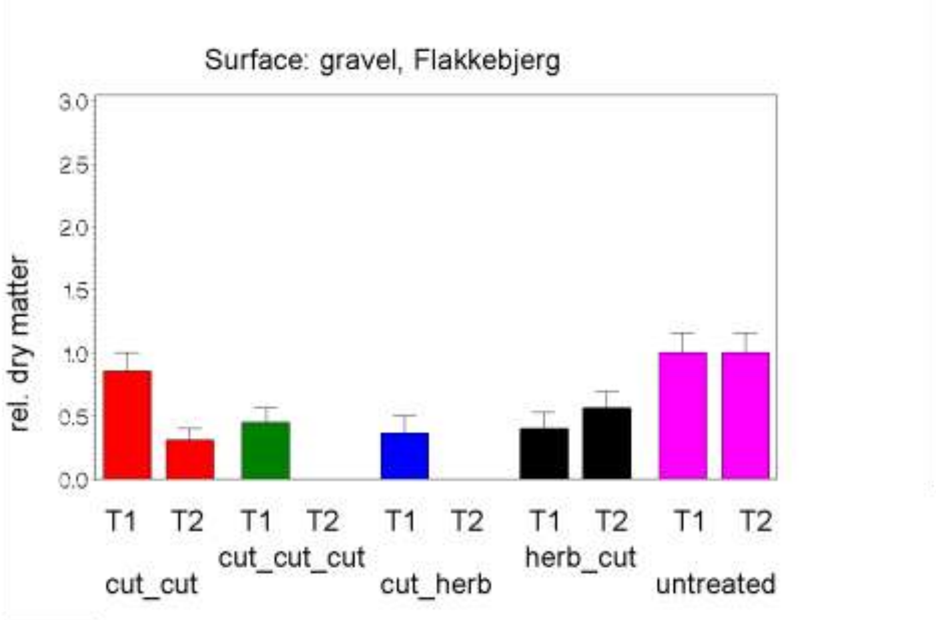


Fig. 3.15. The effect of different treatment strategies on the relative biomass (in relation to the untreated in the same growth stage) of *Ambrosia artemisiifolia* in Braunschweig in gravel and grass. Vertical lines indicate s.e.

Dry matter production (Fig. 3.15) on grass was significantly reduced in all treatments except when cut three times. On gravel only the treatments including herbicides reduced ambrosia dry matter. However, dry matter was reduced up to 96% (Table 3.6).

Flakkebjerg

In the grass covered plots plant height was reduced by two times cutting and by herbicide application followed by cutting, whereas two times cutting yielded even smaller plants than the other treatments. For the bare soil plots, results varied a lot. Herbicide followed by cutting produced smaller plants than untreated and two times cutting, however, two times cutting still reduced plant height compared to untreated. Furthermore, ambrosia plants which were cut three times were smaller than plants which were cut first followed by a herbicide application. There were significant interactions between control strategy and growth stage at the time of treatment independent of the surface.



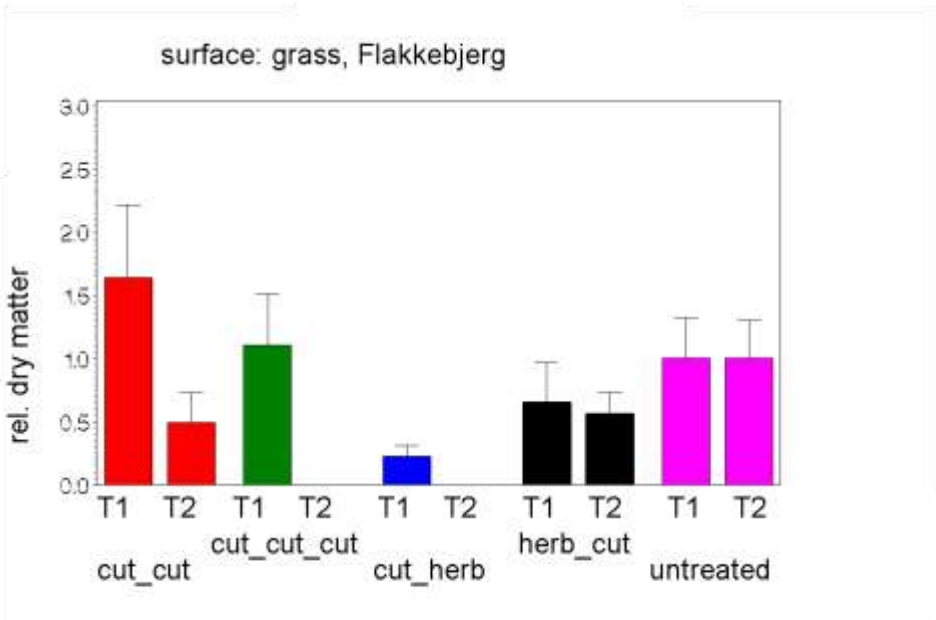


Fig. 3.16. The effect of different treatment strategies on the relative biomass (in relation to the untreated in the same growth stage) of ambrosia in Flakkebjerg in gravel and grass. Vertical lines indicate s.e.

In Flakkebjerg the phenological development was not affected dramatically in any of the treatments, independent of the surface, as the development in the treated followed the untreated plots. Only two times cutting slowed down the development compared to the untreated. However, there were significant interactions between control strategy and growth stage at the time of treatment.

There were marked differences in the final individual plant weight, whether the surface was bare soil or grown with grass (15-16 g per plant in plots of untreated grass, compared to 275-300 g per plant in plots with untreated gravel). Only herbicide application followed by cutting had significantly lower dry matter compared to cutting twice and untreated plots on bare soil. The same was true in the grass plots (Fig. 3.16). Additionally plants, which had been cut three times, yielded more dry matter than the ones treated with cutting first followed by herbicide application. There were significant interactions between control strategy and growth stage at the time of treatment.

Conclusion

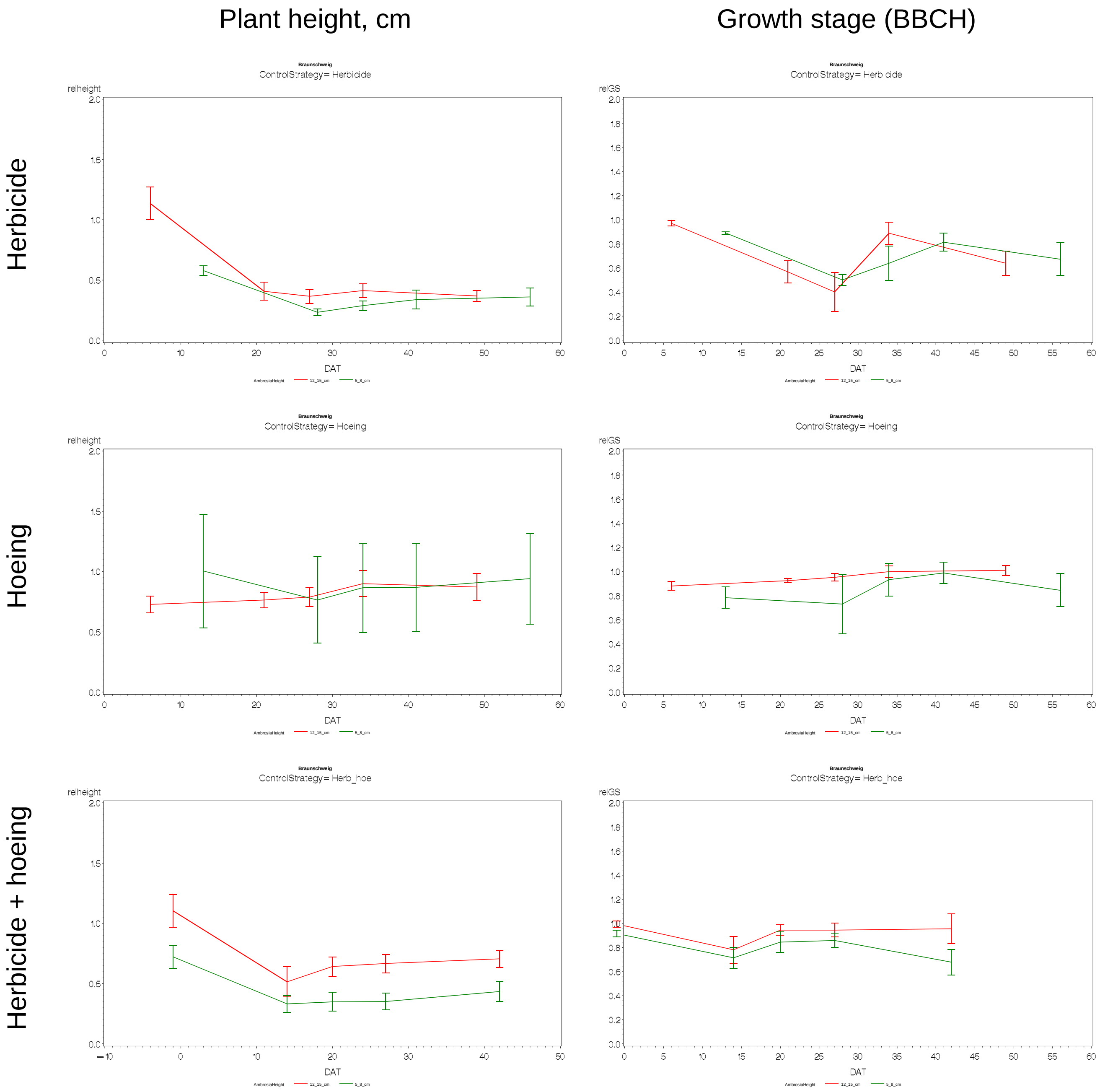
Ambrosia varies a lot in plant growth, phenological development and dry matter production depending on the surface and on the location. Still, treatments including herbicides were the most effective ones in all countries. Especially control with herbicide application followed by cutting was very successful in slowing down ambrosia development and reducing biomass. Cutting reduced ambrosia plant height and biomass in some of the experiments but seemed to increase the growth of ambrosia in the Danish experiments. This might be due to increased growth of side shoots after the main shoot has been destroyed. Ambrosia is not a very competitive plant species. Our results showed that as soon as competition was apparent (grass), cutting treatments were more effective compared to non-competitive environments (gravel). Therefore, if ambrosia is not growing in an optimal environment cutting can applied as a control measure.

In summary, our experiments showed that although a 100% control of ambrosia was not possible, at least pollen production was reduced and seed set was inhibited. Hence, the spread of ambrosia could be slowed down by interrupting its life cycle.

3.4.2. In maize fields

By Birte Wassmuth, Preben K. Hansen, Stephanie Waldispühl and Andrej Simoncic

Germany



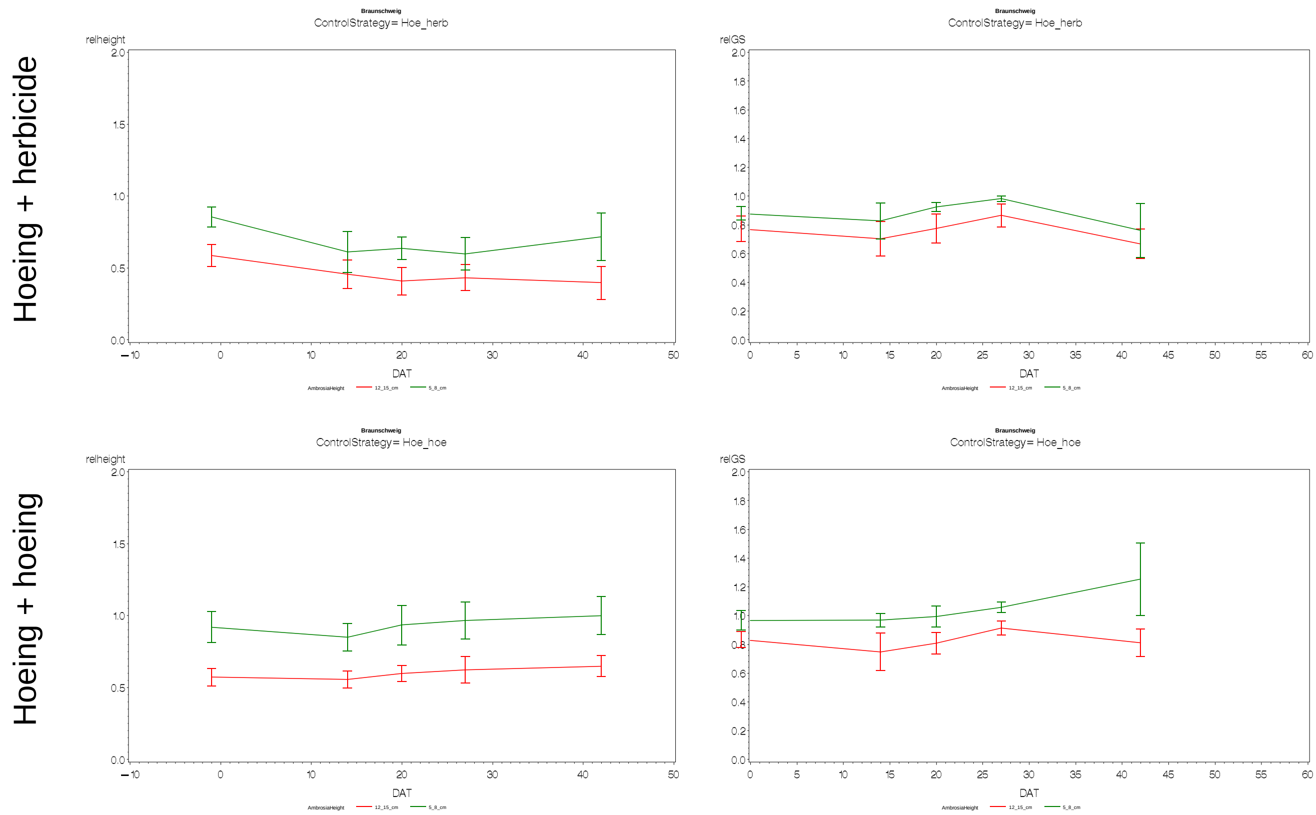


Fig. 3.17. Development in relative (in relation to untreated) maximal height, and relative growth stage of *Ambrosia artemisiifolia* as a result of different chemical or mechanical weed control strategies in Braunschweig. Vertical bars indicate standard error.

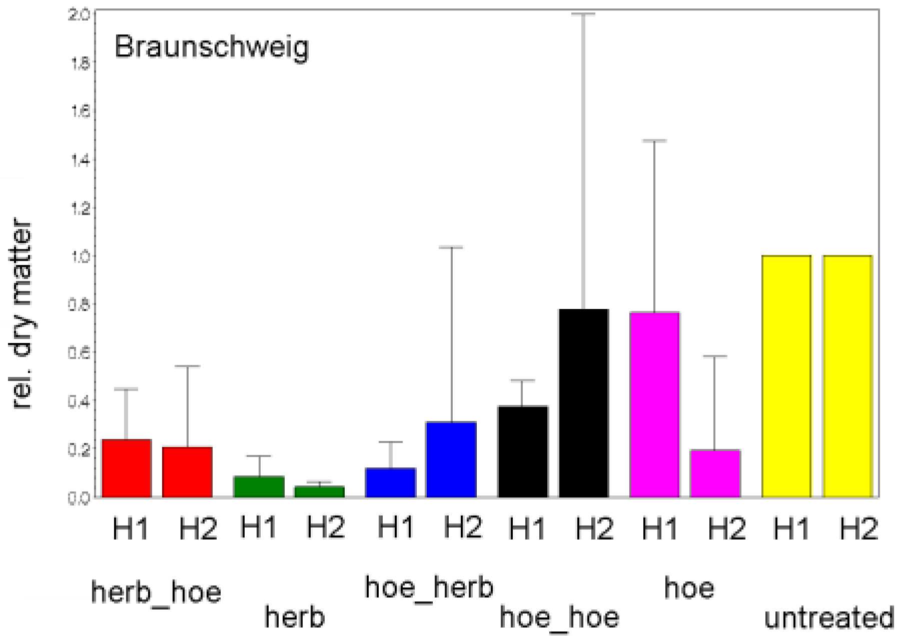


Fig. 3.18. Dry matter of *Ambrosia artemisiifolia* as a result of different chemical or mechanical weed control strategies in Braunschweig. Vertical bars indicate standard error.

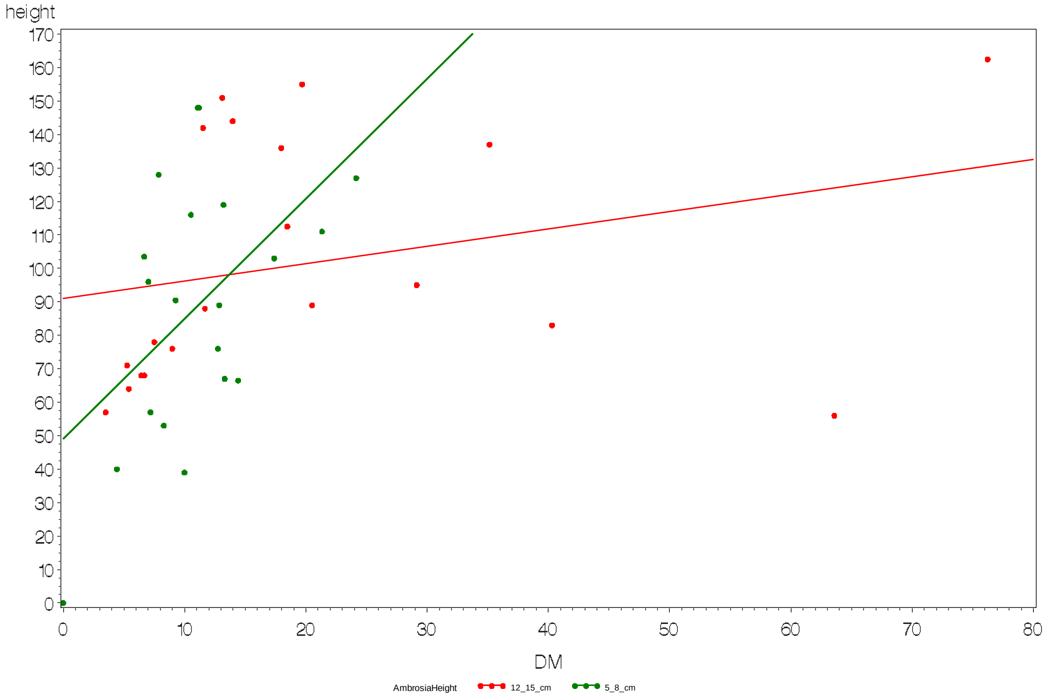


Figure 3.19. Plant height *vs.* dry matter for untreated plots in Braunschweig

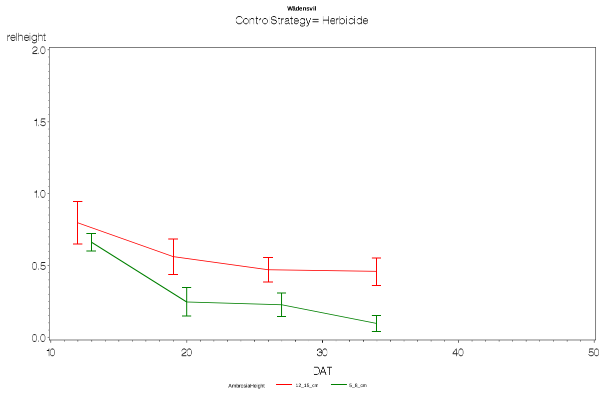
Compared to untreated plots, the most efficient treatment was a single herbicide treatment (either in the early growth stages with 95% efficacy or in the later growth stages with an efficacy of 91%): plant height and developmental stage were reduced. Surprisingly, by combining the herbicide treatment with a mechanical treatment (either at the first or the second treatment in a strategy) an increased effect was not observed in this experiment. The mechanical treatments alone did not give a satisfactory effect, but had a pronounced effect on plant damage when applied at early growth stages. However, the early hoeing gave a significant greater variation in the measurements indicating a more unstable effect.

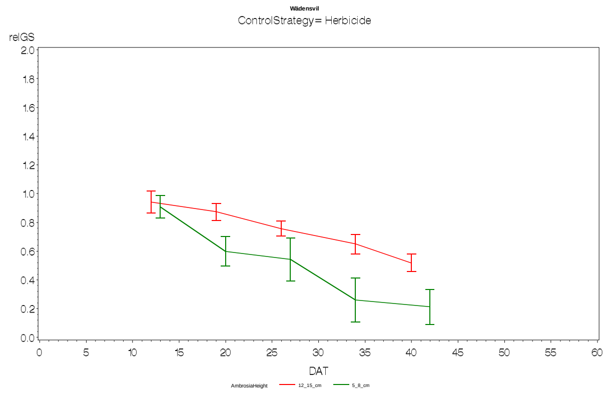
The phenological development was interrupted by the herbicide application but ambrosia plants recovered and were at the same developmental stage at the end of the experiment as all other treatments and untreated plants (Fig. 3.17). The developmental stage at the time of treatment had an effect on plant height and damage at harvest, with higher plants when hoed early. However, all treatments reduced dry matter compared to the untreated control (Fig. 3.18). The time of treatment (either H1 or H2) made a difference; additionally there was a significant interaction between developmental stage at the time of treatment and control strategy.

Switzerland

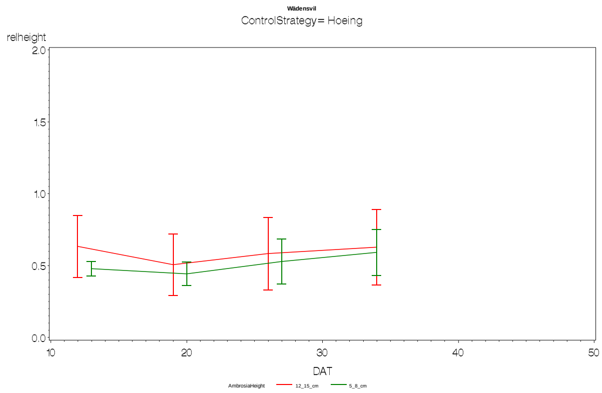
Plant height, cm	Growth stage (BBCH)

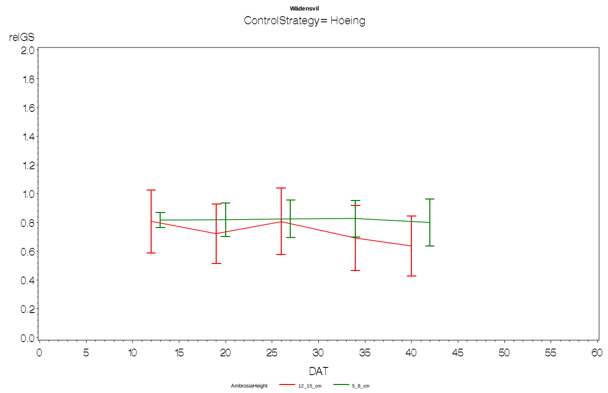
Herbicide



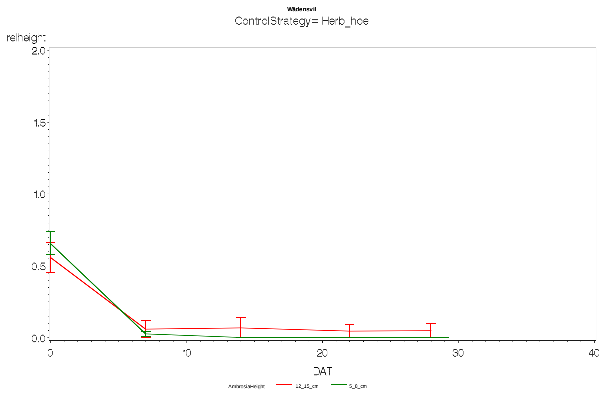


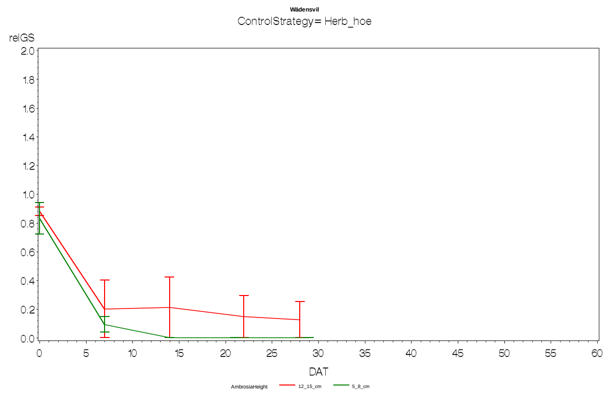
Hoeing



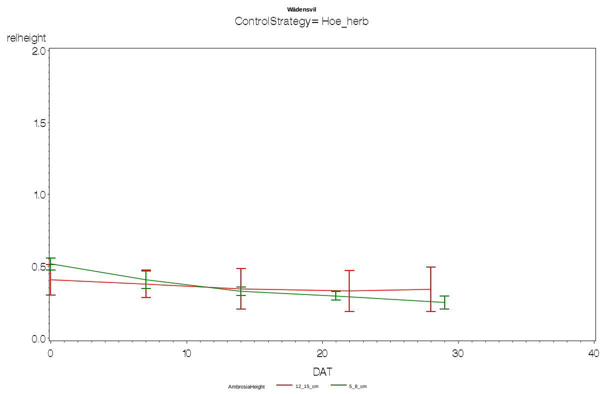


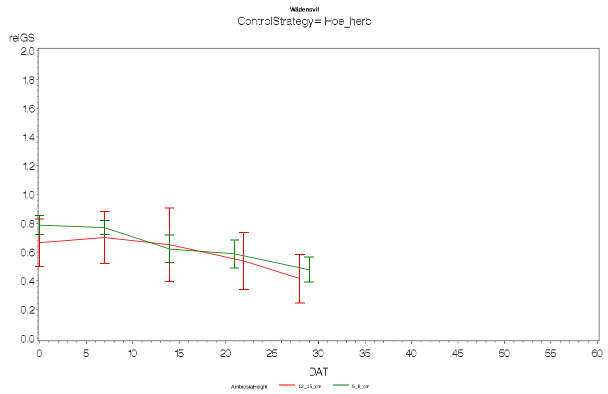
Herbicide + hoeing





Hoeing + herbicide





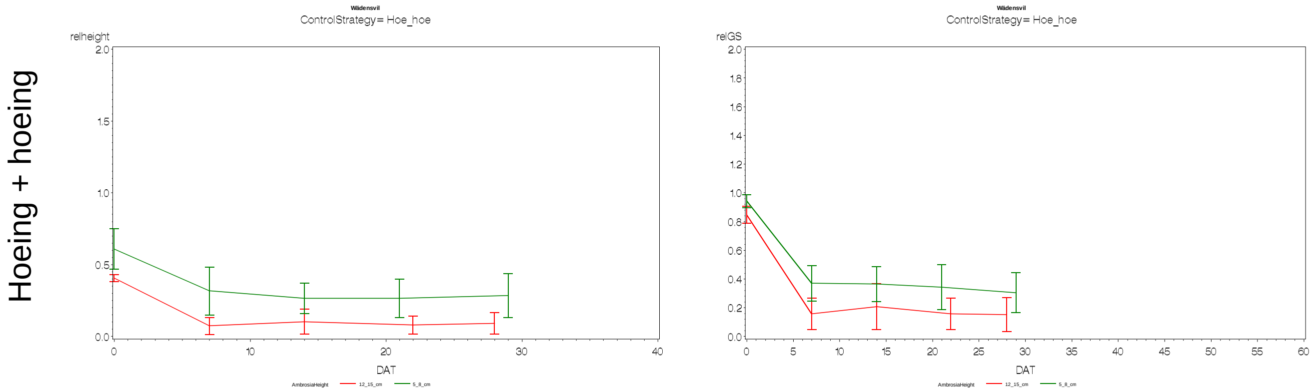


Fig. 3.20. Development in relative (in relation to untreated) maximal height, and relative growth stage *Ambrosia artemisiifolia* as a result of different chemical or mechanical weed control strategies. Vertical bars indicate standard error.

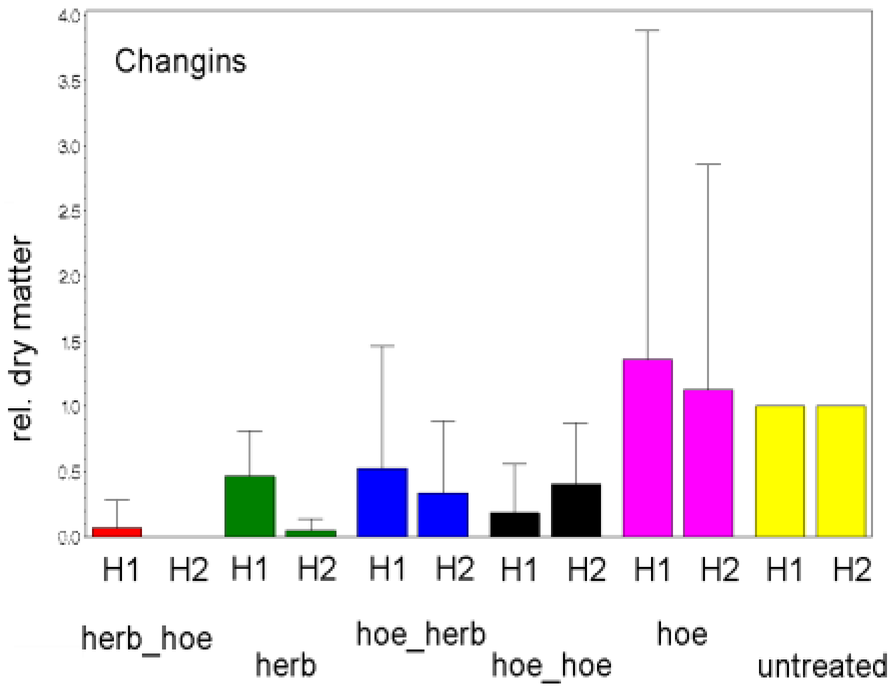


Fig. 3.21. Dry matter of *Ambrosia artemisiifolia* as a result of different chemical or mechanical weed control strategies in Changins. Vertical bars indicate standard error.

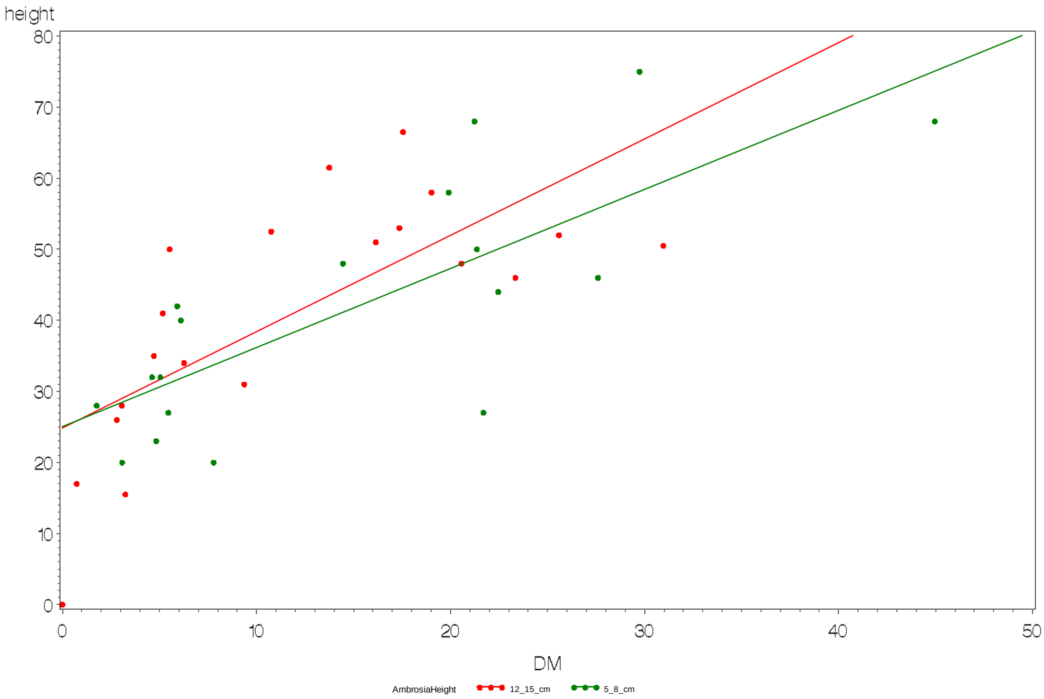


Fig. 3.22. Plant height *vs.* dry matter in untreated plots in Changins

The field in Switzerland was heavily infested with *Chenopodium album* which created a lot of competition for maize emergence. The maize did not grow well actually and was not really meaningful in the experiment.

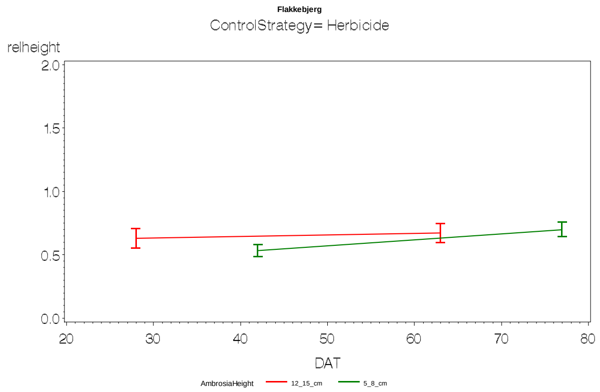
The ambrosia plants emerging from the seed bank in Switzerland (Fig. 3.22) reached only half the size of the ambrosia plants transplanted in Germany (Fig. 3.18) and Denmark (Fig. 3.25). The results from Changins show that an early herbicide application either alone or in combination with subsequently hoeing gave a satisfactory effect (<90%). However, when applying herbicide in that late growth stage the effect was not present. Hoeing alone did increase the biomass of ambrosia, hoeing twice reduced plant height and slowed down phenological development. The highest plant damage was caused by initial herbicide application followed by hoeing. Dry matter was by far highest in the hoeing treatment while in all other treatments reduced dry matter production in relation to the untreated plots (Fig. 3.21).

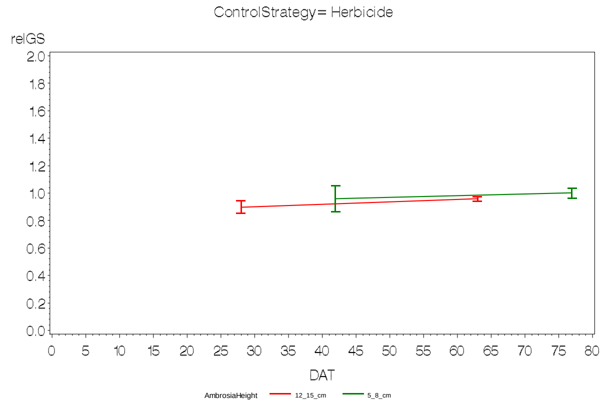
Flakkebjerg

Plant height, cm

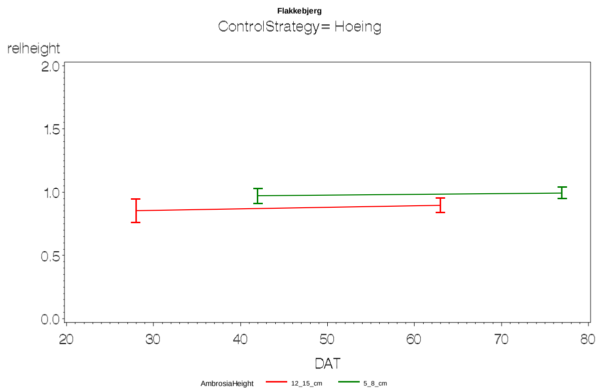
Growth stage (BBCH)

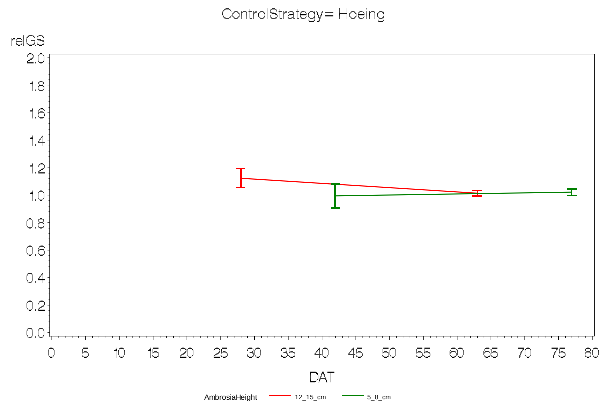
Herbicide



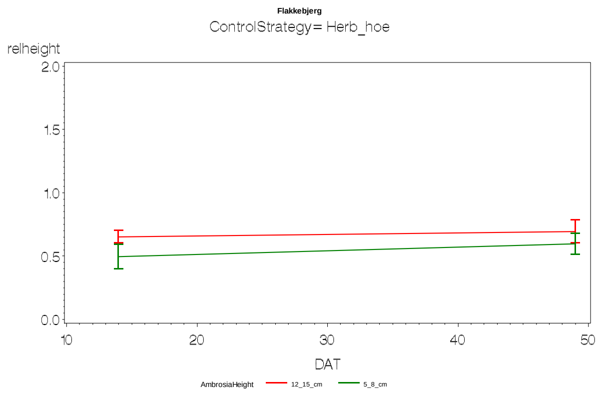


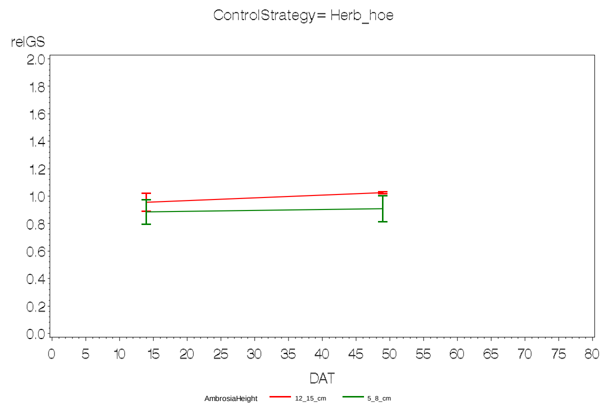
Hoeing



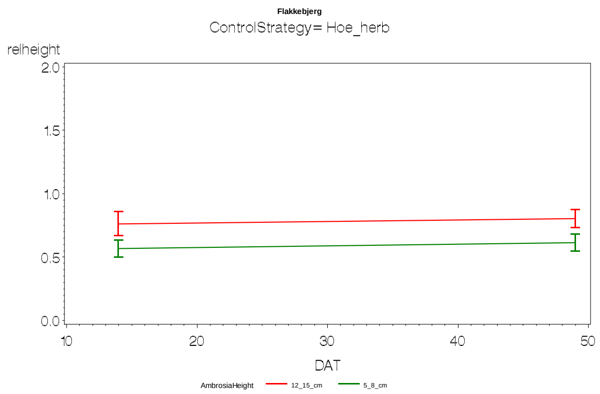


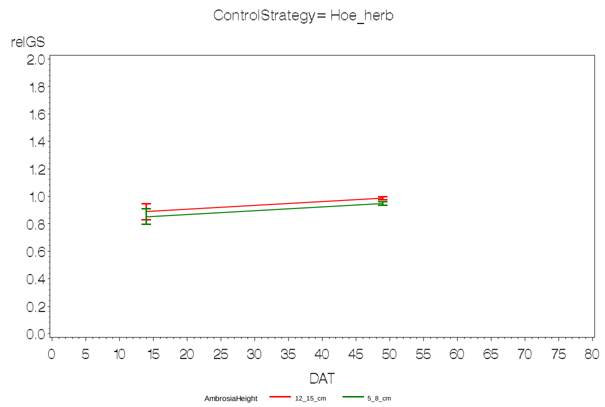
Herbicide + hoeing





Hoeing + herbicide





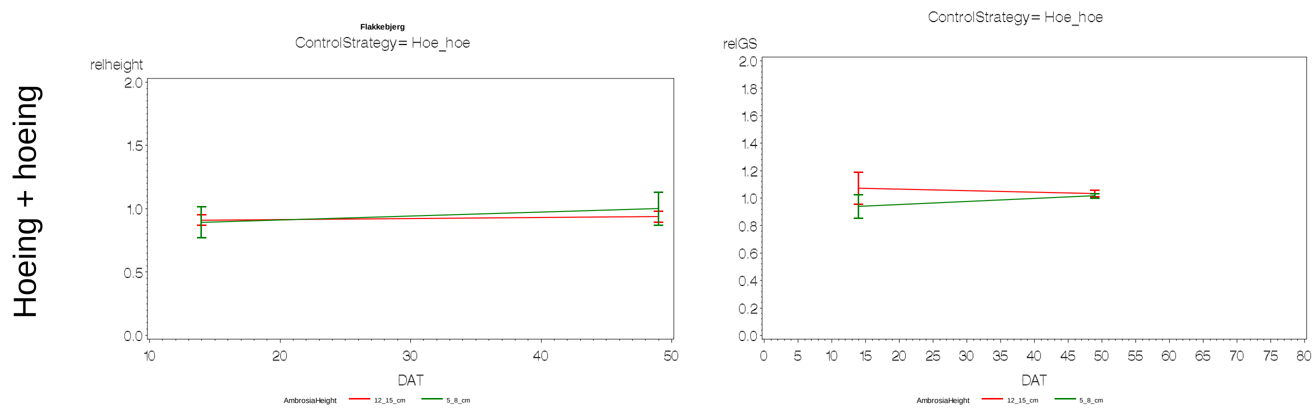


Fig. 3.23. Development in relative (in relation to untreated) maximal height, and relative growth stage ambrosia as a result of different chemical or mechanical weed control strategies in Flakkebjerg. Vertical bars indicate standard error.

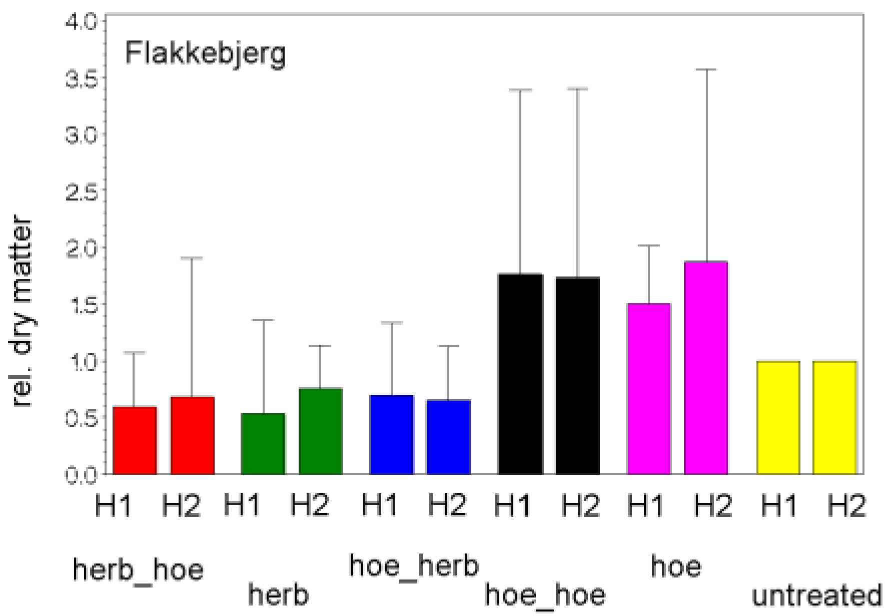


Fig. 3.24. Dry matter of *Ambrosia artemisiifolia* as a result of different chemical or mechanical weed control strategies in Flakkebjerg. Vertical bars indicate standard error.

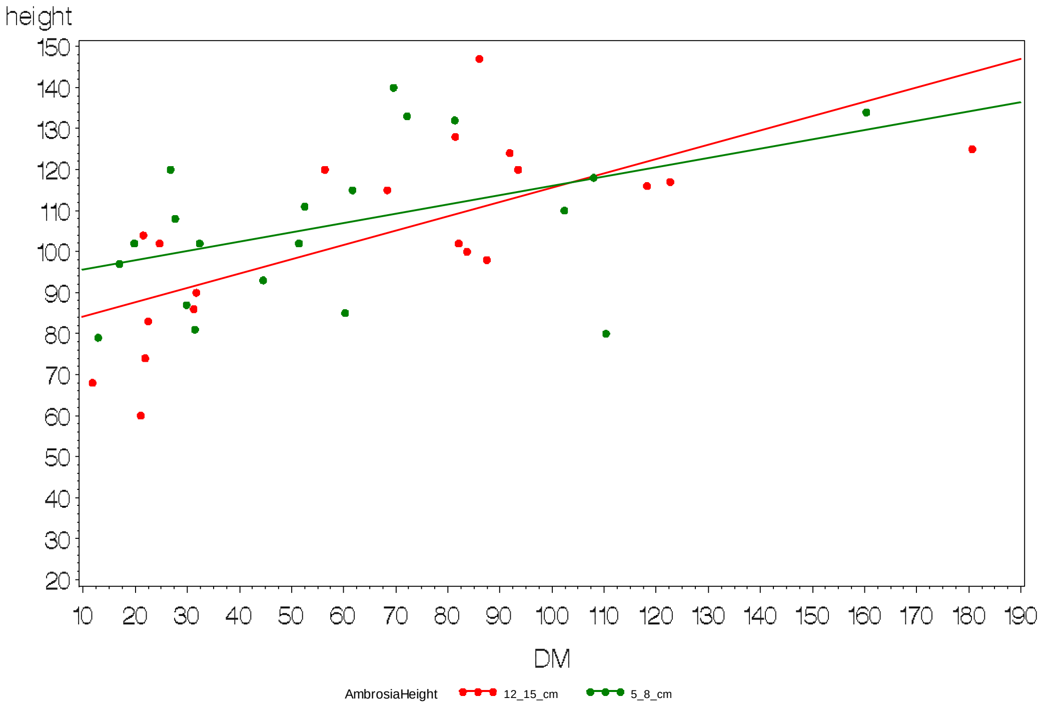


Fig. 3.25. Plant height *vs.* dry matter in untreated plots from Flakkebjerg

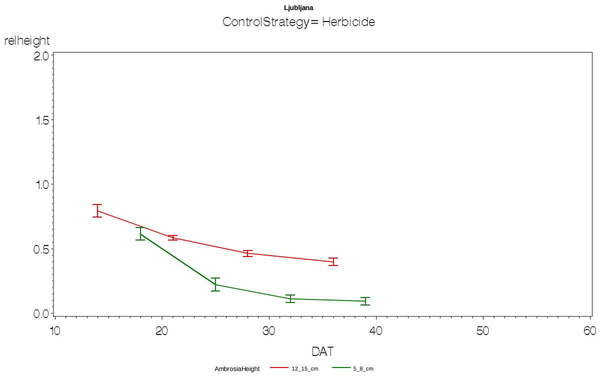
The experiment in Denmark was not hand-weeded which influenced the biomass of ambrosia from the untreated plots. Therefore the conclusions cannot be compared to the results from the other experiments. Furthermore, only two measurements was conducted through the growing season.

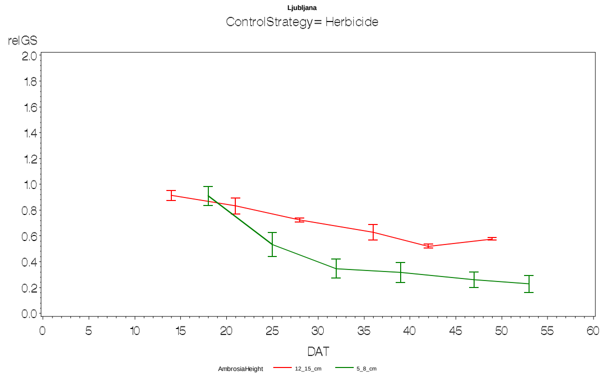
The results from Flakkebjerg show that to be able to suppress the growth of ambrosia, it is necessary to include herbicides; however, the effect was not satisfactory in any of the treatments. None of the treatments postponed the development compared to untreated, nor were there significant differences between treatments (Fig. 3.23). Dry matter was by far highest in the two mechanical control treatments (Fig. 3.24).

<u>Ljubljana</u>

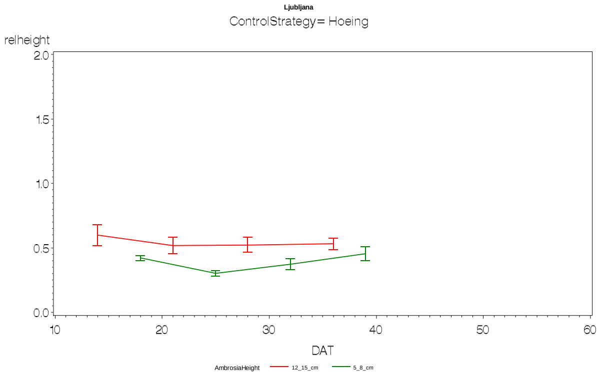
Plant height, cm | Growth stage (BBCH)

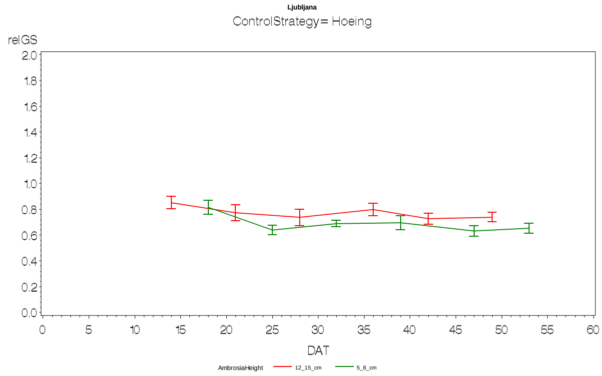
Herbicide



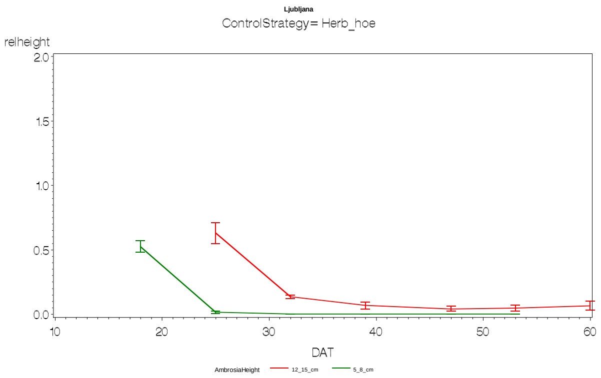


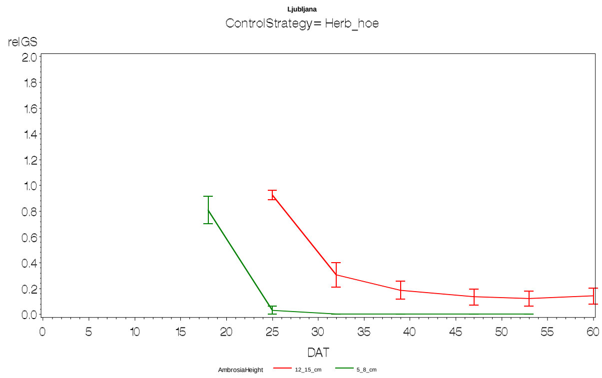
Hoeing



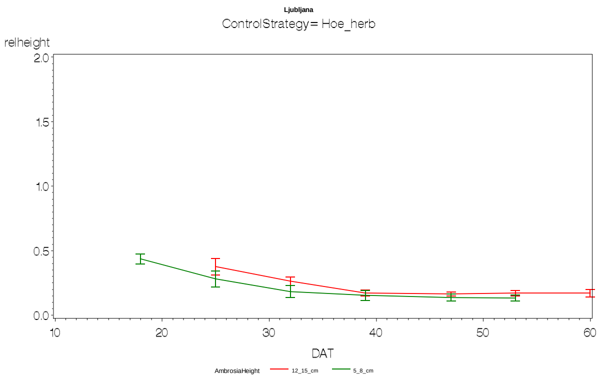


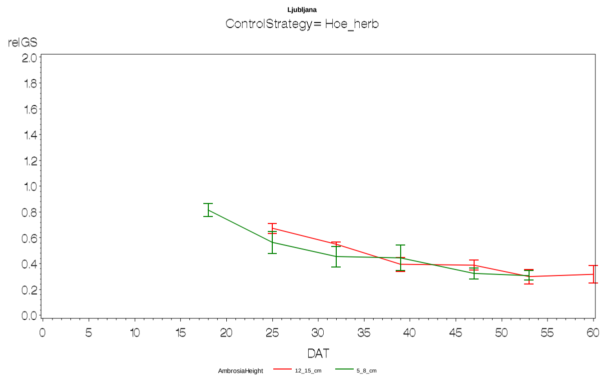
Herbicide + hoeing





Hoeing + herbicide





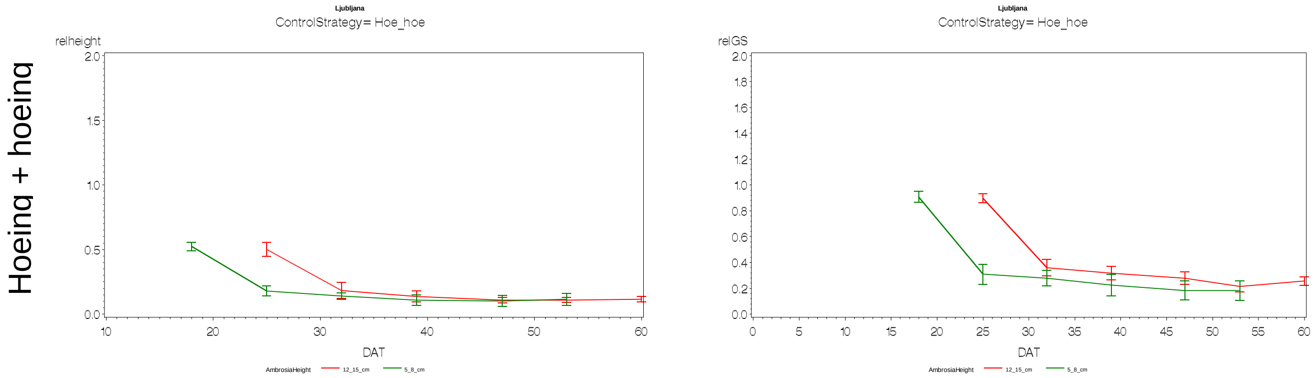


Fig. 3.26. Development in relative (in relation to untreated) maximal height, and relative growth stage *Ambrosia artemisiifolia* as a result of different chemical or mechanical weed control strategies in Ljubljana. Vertical bars indicate standard error.

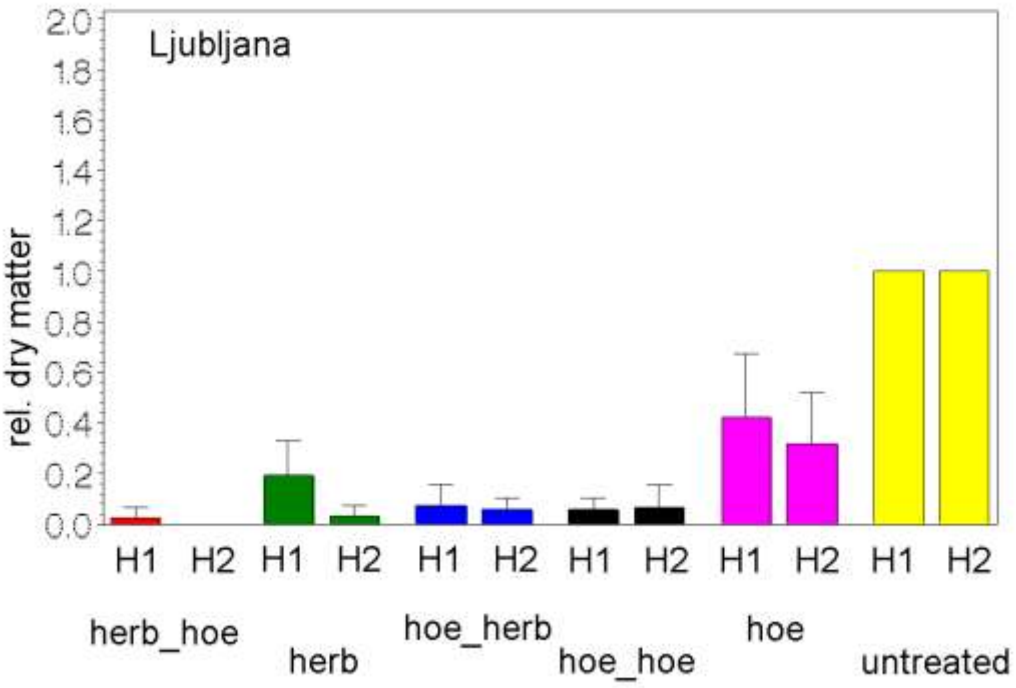


Fig. 3.27. Dry matter of *Ambrosia artemisiifolia* as a result of different chemical or mechanical weed control strategies in Ljubljana. Vertical bars indicate standard error.

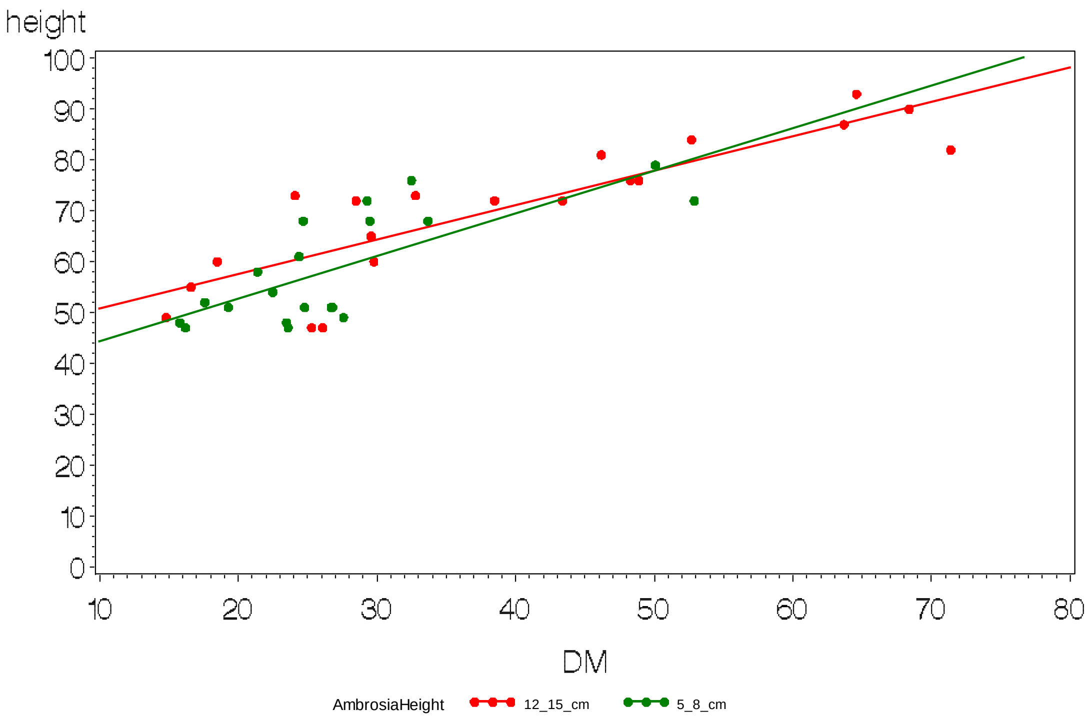


Fig. 3.28. Plant height *vs.* dry matter in untreated plots from Ljubljana.

The experiment was hand-weeded every week depending on weed emergence

In Slovenia the naturally occurring ambrosia plants were smaller (Fig. 3.28) than in Germany (Fig. 3.19) and Denmark (Fig. 3.25). In general there was a strong effect of all treatments except the single hoeing treatments at both growth stages and the herbicide treatment in the late growth stage. Surprisingly two successive hoeing events had an effect at the same level as the treatment with herbicides included.

Plant height was reduced most by the two treatments combining herbicide and hoeing (Fig. 3.26). They had a larger effect than herbicide application alone, which reduced plant height better when applied at the early growth stage. Even hoeing twice decreased plant growth. The phenological development was enhanced when treated with herbicide at the late growth stage and by a single hoeing event. All other treatments were able to slow down or even stop the development. Ambrosia plants were damaged most in the treatment herbicide followed by hoeing. A single herbicide application had a strong effect as well; damage was larger when treated at the early growth stage. The combination of hoeing and herbicide and hoeing twice showed satisfactory results. A single hoeing event increased dry matter production by several times, whereas hoeing twice was as effective as hoeing and herbicide independent of the growth stage at the time of treatment. The most effective treatment in terms of dry matter reduction was the combination of initial herbicide application followed by hoeing (Fig. 3.27). Dry matter was lower than in the herbicide only treatment.

Discussion and conclusion

Variation was very high in and between the four locations. Hoeing was only effective for ambrosia control when ambrosia plants grew between the maize rows. Ambrosia plants within the rows were not affected at all. Dry matter production was reduced by herbicides at all locations while hoeing had an increasing effect on biomass in Germany, Switzerland and Slovenia. For Germany and Switzerland hoeing was not successful, irrespective of one or two treatments, neither was hoeing in combination with hoeing or herbicide. The results from Braunschweig showed that the strategy with herbicides was able to reduce the biomass of ambrosia with 95% when applied at early growth stages. Herbicide alone or herbicide early + hoeing later were the most effective treatments in all experiments. In summary, successful ambrosia control in maize fields is only possible using herbicides due to weed plants within the maize rows. Mechanical control can help to control ambrosia but cannot be used as a single control method.

3.5. Composting of seeds

The experiment failed and the results were discarded (see section 1.2.2).

4 Main conclusions

4.1. Best-bet control strategies

By Stephanie Waldispühl and Christian Bohren

4.1.1. General remarks

Ambrosia is an annual dicotyledonous plant which propagates with seeds exclusively. In agriculture it becomes quickly acquires the status of an annual noxious weed because its control is not as easy as it seems to be. Incompletely controlled plants are able to re-sprout and to produce seeds even though in smaller number.

Ambrosia has an enormous potential to multiply. This is caused by the great number of seeds produced and by their high fertility rate. In effect ambrosia behaves like an invasive plant

The strategy of reproduction by seeds that are not displaced by wind is the weak point of ambrosia. All control strategies must therefore be based on the prevention of the production of fertile ambrosia seeds.

Control strategies must respect the actual situation in the place where ambrosia has to be controlled: i) regions or localities where the invasion is starting and ii) regions or localities where the invasion of ambrosia is already advanced. In a newly invaded locality no or a very small soil seed bank of ambrosia seeds is found, while in a locality with an advanced invasion many fertile ambrosia seeds can be found in the soil seed bank.

The prevention of the production of fertile ambrosia seeds is in the long term more important than the reduction of pollen production in one growth season. It is the only way to reduce the soil seed bank. The best strategy is to prevent seed production and in parallel pollen production.

4.1.2. Herbicide treatments

All herbicide treatments used in this trial series (glyphosate, mesotrione, clopyralid, MCPP and florasulam) reduced the biomass of ambrosia. When controlling ambrosia with herbicides, treatment timing had an influence on biomass reduction. The best efficacy was obtained with one treatment early in the 4-leaf stage. ED50 was calculated for all herbicides, and three growth stages from 4 leaves to inflorescence were investigated. Glyphosate was the only herbicide for which one dose had the same effect in all growth stages. The other three herbicides had also good efficacy on ambrosia biomass, but doses had to be increased with later treatments to reach the same efficacy level.

Split applications, in which the dose is split into two passes, showed synergistic effects. Most split applications did have better effect than one single application (florasulam, MCPP and mesotrione). The dose requirement was highly dependent on growth stage at application. In a split application the lower dose, should be applied first and at an early growth stage.

In agriculture, sequential treatments could be useful in crops, such as sugar beet and maize, where it is already common to split herbicide treatments into two or more applications. If conditions were perfect for the first treatment, a second treatment could possibly be economised depending on the efficacy level of first treatment. On the other hand, if weather conditions were not perfect for a first treatment, good knowledge about sequential treatment allows achieving good efficacy with the second treatment. Sequential treatments do incur extra costs in terms of man and machinery hours.

4.1.3. Mechanical treatments

Ambrosia was observed in our trials to re-grow easily after cutting. The side sprouts thus produced grow along the soil surface and are able to produce fertile seeds although in a reduced number. Subsequent cutting can hardly reach the horizontally growing side sprouts. Hence cutting alone is in general not effective.

In row crops, hoeing is effective against ambrosia growing between the crop rows while ambrosia plants within the rows are not affected.

4.1.4. Efficacy of control measures

In fields where ambrosia occurs as an agricultural weed, herbicide treatments in crops may be sufficient to control the weed species and maintain a high yield. In crops where no herbicide with sufficient efficacy is available (e.g. sunflower, which is botanically related to ambrosia), the crop rotation must be adapted in order to reduce the soil seed bank of ambrosia.

In natural habitats, in disturbed soils and along roadsides and in other non-agricultural habitats, eradication of ambrosia populations within a clear time frame must be the goal of successful ambrosia control.

4.1.5. Competitive ability of ambrosia

Single plants of ambrosia plant were highly susceptible to competition. In a pot trial it was shown that the competitive ability of 340 barley plants per m^2 was equivalent to the efficacy of 225 g/ha of the herbicide MCPP when plant development was simultaneous, while 51 barley plants had the same effect if they emerged 10 days before ambrosia. A combination of herbicidal effect and crop competition showed a cumulative effect. Our results suggest that the invasiveness of ambrosia primarily can be attributed to the high number of produced seeds per plant..

Surrounding vegetation has a great influence on the invasiveness of ambrosia. Ambrosia plants exposed to competition do show a certain delay in their phenological development. This weakness in competition can be used for control strategies in various situations where herbicide use is not allowed. High crop or plant density can effectively reduce ambrosia plant growth, but it cannot fully prevent ambrosia seed production.

4.1.6. Best-bet strategies

In general: Prevention of fertile seed production.

Agricultural fields: Herbicides with good efficacy on ambrosia must be applied according to their label. Sequential treatments can be used to improve herbicide activity. Competitive crops can improve herbicidal performance. Organic farmers should explore the low competitiveness of ambrosia for better control.

Construction sites: Disturbed soil in construction sites is a good habitat for ambrosia. A dense cover of vegetation can significantly reduce growth – and therefore production of fertile seeds – of ambrosia plants.

Roadsides: Vegetation along road sides must be cut in early summer for traffic security. In case of ambrosia abundance, infested zones should be treated subsequently with a herbicide to achieve best control effects on re-growing plants.

Gardens and parks: A dense vegetation cover slows down ambrosia infestation effectively. Single plant stands should be uprooted and destroyed completely before flowering.

Natural habitats: Disturbed soil should immediately be covered by a dense population of native plants in case of an advanced infestation. Single plant stands in areas where infestation is beginning, should be uprooted and completely destroyed. If ambrosia is growing in competition with other plants, mowing can be tried as a control method.

4.2. Communication to stakeholders

By Niels Holst

An illustrated brochure with suggested practical guidelines for ambrosia control were prepared in several languages (Danish, English, French, German and Slovene) and are available in the PDF files appended to this report.

These guidelines pull together existing knowledge on ambrosia and in addition express the main conclusions of this project, not in dry academic prose, but in practical and even local language. Thus we hope to facilitate swift accommodation and implementation all over Europe of guidelines for ambrosia control and prevention, according to national policies and priorities and guided by scientific knowledge.

4.3. Perspectives

By Niels Holst

The project was successful in establishing an informal network of researchers working with invasive weeds. This network will be kept alive in the short run through the writing of the planned papers and in the longer run through the newly formed International Ragweed Society.

4.3.1. Scientific journal papers

Effect of five herbicides on *Ambrosia artemisiifolia* growth and development. Solveig K. Mathiassen *et al*. – Based on results without crop, green house and field trials. Contact: solvejgk.mathiassen@agrsci.dk.

Combined effect herbicide and crop competition on *Ambrosia artemisiifolia* growth and development. Preben K. Hansen *et al*. – Based on results with crop, green house and field trials. Contact: prebenk.hansen@agrsci.dk.

4.3.2. Conference papers

Effect of herbicide and cutting on *Ambrosia artemisiifolia* growing in gravel or grass. Birte Wassmuth *et al*. EWRS Symposium, Hungary, July 2010 – Based on field trials.

Strategies for *Ambrosia artemisiifolia* control in Europe. Niels Holst *et al*. Neobiota, September 2010, Denmark. – Synthesis of this project.

4.3.3. International collaboration

Formation of International Ragweed Society, first assembly 6 December 2009 in Switzerland, orchestrated by Christian Bohren.

Presentation of the project and its achievements at the CABI workshops in Delemont, Switzerland, 7-8 December 2009.

5 Literature cited

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D'AMATO G, CECCHI L, BONINI S et al. (2007) Allergenic pollen and pollen allergy in Europe. *Allergy* 62, 976-990.

BOHREN C, MERMILLOD G & DELABAYS N (2008) *Ambrosia artemisiifolia* L. - Control measures and their effects on its capacity of reproduction. *Journal of Plant Diseases and Protection, Special Issue* 21, Special Issue XXI, 311-316.

DEEN W, HUNT LA & SWANTON CJ (1998a) Photothermal time describes common ragweed (*Ambrosia artemisiifolia* L.) phenological development and growth. *Weed Science* 46, 561-568.

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– For an extensive bibliography, please see the separate National Guidelines document.