

Technical Annex

Scientific description of the project

Title: Effective control of perennial weeds and intra-row weeds in organic cropping through novel technology and new management strategies

Acronym: WEEDS

Duration: 5 years From: Jan 2007 to: Dec 2011

Participating scientists:

Senior scientist, **Bo Melander (BME)**, Department of Integrated Pest Management (DIPM), Danish Institute of Agricultural Sciences (DIAS)

Senior scientist, **Niels Holst (NHO)**, DIPM-DIAS

Senior scientist, **Ilse A. Rasmussen (IAR)**, DIPM-DIAS

Research director, **Svend Christensen (SCH)**, Department of Agricultural Engineering (DAE), DIAS

Senior scientist, **Henning Tangen Søgaard (HTS)**, DAE-DIAS

Scientist, **Erik Fløjgård Kristensen (EFK)**, DAE-DIAS

Research assistant, **Michael Nørremark (MINO)**, DAE-DIAS

Scientist, **Rasmus N. Jørgensen (RJO)**, DAE-DIAS

Senior scientist, **Claus G. Sørensen (CGS)**, DAE-DIAS

Senior scientist, **Kristian Kristensen (KKR)**, Department of Genetics and Biotechnology (DGB), DIAS

Professor, **Jens Carl Streibig (JCS)**, Department of Agricultural Sciences (DAS), The Royal Veterinary and Agricultural University (KVL)

Associate professor, **Jesper Rasmussen (JER)**, DAS, Section for Environment, Resources and Technology, KVL

Associate Professor **Hans-Werner Griepentrog (HWG)**, DAS, Section for Environment, Resources and Technology, KVL

National consultant, **Inger Bertelsen (IBE)**, the Danish Agricultural Advisory Service (DAAS), National Centre, Crop Production

English summary (1 page, suitable for publication):

Currently two major weed problems put severe constraints on organic crop production in Denmark: (i) perennial weeds, most notably *Elymus repens* (L.) Gould, *Cirsium arvense* L. Scop, *Rumex crispus* L. and *Tussilago farfara* L., causing problems in various crops and crop rotations, and (ii) annual intra-row weeds entailing laborious hand-weeding, especially in vegetable rows.

Perennials are traditionally controlled by repeated and prolonged stubble cultivation in late summer and autumn but this strategy conflicts with the objective in organic farming to retain nutrients in the upper soil layer by keeping the soil plant-covered during autumn and winter. In a DARCOF II project just finished, effective control of *C. arvense* was obtained without disturbing the plant cover but treatment intensity was high and not immediately acceptable for organic growers. It was concluded that further research should focus on strategies involving fewer and timelier treatments based on a better understanding of the carbohydrate source/sink dynamics in regenerative roots in response to growth disturbances. In this proposal we will seek to gain a better understanding of the source/sink allocation pattern to optimize tillage and cutting regimes. The work will include both *C. arvense* and *T. farfara* and

also provide other essential information, currently missing to plan proper management strategies: (i) vulnerability to intensity and timing of root/rhizome fragmentation, desiccation and subsequent burial; (ii) the effect of treatments on the fragmentation and distribution of roots/rhizomes in the soil and proliferation potential. The research will be undertaken under controlled conditions in growth chambers and glasshouses and subsequently validated and further modified under semifield and field conditions to identify the most prospective strategies to control the two species.

The work on perennials also includes *E. repens* and *R. crispus* L. but with an entirely different approach. Owing to the rather superficial placement of rhizomes and rootstocks, research will concentrate on the development of novel technology for effective uprooting, exposing and destroying of rhizomes and rootstocks within a short time span. Such technology will meet the key objective of quick and cost-effective *E. repens* and *R. crispus* control, while having the soil plant covered over most of the year. The work includes an iterative development of appropriate tools followed by field validation of functionality and biological effects. Finally, a prototype implement will be used for validation of the new technology in a wider organic cropping system context.

Methods for controlling intra-row weeds have been studied in previous DARCOF-funded projects. However, finding a solution for effective and selective intra-row weed management, which confidently reduces the need for hand-weeding, remains a challenge in organic farming. Several research institutes have studied different advanced technologies for intra-row weeding, some of which have potential for integration into an intelligent system for arable intra-row weed control. In this project, research will be directed towards an integration of knowledge on the biological environment, cultivation tactics, implements, perception, robotic technology and seeding technology into a system capable of unmanned and selective weeding under field conditions in a given growing system. Technical progress will be evaluated iteratively during the project, in terms of weeding effectiveness and reliability under field conditions.

To gain a better understanding of the perspectives for weed management in organic cropping, the results obtained in the project will be included in an ongoing modelling effort to describe the long-term weed population dynamics in organic and conventional crop rotations. Modelling will be used in the project as a tool to integrate knowledge from literature in combination with new results, as they are generated in the project. The model will serve to organize the work packages into a coherent whole, ensuring a common standard that will make results applicable across the project and also be for the benefit of the end-users by providing an analytical tool to formulate integrated weed management strategies.

A.0 Introduction, state of the art and objectives of the project (max. 3 pages):

1. Introduction

The difficulty of solving a weed problem depends on the weed and crop species and the cropping system, e.g. stockless or dairy farming, crop rotation, use of catch crops, fertility level etc. (Rasmussen, Askegaard, and Olesen 2005). Much progress has been achieved in the management of annual weeds in cereals and pulses with mechanical and cultural methods (e.g. Melander, Cirujeda, and Jørgensen 2003; Rasmussen 2004; Melander, Rasmussen, and Barberi 2005), enhancement of crop competitiveness (Hansen 2002; Rasmussen 2002), and proper choice of cropping sequence (e.g. Melander and Rasmussen 2000; Barberi 2002). In row crops, research has focused on replacing laborious hand weeding of intra-row weeds with mechanization (Melander, Rasmussen, and Barberi 2005). Yet, in organic farming, serious weed problems remain unsolved: perennial weeds, notably *Cirsium arvense* (L.) Scop., *Elymus repens* (L.) Gould, *Rumex crispus* L. and *Tussilago Farfara* L., are an increasing problem, and in row crops especially annual intra-row weeds put severe constraints on the production.

In this project we combine research on weed biology with the development of novel technology to develop new and effective weed control strategies. We apply mathematical modelling to generalise our research findings into a wider context, especially the long-term effects of different weed management strategies in various crop rotations.

2. State of the art

4.1 CONTROL OF PERENNIAL WEEDS WITH PROPAGULES IN DEEP SOIL LAYERS

Surveys in Finland and Germany showed that *C. arvensis* is one of the most widespread perennial weeds in organic farming (Salonen, Hyvonen, and Jalli 2001; Verschwele and Häusler 2004), which is in accordance with the Danish situation, although not scientifically verified. In Denmark, *T. farfara* and *R. crispus* are increasing problems on organic farms, according to the organic grower's extension service. *Elymus repens* is considered to be as widespread as *C. arvensis*, but while *E. repens* is a rhizomatous species that proliferates only in the plough layer, *C. arvensis* and *T. farfara* both have regenerative roots or rhizomes in the deeper layers, which excludes control by uprooting. *Rumex crispus* proliferates mainly from rootstocks and seeds (Zaller, 2004).

New strategies to manage field populations of *C. arvensis* were investigated in *Management of perennial weed species in organic farming* (DARCOF II). Repeated hoeing in red clover or repeated mowing in grass-clover during early summer reduced *C. arvensis* population density considerably within the same and subsequent season (Graglia et al. 2004; Graglia, Melander, and Jensen 2005; Graglia and Melander 2005). However, the required intensity of treatment limits the practical applicability of these strategies. Fewer and better-timed treatments could be more effective and less costly, based on a better understanding of the carbohydrate source/sink dynamics in response to growth disturbances.

While the physiological development and the allocation pattern (among shoots and roots) of *C. arvensis* are well described (e.g. Welton, Morris, and Hartzler 1929; McAllister and Haderlie 1985; Tworkoski 1992), studies on the effect of growth disturbance (Ang et al. 1994; Gustavsson 1997), and the source/sink dynamics (Cyr, Bewley, and Dumbroff 1990) are scarce. The biology of *T. farfara* is well described under conditions of undisturbed growth (Otzen and Koridon 1970; Ogden 1974) but research on physical management strategies for this species is missing. Thus, more detailed information on the source/sink allocation pattern in response to disturbance is needed for both species to optimise tillage and cutting regimes. Other information missing to plan proper management for these weed species includes (i) their vulnerability to intensity and timing of root/rhizome fragmentation, desiccation and subsequent burial; (ii) the effect of treatments on the fragmentation and distribution of roots/rhizomes in the soil, and (iii) proliferation potential. A model could incorporate all this information to time optimally the disturbance treatments.

Cutting or mowing of *C. arvensis* in the crop, or cultivation of uncropped soil, is aimed at reducing *C. arvensis* production of photoassimilates, thus emptying its carbohydrate reserves in the roots. Repeated soil cultivation in autumn has been attempted to control *C. arvensis* and other perennials, and considerable control can be achieved (Häusler, Verschwele, and Zwerger 2004) but there is a poor understanding of the mechanisms behind the positive effects and how and when they occur. This strategy also conflicts with the objective in organic farming to retain nutrients in the upper soil layer by keeping the soil plant-covered during autumn and winter (Rasmussen, Askegaard, and Olesen 2005). Thus late summer/early autumn tillage of short duration followed by catch crop growing could be part of a new management strategy. This strategy has been attempted with limited success to control *E. repens* in DARCOF II. However, the hypothesis is that intensive and prolonged soil cultivation without catch crop growing releases nutrients to deeper soil layers, whereby species such as *C. arvensis* with roots in the deeper soil layers subsequently will be favoured relatively to a newly established crop with premature root penetration.

4.2 EXPOSURE AND DESTRUCTION OF *ELYMUS REPENS* RHIZOMES AND *RUMEX CRISPUS* ROOTSTOCKS

The traditional strategy of repeated stubble cultivation to control *E. repens* evolved from the basic studies in the 1960's on *E. repens* rhizome growth in response to mechanical disintegration, uprooting, desiccation and subsequent burial (e.g. Håkansson 1967; 1969a). However, the efficacy depends strongly on weather (Permin 1973). In organic farming, intensive and prolonged post-harvest tillage is often avoided because of the preference to keep the soil plant-covered. Alternatively, a competitive catch crop could be sown immediately after a few initial stubble cultivations. This strategy was investigated in the recent project *Management of perennial weed species in organic farming* (DARCOF II). However, the effect was small and the strategy would only be relevant at low infestation levels (Melander, Rasmussen, and Bertelsen 2004).

To meet the need for plant cover during the post-harvest period, we suggest an innovative approach: effective uprooting, exposing and destroying of the rhizomes within a short time span using

new machinery developed for this purpose. Melander (unpubl. data) found that only half of the rhizome biomass in the soil was exposed on the soil surface, using 1-2 passes on a sandy soil with the currently most promising implements. But previously Permin (1973) obtained much better rhizome exposure, and with new tool designs an even more effective uprooting seems achievable, considering the predominant placement of the rhizomes in the top 5-15 cm soil layer (Håkansson 1969b). Exposing the rhizomes will not necessarily kill them in the humid autumn climate of Scandinavia, and a strategy aimed at exhausting the rhizomes by repeated cultivation, stimulating rhizome buds to sprout repeatedly, is costly and with erratic effect. Mechanic removal of rhizomes from the field (up to 8 tons per ha, Thomsen, pers. comm.) seems not feasible. However, physical destruction quickly after exposure appears possible, and research should look at the practical use and efficiency of different methods of rhizome destruction, e.g. hot water, flaming, steaming, mechanical crushing and high voltage (Bond and Grundy 2001).

Rumex crispus control is most effective when rootstocks are manually uprooted and removed from the field (Dierauer & Stöppel-Zimmer, 1994; Zaller, 2004). However, there is a need to rationalise uprooting and removal of rootstocks and therefore the technology developed for *E. repens* should also include capabilities to control *R. crispus* rootstocks.

4.3 FIELD MACHINERY FOR AUTOMATIC INTRA-ROW WEEDING IN ROW CROPS

Research on precise inter-row weeding (Pullen and Cowell 1997; Tillett, Hague, and Miles 2002; Wiltshire, Tillett, and Hague 2003) has resulted in commercially available solutions. Effective intra-row weed management, however, remains a challenge in organic farming where hand-weeding is often required to obtain sufficient control (Melander and Rasmussen 2001; Melander, Rasmussen, and Barberi 2005). This challenge applies to most other non-chemical methods studied (Nørremark and Griepentrog 2004), e.g. tillage tactics (Jensen 1995; Melander 1998; Melander and Rasmussen 2000), punch planting (Rasmussen 2003) and flaming (Holmøy and Storeheier 1993; Ascard 1995). Soil steaming was investigated in a DARCOF II-funded project and has proven highly effective against weed seeds (Melander, Heisel, and Jørgensen 2002; Melander and Jørgensen 2005). This method is accepted for organic farming but is still controversial due to its impact on soil organisms and high energy demand.

The basis for intelligent field machinery that effectively detects and destroys intra-row weeds is (i) perception of the local environment in the row, (ii) effective means for weed destruction and (iii) proper timing of treatments in relation to crop, weed and growing system. Researchers have investigated the use of computer vision for discriminating weeds and crop (Søgaard and Heisel 2002a; 2002b). To promote practical use of such systems, all *a priori* knowledge of crop topology must be incorporated into a computer vision solution that is fast, precise and reliable. Given precise local information about weeds and crops, an implement (e.g. a laser, a thermal or mechanical device) must deliver a treatment targeted at the weeds. Such intelligent systems require precise localization of the implement relative to the rows. Technology has therefore been investigated that will allow long-term automatic field operations (e.g. Bontsema et al. 1998; Blasco et al. 2002; Bak and Jakobsen 2004; Blackmore et al. 2004). Analyses based on robotic-weeding cases (Garcia-Alegre et al. 2001; Blackmore et al. 2002) indicate that even in the worst case the technology would be profitable (Sørensen, Madsen, and Jacobsen 2005), providing an accuracy that would allow intra-row weeding. Efficient operation of a robotic vehicle in a semi-structured agricultural domain requires vehicle intelligence and behaviour that ensure long-term accuracy and reliability of the system (Blackmore et al. 2004; Arkin 1990). The challenge in this project is to integrate knowledge of the biological environment, implements, perception, and robotic technology into a system capable of unmanned and selective weeding under field conditions in a given growing system.

4.4 DECREASING AND DELAYING WEED EMERGENCE IN ROW CROPS

Seedbed preparation, sowing date and sowing technique all have impacts on weed emergence. The “stale seedbed” strategy (Melander 1998; Caldwell and Mohler 2001), reduced soil disturbance in the seedbed preparation process (Jensen 1999) and sowing with a minimum soil disturbance (Eriksen 1999; Rasmussen 2003) have been shown to reduce weed emergence in row crops significantly. “Punch planting” and “stale seedbed preparation” are potential tools for weed management in organic farming. In

punch planting, a hole is punched into the soil with a dibber, and the seed is dropped into it minimal disruption to the surface. Punch planting requires no preceding seedbed preparation, and it has been shown to improve crop emergence and emergence speed because the seeds are distributed uniformly within the rows and at a uniform depth, and because the soil structure is less disturbed (Finch-Savage *et al.* 1991; Brown *et al.* 1994; Gray *et al.* 1995; Miles and Read 1999). It has also recently been shown that punch planting significantly reduces weed emergence in row crops (Rasmussen 2003). We propose to improve existing prototypes of punch planters that we will obtain from our collaboration partners in Germany, to develop seeding strategies that reduce and delay emergence of annual weeds. We will also develop the “stale seedbed” technique, in which sowing is delayed after tillage and weeds that emerge are then destroyed with minor soil disturbance before crop planting (Mohler 2001). The combination of punch planting and the stale seedbed is expected to be able to reduce weed emergence by more than 50% and to improve the efficiency of existing intra-row control methods and future methods based on automation. The robotic machinery developed in 4.3 will be studied in combination with stale seedbed and punch planting strategies.

4.5 WEED POPULATION DYNAMICS MODELLING

Modelling will be used in the project as a tool to integrate knowledge from literature in combination with new results, as they are generated in the project. Weed population dynamics have been modelled more commonly for annual than for perennial species (Cousens and Mortimer 1995), perhaps because of the complexity introduced by the dynamic carbohydrate reserves of perennials. In this project we will extend a simulation model that we are working on in two current projects: *Crop protection in non-inversion tillage systems, DFFE, 2002-06* and *Herbicide-tolerant GM crops, Danish Environmental Protection Agency, 2004-07*. The simulation model includes currently the processes of (i) seed survival, (ii) seed placement in soil after tillage, (iii) seed germination with respect to placement in soil, time of year and tillage, (iv) weed development in response to crop competitiveness, (v) seed production of the weeds, and (vi) direct and indirect effects of control measures (Rasmussen *et al.* 2002; Rasmussen and Holst 2003). For *C. arvensis* a full photosynthetic and carbohydrate allocation component will be included early 2006.

To complete the model for the proposed project, some components must be added: (i) one new species, *T. farfara*, (ii) the mechanism of re-growth after cutting or tillage, and (iii) effect of novel technology for intra-row weeding. The model will serve to organize the work packages into a coherent whole, ensuring common standards that will make results applicable across the project and also be for the benefit of the end-users by providing an analytical tool to formulate integrated weed management strategies.

3. Long-term objective

Knowledge on how to manage perennial and intra-row weeds effectively by means of novel strategies and technology is available to organic farmers.

4. Project objectives

1. Effective management strategies for *C. arvensis* and *T. farfara*, involving both preventive and direct control measures, have been developed and communicated to organic farmers.
2. Novel technology for exposing and destructing *E. repens* rhizomes and *R. crispus* rootstocks has been developed and for *E. repens* validated in an organic cropping system context.
3. Weeding robot that operates in vegetable crops and physically destroys weeds in the rows has been developed.
4. Punch planting techniques and its strategic use with stale seedbed and physical intra-row weeding has been developed and validated in close collaboration with objective 3.

5. Strategies for the integrated control of two perennial species (*C. arvensis*, *T. farfara*) and major annual weed species have been formulated, based on a weed population dynamics model, and communicated to organic farmers.

A.1 Technical content of the research activity

Organisation

The project is divided into five work packages corresponding to the five project objectives (A.0). Knowledge about perennial weed biology and better management strategies are generated by WP1, while novel technology is developed in WP2 for *E. repens* and *R. crispus* control, and in WP3 and WP4 for intra-row weed control. Results are integrated and shared among the work packages through the simulation model developed in WP5. In addition to the work packages, a cluster of common tasks is defined to gather common outputs: project home page, annual and final reports, and communication to farmers. A PhD position will be announced to carry out the major part of WP1-Task 1. A statistician is engaged in the project to ensure proper planning of experiments and analysis of results.

Management

The project will be managed by the project manager, who will ensure that formal rules for bookkeeping and project reporting are kept. Each work package is headed by a Senior Scientist.

Coordination

A project meeting will be held in January each year with participation of scientists and technicians from all work packages plus the consultant from the Danish Agricultural Advisory Service engaged in the project. The output of the meeting will be detailed research and dissemination plans for each work package in the coming year, according to the projected milestones and deliverables. Dissemination plans include scientific papers, presentations at national and international workshops and conferences, popular papers and demonstrations. Any needed adjustments of budgets and plans are discussed. The project home page will aid in coordination among the geographically spread project partners.

Work plan

The project structure diagram (next page) depicts all work packages and tasks. Arrows show necessary flow of information, as described in the text for each work package. Each arrow is represented as one or more arrows in the project timetable (next page again), where the timing and dependency on milestones and deliverables can be seen.

The project timetable shows the time line of all work packages and tasks, including milestones and deliverables. During project execution the timetable will be revised as needed, the current approved version always being accessible on the project home page.

Work Package list

WP No.	WP title	Responsible scientist	Budget DKK	Start	End	Deliverable No.
1	Effective management strategies for <i>Cirsium arvense</i> and <i>Tussilago farfara</i>	Ilse A. Rasmussen	3,523,636	Jan – 2007	Dec – 2011	D1.1-D1.5
2	Exposure and destruction of <i>Elymus repens</i> rhizomes	Bo Melander	2,144,967	Jan – 2007	Dec – 2011	D2.1-D2.4
3	Field machinery for automatic intra-row weeding in row crops	Svend Christensen	4,125,439	Jan – 2007	Jun – 2011	D3.1-D3.12
4.	Decreasing and delaying weed emergence in row crops	Jesper Rasmussen	1,250,088	Jan – 2007	Dec- 2010	D4.1-D4.3
5	Weed population dynamics model	Niels Holst	797,870	Jan – 2007	Dec – 2011	D5.1-D5.3
Co.	Cluster of common tasks	Bo Melander	158,000	Jan - 2007	Dec - 2011	D.Co.1-D.Co.11
Total			12,000,000			

Project structure

Work plan

Deliverables list

Deliverable No	Deliverable title	Lead scientist	Delivery date	Allocated scientific person months	Type of deliverable
D1.1	Three scientific papers on <i>C. arvensis</i> and <i>T. farfara</i> source-sink dynamics under controlled conditions.	JCS	Dec-09	18	S
D1.2	Ph.D. thesis on <i>C. arvensis</i> and <i>T. farfara</i> source-sink dynamics under controlled conditions.	JCS	Dec-09	18	S
D1.3	Scientific paper on <i>C. arvensis</i> and <i>T. farfara</i> source-sink dynamics under field conditions.	IAR	Dec-09	5	S
D1.4	Scientific paper on <i>C. arvensis</i> and <i>T. farfara</i> preventive control: catch crop and stubble cultivation.	IAR	Jul-10	5.5	S
D1.5	Scientific paper on <i>C. arvensis</i> and <i>T. farfara</i> direct control between-crops	IAR	Nov-11	5.5	S
D2.1	Report on technology for exposing and destroying rhizomes and rootstocks.	BME	Jan-09	3	R
D2.2	Conference paper on the technology for exposing and destroying rhizomes and rootstocks, and its effects on rhizome and rootstock viability and growth.	EFK	Jun-09	4	P
D2.3	Public demonstration of the new technology for rhizome and rootstock exposure and destruction including comparisons with common implements for <i>E. repens</i> control.	EFK	Sep-11	3	O
D2.4	Scientific paper on <i>E. repens</i> control using new technology for rhizome exposure and destruction in organic cropping.	BME	Nov-11	6.9	S
D3.1	Detailed design document - intelligent closed loop weed management implement	SCH	May-08	4.5	R
D3.2	Demonstration of mechanism for intelligent intra-row weeding	SCH	Apr-09	3.5	O
D3.3	Scientific paper on a) weeding mechanism, b) perception using a priori topology information	SCH	Oct-09	5.0	S
D3.4	Detailed design document - augmented machine	SCH	May-08	4.5	R
D3.5	Demonstration of augmented implement carrier – in-field controlled operation	SCH	Apr-09	3.5	O
D3.6	Scientific paper on automatic machinery for autonomous row operation	SCH	Nov-09	4.5	S
D3.7	Requirements specification for implementation of the technology in future organic farming	SCH	Mar-10	4.5	R
D3.8	Model of relevant operational hybrid control	SCH	Sep-07	3.5	O

	strategies and machinery implemented				
D3.9	Detailed design document - software components supporting selected control strategies	SCH	Jun-08	4.5	R
D3.10	Demonstration of integrated Automatic intra-row weeding machinery	SCH	Aug-09	3.5	O
D3.11	Scientific papers on software components for agriculture, dissemination to European partners	SCH	Mar-10	4.5	S
D3.12	Scientific paper on weeding effectiveness and reliability of automatic intra-row weed management	BME	Feb-11	6	S
D4.1	Punch planter adjusted and ready for field experiments	JER	Jan-08	5	O
D4.2	Peer-reviewed article: punch planting in row crops	JER	Jun-10	5	S
D4.3	Peer-reviewed article: interactions between sowing and weed control methods.	JER	Sep-10	5	S
D5.1	Scientific paper on partly validated simulation model of <i>C. arvensis</i> and <i>T. farfara</i> growth and population dynamics.	NHO	May-09	3.5	S
D5.2	Scientific paper on field-validated simulation model of <i>C. arvensis</i> and <i>T. farfara</i> growth	NHO	Jul-11	3.5	S
D5.3	Best-bet control strategies communicated to organic farmers.	NHO	Nov-11	1	P,C
D.Co.1	Project home page implemented	NHO	Jan-07	1	O
D.Co.2	Annual report 2007 submitted.	BME	Sep-07	0.4	R
D.Co.3	Annual report 2008 submitted.	BME	Sep-08	0.4	R
D.Co.4	Annual report 2009 submitted.	BME	Sep-09	0.4	R
D.Co.5	Annual report 2010 submitted.	BME	Sep-10	0.4	R
D.Co.6	Annual report 2011 submitted.	BME	Sep-11	0.4	R
D.Co.7	Communication to farmers: plan for 2008 specified.	IBE	Jan-08	0.6	R,P,C
D.Co.8	Communication to farmers: plan for 2009 specified.	IBE	Jan-09	0.6	R,P,C
D.Co.9	Communication to farmers: plan for 2010 specified.	IBE	Jan-10	0.6	R,P,C
D.Co.10	Communication to farmers: plan for 2011 specified.	IBE	Jan-11	0.6	R,P,C
D.Co.11	Final report submitted.	BME	Dec-11	0.5	R

(The nature of the deliverables must be indicated by S = publication in scientific journal with peer review; P = publication in journals without peer review; R = reports; C = presentation at meetings and congresses or O = other types of deliverables, e.g., prototypes, models, websites, etc.).

Milestones list

Milestone No	Milestone title	Lead scientist	Delivery date
M1.1	Sampling programme and protocol for controlled experiments defined.	JCS	Apr-07
M1.2	Analytical method for determination of carbohydrate reserves identified.	JCS	Aug-07
M1.3	The phenology of above/below-ground source/sink dynamics of carbohydrates under controlled conditions determined for <i>C. arvense</i> and <i>T. farfara</i> , replicate 1.	JCS	Dec-07
M1.4	The timing of physical disturbances to pursue in task 2 identified.	JCS	Dec-07
M1.5	The phenology of above/below-ground source/sink dynamics of carbohydrates under controlled conditions determined for <i>C. arvense</i> and <i>T. farfara</i> , replicate 2.	JCS	Dec-08
M1.6	Sampling programme and protocol for semifield experiments on source/sink dynamics defined.	IAR	Jan-08
M1.7	The phenology of above/below-ground source/sink dynamics of carbohydrates under semifield conditions determined for <i>C. arvense</i> and <i>T. farfara</i> .	IAR	Mar-09
M1.8	Sampling programme and protocol for field test of best-bet strategies defined.	IAR	Mar-07
M1.9	Effect of \pm catch crops combined with \pm stubble cultivation determined for <i>C. arvense</i> .	IAR	Dec-09
M1.10	Effect of best-bet between-crops control determined for <i>C. arvense</i> and <i>T. farfara</i> and communicated to organic farmers	IAR	Nov-11
M2.1	Decisions made on tool design and configuration and appropriate methods for rhizome and rootstock destruction for further studies.	EFK	Mar-07
M2.2	First prototype tools for field investigation and equipment for rhizome and rootstock destruction are ready.	EFK	Aug-07
M2.3	Modification and improvements of the technology for rhizome and rootstock exposure and destruction ended.	EFK	Jul-08
M2.4	Exposing ability assessed under field conditions; first series.	BME	Sep-07
M2.5	Lethality of destructing methods assessed and quantified in the laboratory; first series.	BME	Nov-07
M2.6	Exposing ability assessed under field conditions; second series.	BME	Sep-08
M2.7	Lethality of destructing methods assessed and quantified in the laboratory; second series.	BME	Nov-08
M2.8	Technology for rhizome exposure and destruction implemented in a cropping system context.	BME	Aug-09
M2.9	Weeding effectiveness assessed under the influence of burial and catch crop growing assessed.	BME	Aug-11
M2.10	Strategies taking the new technology into account formulated and communicated to organic farmers.	BME	Oct-11
M3.1	Scenarios for intra-row weeding selected	SCH	Apr-07
M3.2	Decisions made on technology base for implement research	SCH	Jul-07
M3.3	Image set and mathematical foundation for computer vision established	SCH	Mar-08
M3.4	Mechanism for intelligent intra-row weeding demonstrated in	SCH	Feb-09

	laboratory – in field operation		
M3.5	Scenarios for automatic machine use in row crops selected	SCH	Jun-07
M3.6	Decision made on technical modifications required for commercial machine	SCH	Oct-07
M3.7	Augmented implement carrier demonstration under controlled conditions	SCH	Aug-08
M3.8	Augmented implement carrier demonstration - in-field operation	SCH	Feb-09
M3.9	Scenarios for robotic vehicle behaviours selected	SCH	Aug-07
M3.10	Software framework and components selected	SCH	Nov-07
M3.11	Software tests completed on model	SCH	Apr-08
M3.12	Software tests completed on vehicle	SCH	Aug-08
M3.13	Validation of software control strategies completed in selected scenarios	SCH	Feb-09
M3.14	Experiments with weeding effectiveness and reliability of automatic intra-row weed management completed	SCH	Sep-10
M3.15	Optimal crop planting patterns to suit yield optimisation and space requirements to make automatic intra-row weeding operational identified.	SCH	Dec-10
M4.1	Punch planter adjusted to ready for field experiments	JER	Jan-08
M4.2	Punch planting studied in field experiments ended	JER	Oct-09
M4.3	Investigations on the interactions between punch planting, physical weed control and stale seedbed strategies finalised	JER	Oct-09
M5.1	Model of <i>C. arvensis</i> undisturbed growth validated against literature (from other project).	NHO	May-07
M5.2	Model of <i>C. arvensis</i> disturbed growth developed from controlled experiment.	NHO	Dec-07
M5.3	Model of <i>T. farfara</i> growth developed from controlled experiment.	NHO	Feb-08
M5.4	Models above validated against literature.	NHO	Oct-08
M5.5	Best-bet strategies formulated by way of model.	NHO	Mar-08
M5.6	Model validated against field experiments.	NHO	Jun-10
M5.7	Model of major annual weed species validated	NHO	May-07
M5.8	Best-bet strategies fine-tuned.	NHO	Nov-09
M5.9	Strategies taking the new technology of WP3 and WP4 into account formulated by way of simulated scenarios.	NHO	Oct-10

Description of work packages (this page should be copied for each WP)

WP1. Effective management strategies for *Cirsium arvense* and *Tussilago farfara*

	Start date or starting event: January 2007								
Partner id.	DIPM-DIAS	DGB-DIAS	DAS-KVL	DAAS					
Person-months per participant	15 VIP 12 TAP	1 VIP	36 VIP	0.6 VIP					
Total PM VIP:	52.6								
Total PM:	64.6								

Main objective

Effective management strategies for *Cirsium arvense* and *Tussilago farfara*, involving both preventive and direct control measures, have been developed and communicated to organic farmers.

Task objectives

1. The phenology of above/below-ground source/sink dynamics determined under controlled conditions.
2. The phenology of above/below-ground source/sink dynamics determined under semifield conditions.
3. Best-bet control strategies tested in the field.

WP1 Description of work

The work concentrates on two perennial weed species, both with deep roots/rhizomes, 0.5 – 2 m below the ploughing layer: a rhizomatous species, *Tussilago farfara* and a species with a regenerating root system, *Cirsium arvense*. Experiments are carried out under both controlled and field conditions.

Task 1.1 Determine the phenology of above/below-ground source/sink dynamics under controlled conditions

Uniform pieces of rhizomes or roots of *T. farfara* or *C. arvense* are planted in containers either (29x39x15 cm or diam.=30cm x depth 50 cm) and raised in growth cabins and greenhouse. The manipulations in growth cabins include nitrogen and sampling times. At regular intervals, determined by growth rate, plants are sampled and biomass of roots, rhizomes, stem (below- and above-ground), leaves, leaf areas, and reproductive structures are determined. After the first five samplings, disturbance will be introduced by cutting leaves and stems. Carbohydrate reserves in rhizomes of *T. farfara* and roots of *C. arvense* are determined as is nitrogen. Due to the variation of initial propagule size analysis of covariance is required by using initial propagule data as co-variate. An experiment with two species, one factor of three levels (nitrogen), five sampling times and 3 blocks sums up to 90 entities. Consequently, incomplete block designs are necessary due to space limitation. The number of replicates within an experiment depends on the precision of measurements, e.g. carbohydrates, and will be addressed on the basis of initial analysis. The experiments will independently be replicated twice to ensure results are reproducible. The five sampling times are initially being determined by the phenology of the species, e.g. number of fully developed leaves for *C. arvense*, for *T. farfara* we have to find other criteria than leaves due to its somewhat special biology. To measure carbohydrate translocation to underground structures use of $^{14}\text{C}\text{O}_2$ or ^{14}C -sucrose is fast and inexpensive but is not applicable in this experiment, because a confined environment would be needed. The chemical analysis of carbohydrate source/sink relations (sucrose translocation to roots; fructose, glucose, and fructans in roots) is not trivial, nor is the interpretation of results, luckily complexity is simplified as the two species belong to the *Asteraceae* family, and somewhat similar fructans play an important role as underground storage.

The carbohydrates will initially be measured by HPLC (Cyr, Bewley and Dumbroff 1990). Concomitantly, we will explore the possibilities for faster and cheaper, but indirect methods of measurements such as NIR (near-infra red) being calibrated with the HPLC results. Analyses for total nitrogen will be done by an automated nitrogen analyser (Elemental analyser 1108, Carlo Erba, Milano, Italy). The output of the controlled experiments will guide the field experiments in tasks 1.2 and 1.3 by suggesting which timings of physical disturbances would have maximum effect relative to phenology and source-sink relationships. Data will be analysed statistically, published scientifically and also used as input to construct a simulation model, which will incorporate a model for the relationship between aboveground and below-ground biomass and source/sink relationship. (WP5).

Task 1.2 Determine the phenology of above/below-ground source/sink dynamics under semi-field conditions

The experiments are carried out in fields with pre-established stands of *T. farfara* or *C. arvense* but with no crops or other weeds. If needed, herbicides will be used to control other weeds. Control plots without infestation but with planted weed rhizomes/roots of a known weight will be established. Prevailing temperature, light and soil factors determine the environmental conditions, but to reduce variation, the area will be irrigated as needed. Manipulations include various physical disturbances. Growth is observed during development in terms of the samplings suggested in task 1.2. The minirhizotron technique described by Thorup-Kristensen (2001) will be used to investigate the root development and depth. Three minirhizotrones per plot will be placed in control plots into 2-2.5 m depth and the root development of *C. arvense* will be recorded several times by means of video filming until the end of the experiment. At the beginning of the growing season, in the control plots, the distribution of stems, roots and rhizomes in the soil to the ploughing depth (ca. 30 cm) will be described when plants are well established by excavating 1 m² and make soil probes of app. 80 cm². This will enable us to quantify how many such soil probes must be used to estimate root biomass. At the end of the experiment, in all plots, soil cores as above will be taken to 1 m depth and the underground weed parts will be measured as in task 1.1. The data from the two methods (minirhizotrones and soil cores) will be compared to be able to estimate the

root development below 1 m. The output will suggest new strategies for controlling the two species, both direct and preventive measures, which will be implemented in task 1.3. Data will be analysed statistically, published scientifically and also used to validate the simulation model (WP5).

Task 1.3 Test the best-bet control strategies in the field

A first series of field experiments are established on fields with dense populations of *C. arvensis* or *T. farfara* which have been characterised according to the density of the weeds the previous year. Combinations of with or without catch crop and with or without stubble cultivation are established. Effects are measured in the crop the following year. Data will be analysed statistically, published scientifically and also used to validate the simulation model (WP5).

A second series of field experiments are established on fields with dense populations of *T. farfara* or *C. arvensis* which have been characterised according to the density of the weeds the previous year. Mechanical control is carried out outside the growing season (type, depth and timing of stubble cultivation, springtime cultivation and ploughing). The experiments will focus on optimising control on the basis of knowledge from literature, earlier experimental work (i.e. DARCOF II) and results from tasks 1.1, 1.2 and 1.3. Effects are measured in the crop the following year. Data will be analysed statistically, published scientifically and also used to validate the simulation model (WP5).

Deliverables

D1.1 Dec-09. three scientific papers on *C. arvensis* and *T. farfara* source-sink dynamics under controlled conditions.

D1.2 Dec-09. Ph.D. thesis on *C. arvensis* and *T. farfara* source-sink dynamics under controlled conditions.

D1.3 Dec-09. Scientific paper on *C. arvensis* and *T. farfara* source-sink dynamics under semifield conditions.

D1.4 Jul-10. Scientific paper on *C. arvensis* and *T. farfara* preventive control: catch crop and stubble cultivation.

D1.5 Nov-11. Scientific paper on *C. arvensis* and *T. farfara* direct control between-crops

Milestones

Task 1: controlled experiments

M1.1 Apr-07 Sampling programme and protocol for controlled experiments defined.

M1.2 Aug-07 Analytical method for determination of carbohydrate reserves identified.

M1.3 Dec-07 The phenology of above/below-ground source/sink dynamics of carbohydrates under controlled conditions determined for *C. arvensis* and *T. farfara*, replicate 1.

M1.4 Dec-07 The timing of physical disturbances to pursue in task 2 identified.

M1.5 Dec-08 The phenology of above/below-ground source/sink dynamics of carbohydrates under controlled conditions determined for *C. arvensis* and *T. farfara*, replicate 2.

Task 2: semifield experiments

M1.6 Jan-08 Sampling programme and protocol for semifield experiments on source/sink dynamics defined.

M1.7 Mar-09 The phenology of above/below-ground source/sink dynamics of carbohydrates under semifield conditions determined for *C. arvensis* and *T. farfara*.

Task 3: best-bet strategies

M1.8 Mar-07 Sampling programme and protocol for field test of best-bet strategies defined.

M1.9 Dec-09 Effect of \pm catch crops combined with \pm stubble cultivation determined for *C. arvensis*.

M1.10 Nov-11 Effect of best-bet between-crops control determined for *C. arvensis* and *T. farfara* and communicated to organic farmers.

WP 2: Exposure and destruction of *Elymus repens* rhizomes and *Rumex crispus* rootstocks

	Start date or starting event: January 2007								
Partner id.	DIPM-DIAS-	DAE-DIAS	DGB-DIAS	DAAS					
Person-months per participant	9 VIP 9 TAP	7 VIP 8.5 TAP	0.9 VIP	0.6 VIP					
Total PM VIP:	17.5								
Total PM:	35.0								

Main objective
 Novel technology for exposing and destructing *Elymus repens* rhizomes and *Rumex crispus* rootstocks has been developed and validated in an organic cropping system context.

Task objectives

1. Tools for rhizome and rootstock exposure and destruction designed.
2. Novel technology for rhizome and rootstock exposure and destruction validated in the field.
3. The new technology implemented in an organic cropping system context.

WP2 Description of work

Task 2.1 Design tools for rhizome and rootstock exposure and destruction

Appropriate and promising tool designs and configurations for rhizome and rootstock exposure for further investigations and development are identified through meetings and literature review. Relevant expertise from the industry will be invited to inform and discuss about existing knowledge on stubble cultivators and other similar implements.

A 2.5 m wide test frame will be made upon which tools can be mounted for further analyses and investigations. The designing of tools will partly be based on existing non-rotating and rotating tine and blade configurations and how they can be modified to uproot and expose rootstocks and long and thread-like organs placed in 5-15 cm soil depth. Also entirely new configurations are considered, and concepts based on combinations of non-rotating and rotating tools will receive particular attention. Most of the work is undertaken in the laboratory and workshop.

Mechanical methods that crush and/or chop up rhizomes and rootstocks into very short pieces are designed and constructed for rhizome and rootstock destruction in the laboratory. Thermal methods, such as steam, flaming and hot water, and other physical methods, such as high voltages, are considered as well, and appropriate laboratory equipment for thermal destruction will be made. For all methods essential criteria, such as efficiency, applicability and energy consumption, in relation to practical field operation will be analysed before prototype equipment is constructed.

The development of exposing and destructing technology will be undertaken through an iterative analysis of prospective solutions in spring and early summer 2007 and 2008.

Task 2.2 Validate novel technology for rhizome and rootstock exposure and destruction in the field

The tools and tool combinations with most perspectives for rhizome and rootstock exposure developed in task 2.1 are investigated under field conditions. A heavy and uniform infestation of *E. repens* is established on a sandy and a loamy soil through seeding and propagation during 2006 and 2007. Field patches of *R. crispus* are used for rootstock exposure. The uprooting and exposing ability of the prototype implements are assessed and quantified by collecting rhizomes and rootstocks laid bare on the soil surface and by digging up those left behind in the soil. The collected rhizomes and rootstocks are weighed and their length measured. Common stubble cultivation implements and the commercial *E. repens* weeders “Kvik-Up” and “Kvik-Killer” will be included in the field experiments for comparison.

Fragments of rhizomes and rootstocks collected from the field are destroyed mechanically and thermally according to the methods developed in task 2.1. Germinability and early shoot growth of the treated fragments are studied in the glasshouse and compared with the growth of untreated fragments.

These growth studies will be made in early autumn 2007 and 2008.

Task 2.3 Implement the new technology against *E. repens* in an organic cropping system context

A prototype implement consisting of the most promising tools for rhizome uprooting, exposure and destruction is constructed and subsequently studied in a real organic cropping system context. A factorial block experiment is laid out on a heavily infested sandy soil. The experiment is commenced after cereal harvest in August 2008 and are preliminarily planned to include the following factors:

Factor A. Exposure/destruction (3 levels):

A.1 Untreated

A.2 Prototype implement for uprooting and destruction (will be treated again post-harvest in the subsequent year)

A.3 Prototype implement for uprooting and destruction (remains untreated the

subsequent year)

Factor B. Burial (2 levels):

B.1 No immediate burial of rhizomes following destruction/no destruction

B.2 Immediate burial of rhizomes by ploughing

Factor C. Catch crop growing (2 levels):

C.1 No catch crop growing

C.2 Catch crop growing

The experimental area is ploughed following the treatments A-C, and spring barley is grown, in which assessment of *E. repens* shoot growth will be made close to barley harvest in 2010 by cutting above-ground shoot biomass at ground level. Then the treatments under factor A-C are conducted again after barley harvest. Finally *E. repens* shoot biomass and rhizome development are assessed close to harvest the subsequent season 2011 (the third year). This gives the opportunity to quantify the effects of a single and two consecutive year's treatment with the prototype implement, and regarding the single year's treatment whether the effects are still lasting up to two years after treatment. Besides shoot biomass assessments close to harvest, *E. repens* growth is also assessed in spring in barley and during the autumn in the catch crop. Data will be analysed statistically and published scientifically.

Deliverables

- D2.1 Jan-09. Report on technology for exposing and destroying rhizomes and rootstocks.
- D2.2 Jun-09. Conference paper on the technology for exposing and destroying rhizomes and rootstocks, and its effects on rhizome and rootstock viability and growth.
- D2.3 Sep-11. Public demonstration of the new technology for rhizome and rootstock exposure and destruction including comparisons with common implements for *E. repens* control.
- D2.4 Nov-11. Scientific paper on *E. repens* control using new technology for rhizome exposure and destruction in organic cropping.

Milestones

Task 1: design

- M2.1 Mar-07. Decisions made on tool design and configuration and appropriate methods for rhizome and rootstock destruction for further studies.
- M2.2 Aug-07. First prototype tools for field investigation and equipment for rhizome and rootstock destruction are ready.
- M2.3 Jul-08. Modification and improvements of the technology for rhizome and rootstock exposure and destruction ended

Task 2: validation

- M2.4 Sep-07. Exposing ability assessed under field conditions; first series.
- M2.5 Nov-07. Lethality of destructing methods assessed and quantified in the laboratory; first series.
- M2.6 Sep-08. Exposing ability assessed under field conditions; second series.
- M2.7 Nov-08. Lethality of destructing methods assessed and quantified in the laboratory; second series.

Task 3: implementation

- M2.8 Aug-09 Technology for rhizome exposure and destruction implemented in a cropping system context.
- M2.9 Aug-11 Weeding effectiveness assessed under the influence of burial and catch crop growing assessed.
- M2.10 Oct-11 Strategies taking the new technology into account formulated and communicated to organic farmers.

WP3: Field machinery for automatic intra-row weeding in row crops

	Start date or starting event: January 2007								
Partner id.	DAE-DIAS	DIPM-DIAS	DAAS						
Person-months per participant	47 VIP 13 TAP	5 VIP 4 TAP	0.6 VIP						
Total PM VIP:	52.6								
Total PM:	69.1								

Main objective
Weeding robot that operates in vegetable crops and physically destroys weeds in the rows has been developed.

Task objectives

1. Intra-row weed detect-and-destroy implement developed and validated under controlled conditions.
2. Automatic field carrier for the intra-row weed detect-and-destroy implement constructed.
3. Intelligent autonomous behaviour of the carrier and implement developed and embedded.
4. Weeding effectiveness and reliability in relation to various weed management scenarios evaluated.

Description of work

The success of previous intra-row automatic weed management strategies applied to practical agriculture has been limited and there is a need to investigate new more robust and efficient solutions. Solutions that build on existing solid mechanical frameworks and augments these with new advanced perception, intelligence and weed control action. Results from previous projects provide a good basis for these investigations and input from WP1 allows a new focus on the biological effects and potential of new weed management strategies for perennial weeds. The result is novel robust technology that supports automatic intra-row weeding. The technology is interpreted in a broader, crop rotation context in WP 4.

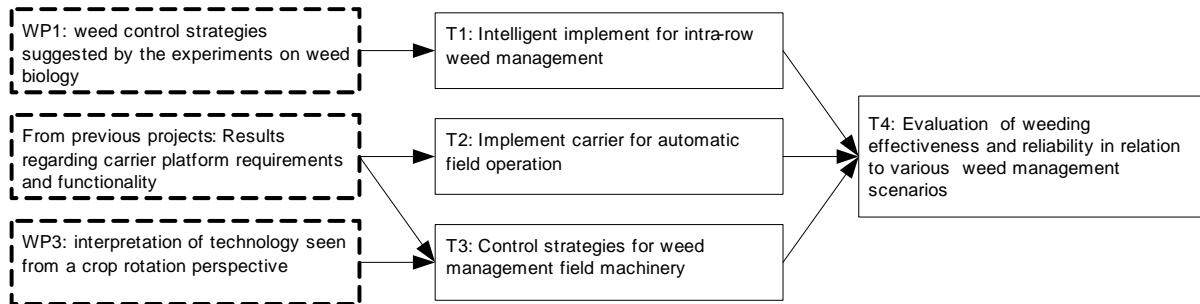


Figure. Broken-line boxes: Inputs from work packages and other sources. Full-line boxes: Outputs resulting from this work package. Arrows: Flow of information.

Task 3.1 Develop and validate intra-row weed detect-and-destroy implement under controlled conditions

Based on previous work with physical intra-row weed control and input from WP1, a requirement specification for an automatic intra-row weeding mechanism will be developed, with emphasis on applicability. To facilitate intra-row operation an intelligent closed loop implement will be designed. An intelligent system allows the weed management input to be optimised using local perceptive feedback (vision). The research will extend existing state-of-the art computer vision (Søgaard and Heisel 2002) to the practical application domain by utilizing a priori topological information in a novel algorithm that estimates crop and weed locations with high efficiency. The resulting design will be validated under controlled conditions and the result will be a mechanism with embedded intelligence and perception that will be integrated with the machinery from task 2 and demonstrated and evaluated in task 4.

Task 3.2 Construct automatic field carrier for the intra-row weed detect-and-destroy implement

Results from previous projects (API, Robotic Weeding, AgroBotics) provide the background for establishing a requirement specification for an implement carrier for automatic field operation. To support a practical application, the development will build on an existing commercial mechanical framework proven in the outdoor domain. New technological extensions to the existing framework will result in a design that support automatic field operation, and provide a mechanical and electrical infrastructure for the intelligent implement from task 1 and the control strategies in task 3. The resulting augmented implement carrier will be validated under controlled conditions and the result will be demonstrated and evaluated in task 4.

Task 3.3 Develop and embed intelligent autonomous behaviour of the carrier and implement

The implement carrier in task 2 provides the infrastructure for field operation and task 1 provides a novel intelligent implement system. To support automatic behaviour, relevant operational control strategies will be analysed and documented. The research will focus on reactive robotic behaviours for operation in a semi-structured environment with row crops. Hybrid software components will be developed that support intelligent autonomous behaviour of the machine and implement being investigated. Focus will be on robust, autonomous operation with minimal operational oversight from an operator. The result is autonomous weed management field machinery that is evaluated in task 4.

Task 3.4 Evaluate weeding effectiveness and reliability in relation to various weed management scenarios

Whenever operational, technical progresses are constantly evaluated for weeding effectiveness and reli-

ability. Field experiments will be established with row crops having different leaf sizes and morphology. Weeding operations are considered to reflect the need for weed control as well as the obstacles that may occur under practical agricultural conditions. This will include aspects such as effectiveness according to weed species and weed size and density manipulated through stale seedbed techniques and punch planting (WP4), crop size and visibility for automatic detection, appropriate planting patterns to integrate crop yield optimisation with spatial requirements for operating field machinery. Apart from assessing the biological effects on weeds, crop injuries caused by automatic intra-weeding will be assessed in terms of crop growth and marketable yield and quality. Finally, the agronomic perspectives of implementing machinery for automatic intra-row weed control are elucidated, and the best future strategies will be formulated and communicated to organic farmers.

Deliverables

Task 1: detect and destroy

D3.1 May-08. Detailed design document - intelligent closed loop weed management implement

D3.2 Apr-09. Demonstration of mechanism for intelligent intra-row weeding

D3.3 Oct-09. Scientific paper on perception using a priori topology information

Task 2: field carrier

D3.4 May-08. Detailed design document - augmented machine

D3.5 Apr-09. Demonstration of augmented implement carrier – in-field controlled operation

D3.6 Nov-09. Scientific paper on automatic machinery for autonomous row operation

D3.7 Mar-10. Requirements specification for implementation of the technology in future organic farming

Task 3: intelligent behaviour

D3.8 Oct-07. Model of relevant operational hybrid control strategies and machinery implemented

D3.9 Jun-08. Detailed design document - software components supporting selected control strategies

D3.10 Aug-09. Demonstration of integrated Automatic intra-row weeding machinery

D3.11 Mar-10. Scientific papers on software components for agriculture, dissemination to European partners

Task 4: evaluation

D3.12 Feb-11. Scientific paper on weeding effectiveness and reliability of automatic intra-row weed management

Milestones:

Task 1: detect and destroy

M3.1 Apr-07. Scenarios for intra-row weeding selected

M3.2 Jul-07. Decisions made on technology base for implement research

M3.3 Mar-08. Image set and mathematical foundation for computer vision established

M3.4 Feb-09. Mechanism for intelligent intra-row weeding demonstrated in laboratory – in field operation

Task 2: field carrier

M3.5 Jun-07. Scenarios for automatic machine use in row crops selected

M3.6 Oct-07. Decision made on technical modifications required for commercial machine

M3.7 Aug-08. Augmented implement carrier demonstration under controlled conditions

M3.8 Feb-09. Augmented implement carrier demonstration - in-field operation

Task 3: intelligent behaviour

M3.9 Aug-07. Scenarios for robotic vehicle behaviours selected

M3.10 Nov-07. Software framework and components selected

M3.11 Apr-08. Software tests completed on model

M3.12 Aug-08. Software tests completed on vehicle

M3.13 Feb-09. Validation of software control strategies completed in selected scenarios

Task 4: evaluation

M3.14 Sep-10. Experiments with weeding effectiveness and reliability of automatic intra-row weed management completed

M3.15 Dec-10. Optimal crop planting patterns to suit yield optimisation and space requirements to make automatic intra-row weeding operational identified.

WP4: Decreasing and delaying weed emergence in row crops

	Start date or starting event: January 2007						
Partner id.	DAS-KVL	DAAS					
Person-months per participant	16 VIP 5 TAP	0.6 VIP					
Total PM VIP:	16.6						
Total PM:	21.6						

Objectives:

- Adaptation and modification of punch planter prototypes to fit to project requirements
- To assess the potential for weed emergence reduction and delay by applying the punch planting principle in different row crops in combination with the stale seed bed technique and flame weeding
- To assess the potential for increased effectiveness of physical weed control in crops that have been sown by a punch planter

Description of work:

Technical work on the punch planter prototypes to adapt them to the project requirements. Seed spacing and row width have to be adjusted to the project needs. Lab and field testing will be conducted to optimise the operational performance

Field experiments will be conducted in two years in row crops to determine main effects and interactions between timing of seed bed preparation in the context of the stale seed bed technique, delayed sowing and sowing techniques (normal versus punch planting) with respect to weed emergence and crop development.

Field experiments will be conducted in two years in row crops to determine the efficacy of different intra-row weed control methods (robotic weeder from WP3 when operational, cycloid hoe, torsion weeder and spring tine harrow). The experiments will quantify the importance of delayed weed emergence associated with punch planting. A weed emergence delay is expected to increase the selectivity of mechanical weed control, which is essential to reduce crop damages and selectivity. The testing procedure developed by Rasmussen (1992) will be applied.

Punch planting is expected to hold its most promising perspectives as regarding to weeds in slow germinating crops (Rasmussen, 2003). Therefore, weed impacts of punch planting in crops with different requirements of temperature for germination will be investigated in model experiments. These experiments will determine how punch planting will influence weed emergence in row crops.

Deliverables:

D4.1 Jan-08 Punch planter adjusted to ready for field experiments

D4.2 Jun-10 Peer-reviewed article: punch planting in row crops

D4.3 Sep-10 Peer-reviewed article: interactions between sowing and weed control methods

Milestones:

M4.1 Jan-08 Punch planter adjusted to ready for field experiments

M4.2 Oct-09 Punch planting studied in field experiments ended

M4.3 Oct-09 Investigations on the interactions between punch planting, physical weed control and stale seedbed strategies finalised

WP 5: Weed population dynamics model

	Start date or starting event: January 2007								
Partner id.	DIPM- DIAS								
Person-months per participant	9 VIP								
Total PM VIP:	9								
Total PM:	9								

Main objective

Strategies for the integrated control of two perennial species (*C. arvensis*, *T. farfara*) and major annual weed species have been formulated, based on a weed population dynamics model, and communicated to organic farmers.

Task objectives

1. Simulation model based on literature and controlled experiments developed.
2. Simulation model validated against field experiments.
3. Weed control scenarios simulated and best-bet strategies formulated.

Description of work

Model linkages

The weed control strategies suggested by the experiments on weed biology (WP1) are limited in their scope to the circumstances under which the experiments were carried out. The simulation model enlarges this scope by extrapolating the strategies to crop rotations and weather conditions not tested in the experiments. Thus, with the model as a tool, additional control strategies can be formulated and the long-term effect of the strategies explored. Likewise the efficacy of the novel technologies (WP2, WP3, WP4) must be interpreted in a broader, crop rotation context to look into the possible practical uses of this equipment as part of an integrated weed control strategy.

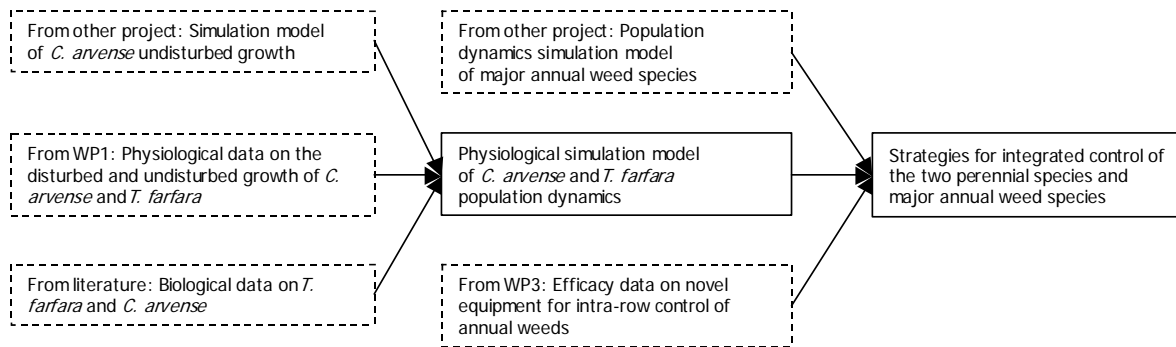


Figure. Broken-line boxes: Inputs from work packages and other sources. Full-line boxes: Outputs resulting from this work package. Arrows: Flow of information.

Model rationale

The new strategies for control of *C. arvensis* and *T. farfara* (WP1) involve various forms of physical disturbance that interact with weed biology in a complex manner. This is reflected in the modelling approach chosen. A detailed physiological model will be developed for *C. arvensis* and *T. farfara*; it involves simulation of photosynthesis, nutrient uptake and allocation among plant organs using the supply-demand approach (Gutierrez 1996); the density will be in both biomass and shoots per m². Model development will be discussed during the project with parallel model work (e.g. Park et al. 2001) at *Horticultural Research International, UK*.

The models of the two perennial species and the effects of the novel machinery (WP3, WP4) will be incorporated into the simulation model currently being developed at DIAS (Rasmussen et al. 2002; Rasmussen and Holst 2003). This model simulates the population dynamics in different crop rotations of the major annual weeds and by end-2005 also *C. arvensis*. The components included in the model reflect those mechanisms we find most important for weed management: weed population dynamics, crop competition, and different cultural and direct control measures. To keep the model simple we simulate just one square meter representing the average of the field, even though such a model is not informative of the rate of spread in the field of an invasive weed (Higgins and Richardson 1996), and it does not take into account the typically clumped distribution of weeds within the field (Rew and Cousens 2001). However, we find that spatially-explicit models demand too much data in comparison to the value added to the model by including space.

Weed population dynamics have been claimed inherently chaotic and thus in principle unpredictable (Firbank 1989; Gonzalez-Andujar and Hughes 2000). In the field, however, environmental variation caused by weather and agricultural practice are the main causes for the variability of weed population dynamics, rather than chaos (Berryman and Millstein 1989; Freckleton and Watkinson 2002). Thus weed populations dynamics are predictable—within bounds. This is reflected in the built-in capacity for sensitivity analysis in our model (Rasmussen and Holst 2003); simulations result not only in the expected average response but also in the variance on that given known uncertainty or inherent variability in biological or agronomical parameters (cf. Vose 2000).

Task 5.1 Develop simulation model based on literature and controlled experiments

The physiological model of *C. arvensis* is being modelled already from literature data only, financed by another project. The structure of this model will be re-used to model *T. farfara* for which literature, how-

ever, is much more limited. Both models will be refined through the results on disturbed and undisturbed growth resulting from the controlled experiments of WP1. The models will be validated for each species against data available in literature (mostly on undisturbed growth, e.g. Welton, Morris, and Hartzler 1929; Otzen and Koridon 1970; Tørresen et al. 2003) and published scientifically.

Task 5.2 Validate simulation model against field experiments

The initial model study (task 1) will be used to select the most promising ('best-bet') control strategies as a basis for planning the field experiments (WP1). Data from the field experiments will be used to refine and possibly validate the model and the results published scientifically.

Task 5.3 Simulate weed control scenarios and formulate best strategies

The perennial weed model resulting from task 1 and 2, together with the annual weed model developed in another project, will be used to fine-tune the strategies from task 2 (even better timing of treatments depending on crop and weather; need-based control depending on crop rotation) and to forecast the long-term consequences of different strategies. The strategies will take into account the possible uses of the new technology developed in WP3 and WP4. The best strategies will be formulated and communicated to organic farmers.

Deliverables

D5.1 May-09 Scientific paper on partly-validated simulation model of *C. arvensis* and *T. farfara* growth and population dynamics.

D5.2 Jul-11 Scientific paper on field-validated simulation model of *C. arvensis* and *T. farfara* growth .

D5.3 Nov-11 Best-bet control strategies communicated to organic farmers.

MilestonesTask 1: development

M5.1 May-07 Model of *C. arvensis* undisturbed growth validated against literature (from other project).

M5.2 Dec-07 Model of *C. arvensis* disturbed growth developed from controlled experiment.

M5.3 Feb-08 Model of *T. farfara* growth developed from controlled experiment.

M5.4 Oct-08 Models above validated against literature.

Task 2: validation

M5.5 Mar-08 Best-bet strategies formulated by way of model.

M5.6 Jun-10 Model validated against field experiments.

Task 3: best-bet strategies

M5.7 May-07 Model of major annual weed species validated (from other project).

M5.8 Nov-09 Best-bet strategies fine-tuned.

M5.9 Oct-10 Strategies taking the new technology of WP3 and WP4 into account formulated by way of simulated scenarios.

A.3 Project resources and budget overview

Department of Integrated Pest Management (DIPM), DIAS

Research on non-chemical weed control in arable crops has been a long-standing activity undertaken by the research group *Weed Ecology* at DIPM, previously being involved in several DARCOF funded research projects. Physical methods, and their interactions with cultural and preventive methods, have been investigated for the use in cereals, pulses and row crops. In row crops, research has especially focused on replacing laborious hand weeding of intra-row weeds with mechanization. Perennial weeds have a special biology, which we have demonstrated demand an intelligent use of direct and indirect measures for effective control. In organic cropping systems, weed management on the long term becomes more important and for the last three years a simulation model of weeds in the crop rotation has been developed to integrate previous and new results into a coherent understanding of the system. The group will be responsible for WP1, WP2 and WP5 and participate in WP3.

Department of Agricultural Engineering (DAE), DIAS

The research group *Automation and System Technology* under DAE are developing automation and systems technology for dynamical systems that interact with natural and biological objects. The objective is to develop technology and production systems that reduce the environmental impact, increase precision and efficiency, and allow care and management of crops and animals in new ways. Of particular interest are robotics, sensor systems, implement technology, operational management, and decentralized production systems for organic farming. The group has participated in a number of projects related to new innovative implement design and robotic systems for agriculture and is currently heading several strategic projects in the area. The aim is to be the leading European centre for research in robotic systems for agriculture. The group will be responsible for WP3 and participate in WP2.

Department of Genetics and Biotechnology (DGB), DIAS

The research unit *Statistics and Decision Theory* does research in statistical methods and theory for biological applications, including agricultural research. By this, the research unit has state-of-the-art statistical knowledge and contributes to the use of relevant and optimal use of statistical methods for design and analyses of biological experiments within DIAS. The unit cooperates with many departments and research unit within DIAS in a large number of research projects. The research unit will contribute with statistical expertise, particularly in WP1 and WP2.

The Department of Agricultural Sciences (DAS), KVL

DAS has competences within the biology, ecology and distribution of weed species including perennial weeds. Over the years, research in control measure has encompassed a variety of methods such as radiation, laser and various cultural methods. The group has also been prolific in the survey of weeds in conventional agriculture, and is probably the only group in Europe that has a database of weed surveys for the last almost 100 years. Of further interest for weed management in organic agriculture, we have done research and published within the areas of allelopathy and natural compounds as potential weed management tools. DAS will be responsible for WP4 and participate in WP1 and supervise the Ph.D. student.

Danish Agricultural Advisory Service, National Centre, Crop Production

The National Centre has expertise on weed management in organic farming, on perennial weed control especially through the project *Prevention of perennial weeds in organic farming* (2003-2005). The National Centre is the primary source of communication to advisors and farmers in Denmark and will contribute to the project by communication of the results. In this project, the National Centre will contribute with input to the trials in order to ensure that they are in accordance with the requirements of knowledge in organic farming. The National Centre will continuously contribute by commenting the development in the project. The participation of the National Centre will ensure that the results of the project will be integrated in the organic field trials carried out by the National Centre and thereby be implemented in organic farming.

Table for person month allocated on WP's and partners

Partner WP	1 (DIPM- DIAS)	2 (DAE- DIAS)	3 (DGB- DIAS)	4 (DAS-JCS- KVL)	4 (DAS-JER- KVL)	5 (DAAS)	Total
WP1	15		1	36		0.6	52.6
WP2	9	7	0.9			0.6	17.5
WP3	5	47				0.6	52.6
WP4					15	0.6	15.6
WP5	9						9
Management	2.5						2.5
Total	40.5	54	1.9	36	15	2.4	149.8

(Please give Institution or Department as partner id.)

Table for breakdown of total budget on partners and different cost categories (1000 DKK)

Participating institution	Responsible scientist	Salaries		Equipment	Operational expenses	Total budget DKK
		Academic	Techn. adm.			
DIPM-DIAS	BME	2,258	0,716	0,025	0,766	4,518
DAE-DIAS	SCH	2,278	0,568		0,772	4,342
DGB-DIAS	KKR	0,103			0,002	0,126
DAS-KVL	JCS	1,086			0,258	1,614
DAS-KVL	JER	0,508	0,140	0,044	0,308	1,200
DAAS	IBE	0,149	0,007		0,011	0,200

A.4. Dissemination of scientific results

- Planned education of scientists including Ph.D. and post-docs

WP 1 includes a Ph.D. study at KVL. The student will be attached to the Research School for Organic Agriculture and Food Systems (SOAR).

The proposed project is expected to attract a number of MSc students at KVL.

The project will partly be integrated into teaching and demonstration activities at KVL. Especially the course 'Ecological Agriculture I' of the Socrates programme.

- Stays abroad, guest researchers etc.

The Ph.D. student will be encouraged to stay abroad for a period, for example at North Central Soil Conservation Research Laboratory, Morris, MN, USA (see A.5. below)

- Communication of results. Publication strategy, contributions to national or international workshops etc.

Scientific communication

Progresses in the project will be communicated continuously through FØJOenyt, DARCOFenews and international and national conference proceedings. The project will maintain a web-site with general information on the project and its results. Communication through refereed scientific journals is specifically mentioned in the deliverables for each working package. The Ph.D. project lasts

three years and at least three papers in refereed journals are anticipated to fulfil the requirements of being awarded a Ph.D. degree. The Ph.D. student should participate in at least one international meeting relevant to the subject area of weed management in organic agriculture. Main results are planned to be presented at international conferences, symposia and workshops organised by the European Weed Research Society (EWRS), International Weed Science Society, ISOFAR, ICRA 2007/2008, AgEng 2007 and SPIE computer vision conference 2008.

DIPM-DIAS will be co-arranger of:

- a workshop on weed population dynamics modelling held in 2006 by the EWRS in collaboration with several working groups.
- a workshop on Physical and Cultural Weed Control held in 2007 by EWRS in collaboration with Rostock University.

DAE will be co-arranger of:

- a workshop on site-specific weed management held in 2006 by EWRS

Communication of results to extension services and organic growers

To ensure the effect in practise of the knowledge gained in the project, it is essential that the results will be communicated to the organic farmers in a way that makes them of practical use.

- The results will be communicated to organic advisers and farmer through articles on the *LandbrugInfo* web page and in the agricultural press.
- The results will be incorporated in practical advice to the organic farmers.
- Field visits for advisors and farmers will be arranged to show the results of the trials of the developed management strategies and to demonstrate the developed machinery.

A.5. Scientific collaborations

- Collaboration with other research institutes (national and international collaborative partners etc. please include a brief description of the collaborative scheme)

Relevant for WP1

Dr. Frank Forcella, Ph.D., North Central Soil Conservation Research Laboratory, USDA-ARS, Morris, MN, USA. The laboratory holds extensive experience in the ecology and biology of weeds of the temperate regions of the North West US. It is planned that the PhD student visits the lab to discuss the results of the project.

Relevant for WP1 and 2

A Nordic NJF (Nordic Association of Agricultural Scientists) working group dealing with the management of perennial weeds in organic farming with participants from Finland, Norway, Sweden, and Denmark, was established in 2000 (www.njf.nu). The group, chaired by Jukka Salonen MTT Agrifood Research Finland, Plant Protection, FIN-31600 Jokioinen, will continue its activities with regular meetings to discuss progresses in the management of perennial weeds in the Nordic countries. All the Nordic countries mentioned have ongoing research projects on the management of perennial weeds in organic farming, and the proposed project will be included in this suite.

Relevant for WP3

During research and development, technical discussions will be held with our collaborators at several Danish institutions: Aalborg University, The Maersk Mc-Kinney Moller Institute for Production Technology, University of Southern Denmark and Ørsted•DTU.

Relevant for WP4

Bonn University, Institute of Agricultural Engineering, Germany, will provide the Punch Planter prototypes for field experiments and expertise and advice for sugar beet and maize crop and weed control management.

Prof. Dr. P. Schulze Lammers

tel. +49 (0)228 73-2389, email lammers@uni-bonn.de
Nussalle 5, D – 53115 Bonn

University of Applied Sciences, Osnabrück, Germany, will provide the Cycloid hoe for row crop weeding and expertise in weeding of row crops and cycloid hoe controller software

Prof. Dr. D. Trautz

tel. +49 (0)541 969-5058, email d.trautz@fh-osnabrueck.de

Postfach 1940, D – 49009 Osnabrück, Germany

Relevant for WP5

Dr. Andrea Grundy, Horticultural Research International, UK. Weed modelling is emphasised at this institution, and a schedule for yearly meetings will be set up to share ideas and model components.

Dr. Jørgen A. Axelsen, DMU, Silkeborg. An agro-ecosystem model, which includes a few weed species, is being developed at this institute. Close collaboration is already in place through the running project *Herbicide-tolerant GM crops* and will be extended in the proposed project.

Relevant for all WPs

- Co-ordination with other projects (relations with other projects within the same field, which have been granted public funding)

The activities in WP3 builds on on-going research activities (related to computer vision and robot systems) in the projects, Robotic Weeding (funded by the Danish Research Agency), AgroBotics (funded by the Danish Research Agency) and AgroBots (funded by IT-korridoren under the Danish Research Agency).

Population dynamic modelling of weeds is also undertaken in the projects:

- 1) Crop protection in non-inversion tillage systems, DFFE, 2002-06
- 2) Herbicide-tolerant GM crops, Danish Environmental Protection Agency, 2004-07.

- Collaboration with private business partners or networks (names, titles)

Engineer Frank Poulsen, F Poulsen APS Engineering (www.fp-engin.dk), see also the attached letter of statement by F. Poulsen in the Application form.

A.6 Other issues

In WP1 and WP2, experiments conducted in climate chambers, glasshouse and semifield will not be conducted according to the Organic Principles, e.g. inorganic nitrogen fertilizer will be used to assure exact concentrations, soil will not be of organic origin, herbicides may be used to control other weeds etc. The field experiments in WP1 will be carried out in the Organic Workshop Areas at Research Centre Flakkebjerg and Jyndevad Experimental Station. The experimental areas are not certified organic, but have been run according to organic standards at least since 2000. Deviations from organic standards have occurred in previous experiments in the workshop areas. At Flakkebjerg, the manure used has been degassed slurry, which is not approved for use in organic farming.

In WP 2 and 3, apart from a few detailed studies on technical modifications and optimisations, field experiments will be conducted on organically grown land, e.g. Rugballegård at Research Centre Bygholm, and in close accordance with the principles of organic cropping. The participation of the Danish Agricultural Advisory Service in the project will ensure a strong connection to these principles and to practical organic farming and the problems it is facing.

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A.8 Curriculum vitae for *Bo Melander*, DIPM-DIAS, project manager and responsible for WP2

Education and employment

October 1987: Master of Science in Agriculture at the Royal Veterinary and Agricultural University, Copenhagen.

March 1988 employment at DIAS: 1988-94 research assistant; 1994-98 researcher; 1997-98 interim head of research unit, *Non-chemical Weed Control*; 1998-00 senior scientist; 2000-03, interim head of research unit, *Weed Ecology*; 2003- senior scientist.

Key qualifications

Extensive experiences and scientific merits achieved with physical and cultural weed control in organic and conventional cropping systems. Considerable research has focused on replacing laborious hand weeding of intra-row weeds in row crops with mechanization (ref. 4, 5, 6) in the projects: a) subproject manager in *Organic vegetables cropping* (1993-1997) funded by the Danish Ministry of Agriculture; b) subproject manager in DARCOF-I (1996-2001) *II.5 Weed control and transplanting techniques in row crops*; c) subproject manager in DARCOF-I (1996-2001) *II.2 Vegetables*; d) subproject manager in DARCOF-II (2000-2005) *1.9 Band beating for intra-row weed control*. The work has contributed significantly to lighten the burden of hand weeding in demanding organic vegetables and has recently been reviewed in three peer-reviewed papers (ref. 2, 3, 7).

Perennial weeds have been studied in two projects periods: 1988-1993 as subproject leader where important competition and population dynamic aspects of *Elymus repens* were elucidated; and 2000-2005 as project manager of DARCOF-II *1.8 Management of perennial weed species in organic farming*, where new management strategies (ref. 1, 8) of *Cirsium arvense* and *E. repens* in organic cropping were developed.

Other scientific qualifications

Member of the Scientific Committee of the *European Weed Research Society* (EWRS) and chairman of the EWRS working group *Physical and Cultural Weed Control* (www.ewrs.org/ewrs-pwc.htm) with more than 200 members. Invited speaker and session organiser at several international scientific conferences, symposia and workshops. Subject editor for *Weed Research*.

Publications

Seventeen peer-reviewed papers: 15 published and 2 submitted. Thirty-eight international and 21 national conference papers and reports, and 84 extension publications.

Significant publications during the last five years

¹Graglia E., Melander B. & Jensen R.K. (2005). Mechanical and cultural strategies to control *Cirsium arvense*. *Weed Research* (submitted March 2005).

²Hatcher P.E. & Melander B. (2003). Combining physical, cultural and biological methods: prospects for integrated non-chemical weed management strategies. *Weed Research* 43, 303-322.

³Melander B. (2004). Non-Chemical Weed Control: New Directions in. In: *Encyclopedia of Plant and Crop Science* (ed. Robert M. Goodman, University of Wisconsin), Marcel Dekker, Inc., New York USA, 3 pp. (www.dekker.com).

⁴Melander B. & Jørgensen M.H. (2005). Soil steaming to reduce intra-row weed seedling emergence. *Weed Research* 45(3), 202-211.

⁵Melander B. & Rasmussen K. (2000). Reducing intrarow weed numbers in row crops by means of a biennial cultivation system. *Weed Research* 40, 205-218.

⁶Melander B. & Rasmussen G. (2001). Effects of cultural methods and physical weed control on intrarow weed numbers, manual weeding and marketable yield in direct-sown leek and bulb onion. *Weed Research* 41, 491-508.

⁷Melander B., Rasmussen I.A. & Barberi P. (2005). Integrating Physical and Cultural Methods of Weed Control – Examples from European Research. A review. *Weed Science* 53(3), 369-381.

⁸Melander B., Rasmussen I.A. & Bertelsen I (2004). Common Couch-grass control with less tillage. DARCOF-news, December 2004 No. 4, 4 pp., (www.darcof.dk/enews/dec04/couch.html).

Curriculum vitae for *Niels Holst*, DIPM-DIAS, responsible for WP4

Education and employment

1990: MSc in Biology and BSc in Computer Science, University of Copenhagen.

1996: PhD in Biology, University of Copenhagen.

1987-1993: Director and Systems Analyst in DataMagic ApS, Copenhagen.

1997-: employment at DIAS: 1997 Scientist, since 1999 Senior Scientist; 1998-2002 Head of Decision Support and Development Research Unit; since 2002 Head of Weed Ecology and Decision Support Unit.

Key qualifications

Extensive experience in quantitative ecology, using computer technology (programming, simulation modelling, geographical information systems, statistics) to analyse, and implement decision tools for, integrated pest management of agricultural crops in the field and on store, both in temperate and tropical systems. Mathematical modelling of weed population dynamics to develop integrated management strategies both in Denmark (*Management of perennial weed species in organic farming*, DARCOF-II 2000-05; *Herbicide-tolerant GM crops: Long-term effect of spraying strategies on flora and fauna in neighbouring biotopes*, Danish Environmental Protection Agency 2004-07) and internationally (*The International mycoherbicide programme for water hyacinth control in Africa*, Danida 2000-02). Modelling of honey bee management (*Research and communication concerning key problems in Danish apiculture*, EU Commission 2005-07). Recent scientific work includes several modelling studies on weeds^{1,2}, biological control^{3,4,7} and integrated pest management⁵; advanced statistics for integrated pest management^{8,9,10}; and honey bees⁶.

Publications

Peer-reviewed: 18 papers and 1 book chapter. Conference papers: 18 international and 7 national.

Extension publications: 5 papers and 1 web book.

Significant publications during the last five years

¹Wilson, J. R.; Holst, N.; Rees, M. (2005). Determinants and patterns of population growth in water hyacinth. *Aquatic Botany* 81:51-67

²Rasmussen, I.A.; Holst, N. (2003). Computer model for simulating the long-term dynamics of annual weeds: from seedlings to seeds. *Aspects of Applied Biology* 68: 277-284.

³Borgemeister, C.; Holst, N.; Hodges, R.J. (2003). Biological control and other pest management options for larger grain borer *Prostephanus truncatus*, pp. 311-328. In: *Biological Control and IPM Systems in Africa*, Neuen-schwander, P.; Borgemeister, C.; Langewald, J., eds. CABI Publishing, Oxon, UK.

⁴Holst, N.; Meikle, W.G. (2003). *Teretrius nigrescens* against larger grain borer *Prostephanus truncatus* in African maize stores: biological control at work? *Journal of Applied Ecology* 40: 307-319.

⁵Meikle, W.G.; Markham, R.H.; Nansen, C.; Holst, N.; Degbey, P.; Azoma, K., Korie, S. (2002). Pest management in traditional maize stores in West Africa: a farmer's perspective. *Journal of Economic Entomology* 95: 1079-1088.

⁶Nansen, C.; Holst, N. (2002). Dynamics of short-term variation in pollen foraging by honey bees. *Portugaliae Acta Biol.* 20: 249-264.

⁷Meikle, W. G.; Cherry, A. J.; Holst, N. ; Hounna, B., Markham, R. H. (2001). The effects of an entomopathogenic fungus, *Beauveria bassiana* (Balsamo) Vuillemin (Hyphomycetes), on *Prostephanus truncatus* (Horn) (Col.:Bostrichidae), *Sitophilus zeamais* Motschulsky (Col.: Curculionidae), and grain losses in stored maize in the Benin Republic. *Journal of Invertebrate Pathology* 77: 198-205..

⁸Nansen, C.; Korie, S.; Meikle, W. G.; Holst, N. (2001). Sensitivity of *Prostephanus truncatus* (Horn)(Coleoptera: Bostrichidae) flight activity to environmental variables in Benin, West Africa. *Environmental Entomology* 30:1135-1143.

⁹Holst, N.; Meikle, W. G.; Markham, R. H. (2000). Grain injury models for *Prostephanus truncatus* (Coleoptera: Bostrichidae) and *Sitophilus zeamais* (Coleoptera: Curculionidae) in rural maize stores in West Africa. *Journal of Economic Entomology* 93, 1338-1346.

¹⁰Meikle, W.G.; Holst, N.; Degbey, P.; Oussou, R. (2000). An evaluation of sequential sampling plans for the larger grain borer (Coleoptera: Bostrichidae) and the maize weevil (Coleoptera: Curculionidae) and of visual grain assessment in West Africa. *Journal of Economic Entomology* 93, 1822-1831.

Curriculum vitae for *Ilse A. Rasmussen*, DIPM-DIAS, responsible for WP1

Education and employment:

- 1985: M.Sc. in agriculture from The Royal Veterinary and Agricultural University (KVL).
- 1984 – 1985 Teacher in organic farming at St. Restrup Højskole.
- 1986 – 1989 Advisor in organic farming at Frederiksborg County
- 1989 – 2004 Researcher at Danish Institute of Agricultural Sciences, Dept. of Integrated Pest Management, Research Group Weed Ecology
- 2004 - Senior Scientist at Danish Institute of Agricultural Sciences, Dept. of Integrated Pest Management, Research Group Weed Ecology.

Key qualifications:

Extensive research in population dynamics of weeds, weed seed production and soil seed reserve, non-chemical weed control in cereals, pulses and oil seed rape with focus on preventive measures, organic farming - crop rotations and weed control and generally weed management in organic farming. Leader of several interdisciplinary projects including projects on pesticide-free production of malting barley and cultivation of cereals and pulses in organic farming. Workshop-coordinator, session-organiser and co-arranger of several national and international workshops, symposia and conferences including the biennial Organic Conference in Denmark 2004, the EWRS Workshop on Physical and Cultural Weed Control, Norway, 2004 and the 12th International conference on weed biology, Dijon, France, 2004.

Other scientific qualifications

Member of the working groups on Physical and Cultural Weed Control and Weed Seed Germination and Early Growth under the European Weed Research Society (EWRS) and the Working Group on long-term experiments under the International Society of Organic Agriculture Research (ISO FAR).

Publications

12 papers in international scientific journals or books, 31 papers at international conferences and workshops, 27 papers at national conferences and workshops and 48 in reports and technical letters.

Significant publications during the last five years

- Grundy, A.C., Peters, N.C.B., Rasmussen, I.A., Hartmann, K.A., Sattin, M., Andersson, L., Mead, A., Murdoch, A.J., Forcella, F. (2003): Emergence of *Chenopodium album* and *Stellaria media* of different origins under different climatic conditions. *Weed research* 43, 163-176.
- Kristensen, K. & Rasmussen, I.A. (2002): The use of a Bayesian network in the design of a decision support system for growing malting barley without use of pesticides. *Computers and Electronics in Agriculture* 33 (3), 197-217.
- Melander B., Rasmussen I.A. & Barberi P. (2005). Integrating Physical and Cultural Methods of Weed Control – Examples from European Research. A review. *Weed Science* 53 (3), 369-381.
- Olesen, J.E., Askegaard, M. & Rasmussen, I.A. (2000): Design of an Organic Farming Crop-Rotation Experiment. *Acta Agriculturae Scandinavica, Sect. B, Soil and Plant Science* 50, 13-21.
- Olesen, J.E., Rasmussen, I.A., Askegaard, M. & Kristensen, K. (2002): Whole-rotation dry matter and nitrogen grain yields from the first course of an organic farming crop rotation experiment. *Journal of Agricultural Science* 139, 361-370.
- Rasmussen, I.A. 2004: Weed management in organic cropping systems. In: Goodman, R.M. (ed.): *Encyclopedia of Plant and Crop Science*. Marcel Dekker, Inc., (www.dekker.com)
- Rasmussen, I.A. 2004: The effect of sowing date, stale seedbed, row width and mechanical weed control on weeds and yields of organic winter wheat. *Weed Research* 44, 12-20.
- Rasmussen, I.A. & Holst, N. (2003): Computer model for simulating the long-term dynamics of annual weeds: from seedlings to seeds. *Aspects of Applied Biology* 69: Seedbanks: Determination, Dynamics & Management, 277-284.
- Rasmussen, I.A., Askegaard, M. & Olesen, J.E. (2005): Long-term organic crop rotation experiments for cereal production – perennial weed control and nitrogen leaching. *Researching Sustainable Systems – 1st ISO FAR Conference*, Adelaide, 227-230.

Curriculum vitae for *Svend Christensen*, DAE-DIAS, responsible for WP3

Education and employment

- 2001 - Research Director, Department of Agricultural Engineering.
2003 - 2006 Project manager on the project 'Robotic Weeding'
2000 - 2004 Project manager on the project 'Autonomous Platform and Informations system for crop and weed monitoring'.
2000 - 2001 Deputy Director, Department of Engineering.
1997 - 2000 Project manager on the contract project 'Reducing or eliminating herbicide use by spatial-temporal crop and weed management'.
1997 - 2000 Project manager on the contract project 'Development of a computer vision system for advanced vegetation control on railways in Denmark'.
1996 - 2000 Head of Research Unit
1996 - 2000 Project manager on a joint project with breeders 'The competitive ability of cereals varieties against weeds'.
1996 - 2000 Project manager on the project 'Novel cropping systems in livestock farming and novel strategies in weed control providing for the environment, economy and landscape natural resources'.
1995 - Senior Scientist
1994 - 1996 Researcher on the EU-project 'Reducing or eliminating agro-chemical inputs in efficient production of high quality produce with conventional, sustainable and organic farming systems'.
1992 - 1995 Researcher on the project 'Site specific farming'.
1993 - 1996 Researcher on the interdisciplinary modelling project 'Developing a management system for winter wheat cropping'
1993 Ph.D. in Weed Science, The Royal Veterinary and Agricultural University
1990 - 1991 Guest researcher at the University of Wageningen, Department of Theoretical Production Ecology, The Netherlands
1988 Researcher and Ph.D. student, Danish Institute of Plant and Soil Science - from January 1st. 1997 Danish Institute of Agricultural Sciences.
1988 M.Sc. Agr., the Royal Veterinary and Agricultural University

Publications

15 papers in international scientific journals, 38 papers at international conferences and workshops, 33 papers at national conferences and workshops and 42 in reports and technical letters.

Significant publications during the last five years

- Christensen, S., Heisel, T., Walter, A.M. & Graglia, E., 2003. A decision algorithm for patch spraying. *Weed Research* 43(4), 276-284
Gerhards, R. & Christensen, S., 2003. Real-time weed detection, decision making and patch spraying in maize, sugarbeet, winter wheat and winter barley. *Weed Research* 43, 385-392.
Heisel, T., Schou, J., Andreasen, C. & Christensen, S., 2002. Using laser to measure stem thickness and cut weed stems. *Weed Research* 42, 242-248.
Heisel, T., Schou, J., Christensen, S. & Andreasen C. 2001. Cutting weeds with a CO2 laser. *Weed Research* 41, 19-29
Olesen, J.E., Hansen, P.K., Berntsen, J. & Christensen, S., 2004. Simulation of above-ground suppression of competing species and competition tolerance in winter wheat varieties. *Field Crops Research* 89, 263-280
Perez, A.J., Lopez, F., Benloch, J.V. & Christensen, S., 2000. Colour and shape analysis techniques for weed detection in cereal fields. *Computers and Electronics in Agriculture* 25(3), 197-212.
Wang, J., Hansen, P.K., Christensen, S. & Qi, G., 2004. The Mathematical Method of Studying the Reproduction Structure of Weeds and its Application to *Bromus Sterilis*. *Discrete and Continuous Dynamical Systems-Series B* 4(3), 779-790

Curriculum vitae for *Kristian Kristensen*, DGB-DIAS, participation in all WPs

Education and employment

Cand. hort. Royal Veterinary and Agricultural University, Copenhagen, 1970

Ph.D. Department of Mathematics and Statistics, Royal Veterinary and Agricultural University, Copenhagen, 1980

1970-76. Research assistant, Danish Institute of Plant and Soil Science (SP)

1976-79. Ph.D student. Department of Mathematics and Statistics, Royal Veterinary and Agricultural University, Copenhagen

1979-1987. Research assistant, SP

1987-1992. Temporary head of department, Department of Biometry and Informatics, SP

1992-1998. Scientist, SP/Danish Institute of Agricultural Sciences (DIAS)

1998- Senior scientist, DIAS.

Research areas

Many years experience in applied statistics. Especially analyses of data from crop and soil science using different kind of methods, such as linear and non-linear mixed model, generalised mixed models and other multivariate models. Participation in an number of different projects among which the following may be mentioned: 1) Setting up and evaluation of models for nitrogen leaching from agricultural fields (N-LES, N-LES₂ and N-LES₃), 2) Construction and setting up a decision support system for growing malting barley without use of pesticides, 3) Setting up a model for simulation of weeds on sidewalks in Denmark and 4) Characteristics of spring barley varieties for organic farming.

Great expertise in design of experiments within crop and soil science.

Other activities

Participates in COST action 860, where he coordinates WP2 on biostatistics. Planned and coordinated workshops on DUS data in Kiev (2000), Mexico (2002) and Beijing (2004).

Publications

Published 25 papers in international scientific journals, 38 papers at conferences, 44 other papers and reports and more than 100 oral presentations. Some selected publications:

Kristensen, K.; Hansen, P.K. & Kristoffersen, P. 2004. Simulation of vegetation cover on sidewalks in Denmark. *Pest Management Science* 60, 588-594.

Kristensen, K. 2003 Incomplete split-plots in variety trials - based on α -designs. Seventh Working Seminar on Statistical methods in Variety Testing. *Biuletyn Oceny Odmian (Cultivar Testing Bulletin)* 31, 7-17.

Kristensen, K. & Rasmussen, I.A. 2002. The use of a Bayesian network in the design of a decision support system for growing malting barley without use of pesticides. *Computers and Electronics in Agriculture*. 33, 197-217.

Hansen, E.M., Djurhuus & Kristensen, K. 2000. Nitrate Leaching as Affected by Introduction or Discontinuation of Cover Crop Use. *Journal of Environmental Quality*. 29, 1110-1116.

Simmelsgaard, S.E., Kristensen, K., Andersen, H.E., Grant, R., Jørgensen, J.O., Østergaard, H.S. 2000. Empirisk model til beregning af kvælstofudvaskning fra rodzonen. N-LES. Nitrate Leaching EStimator. DJF rapport, Markbrug. 32, 67 pp.

Fomsgaard, I.S. & Kristensen, K. 1999. Influence of microbial activity, organic carbon content, soil texture and soil depth on mineralisation rates of low concentrations of ¹⁴C-mecoprop – development of a predictive model. *Ecological Modelling* 122, 45-68.

Kristensen, K and Rasmussen, I.A. 1997. A Decision Support System for Mechanical Weed Control in Malting Barley. *Proceedings of First European Conference for Information Technology in Agriculture* (Ed. Kure, H., Thyssen, I., Kristensen, A.R.). The Royal Veterinary and Agricultural University, Copenhagen, Denmark. p 447-452.

Curriculum vitae for *Jens Carl Streibig*, DAS-KVL, responsible for Ph.D. project in WP1

Education and employment

- 1972 Final examination in Agricultural Science (KVL)
1977 Ph. D. (Agricultural Botany) (KVL)
1992 Dr. agro. (D.Sc) (KVL)
1996- Professor (Weed Science), Department of Agricultural Sciences (KVL).

Key qualifications

Experiences in weed biology and ecology, weed competition, Allelopathic and chemical weed management, Ecotoxicology of pesticides and other xenobiotics

Other scientific qualifications

Fabrikant Ulrik Brinch og hustru Marie Brinchs legat, 1987 for outstanding research in Weed Science
Honorary Member of the Weed Science Society of America (WSSA) 1998.
Scientific Secretary of European Weed Research society (EWRS) 1994-2002
President for the Second International Weed Control Congress, Copenhagen 1996.

Publications

ISI Indexed Reference List relevant for the proposed work (1999- July 2004)

- CEDERGREEN N, SPLIID NH, & STREIBIG JC (2004) Species-Specific Sensitivity of Aquatic Macrophytes Towards Two Herbicide. *Ecotoxicology and Environmental Safety* 58, 314-323.
- NIELSEN OK, RITZ C, & STREIBIG JC (2004) Nonlinear Mixed-Model Regression to Analyze Herbicide Dose-Response Relationships. *Weed Technology* 18, 30-37.
- CEDERGREEN N, STREIBIG JC, & SPLIID NH (2004) Sensitivity of Aquatic Plants to the Herbicide Metsulfuron-Methyl. *Ecotoxicology and Environmental Safety* 57, 153-161.
- CHRISTENSEN MG, TEICHER HB, & STREIBIG JC (2003) Linking Fluorescence Induction Curve and Biomass in Herbicide Screening. *Pest Management Science* 59, 1303-1310.
- KUDSK P & STREIBIG JC (2003) Herbicides - a Two-Edged Sword. *Weed Research* 43, 90-102.
- RIMANDO AM, DAYAN FE, & STREIBIG JC (2003) PSII Inhibitory Activity of Resorcinolic Lipids From Sorghum Bicolor. *Journal of Natural Products* 66, 42-45.
- INDERJIT, OLOFSDOTTER M, & STREIBIG JC (2001) Wheat (Triticum Aestivum) Interference With Seedling Growth of Perennial Ryegrass (Lolium Perenne): Influence of Density and Age. *Weed Technology* 15, 807-812.
- INDERJIT, STREIBIG JC, & OLOFSDOTTER M (2002) Joint Action of Phenolic Acid Mixtures and Its Significance in Allelopathy Research. *Physiologia Plantarum* 114, 422-428.
- AL HAMDI B, INDERJIT, OLOFSDOTTER M, & STREIBIG JC (2001) Laboratory Bioassay for Phytotoxicity: An Example From Wheat Straw. *Agronomy Journal* 93, 43-48.
- SEIDEN P, BOSSI R, & STREIBIG JC (2000) Applicability of ELISA for Determination of Metsulfuron-Methyl in Soil Samples. *Pest Management Science* 56, 637-643.
- MADSEN KH & STREIBIG JC (2000) Simulating Weed Management in Glyphosate-Tolerant Crops: Greenhouse and Field Studies. *Pest Management Science* 56, 340-344.
- ANDREASEN C, HANSEN L, & STREIBIG JC (1999) The Effect of Ultraviolet Radiation on the Fresh Weight of Some Weeds and Crops. *Weed Technology* 13, 554-560.
- OLOFSDOTTER M, NAVAREZ D, REBULANAN M, & STREIBIG JC (1999) Weed-Suppressing Rice Cultivars - Does Allelopathy Play a Role? *Weed Research* 39, 441-454.
- BOSSI R, SEIDEN P, ANDERSEN SM, JACOBSEN CS, & STREIBIG JC (1999) Analysis of Metsulfuron-Methyl in Soil by Liquid Chromatography/Tandem Mass Spectrometry. Application to a Field Dissipation Study. *Journal of Agricultural and Food Chemistry* 47, 4462-4468.
- MADSEN KH, BLACKLOW WM, JENSEN JE, & STREIBIG JC (1999) Simulation of Herbicide Use in a Crop Rotation With Transgenic Herbicide-Tolerant Oilseed Rape. *Weed Research* 39, 95-106.
- MADSEN KH, POULSEN GS, FREDSHAVN JR *et al.* (1998) A Method to Study Competitive Ability of Hybrids Between Seabeet (Beta Vulgaris Ssp. Maritima) and Glyphosate Tolerant Sugarbeet (B-Vulgaris Ssp. Vulgaris). *Acta Agriculturae Scandinavica Section B-Soil and Plant Science* 48, 170-174.
- STREIBIG JC, DAYAN FE, RIMANDO AM, & DUKE SO (1999) Joint Action of Natural and Synthetic Photosystem II Inhibitors. *Pesticide Science* 55, 137-146.

Curriculum vitae for *Jesper Rasmussen*, DAS-KVL, responsible for WP4

Education

- 1979 Master of Science, Agronomy, KVL.
1986 Ph.D in agronomy, KVL.

Work experience

- 1980 - 1982 Farmer consultant in farmers association (Ringsted)
1982 - 1985 Scholar at KVL
1985 - 1987 Assistant professor at KVL, Department of Crop Husbandry
1987 - 1997 Scientist and senior scientist at The Danish Institute of Plant and Soil Science (DIPS), Department of Weed Control and Pesticide Ecology.
1994- 1997 Leader of the section "Physical Weed Control", The Danish Institute of Plant and Soil Science (DIPS), Department of Weed Control and Pesticide Ecology.
1997- Associate professor in organic farming at KVL, with organic farming as subject area

Relevant experience

From 1987 to 1997 my main research area was physical weed control, and I published peer-refereed articles, book chapters and popular papers about physical weed control. Since 1997, I have worked with several different disciplines in relation to organic farming.

Selected publications

- Rasmussen, J. (1991) A model for prediction of yield response in weed harrowing. *Weed Research* **31**, -401-408.
- Rasmussen, J. (1992) Testing harrows for mechanical control of weeds in agricultural crops. *Weed Research* **32**, 267-274.
- Rasmussen, J. (1993) Yield response models for mechanical weed control by harrowing in early growth stages in peas (*Pisum sativum* L.). *Weed Research* **33**: 231-240.
- Rasmussen, J. & T. Svenningsen (1995) Selective weed harrowing in cereals. *Biological Agriculture and Horticulture* **12**, 29-46
- Rasmusen, K.; J. Rasmussen & J. Petersen (1996) Effets of fertilizer placement on weeds in weed harrowed spring barley. *Acta Agricultura Scandinavica, Section, B: Soil and Plant Science*, **46**, 192-196
- Rasmussen, K. & J. Rasmussen (2000), Barley seed vigour and mechanical weed control. *Weed Research* **40**, 219-230
- Henriksen, C.B. & Rasmussen, J. (2002): Kamdyrkning – et økologisk alternativ. Den nasjonale kongress for økologisk landbrug 2002. Høgskolen i Hedemark Rapport nr. 3 –2002, 61-67.
- Rasmussen, J. (2003) Punch planting, flame weeding and stale seedbed for weed control in row crops. *Weed Research* **43**, 393-403
- Rasmussen, J. & Kaltoft, P. (2003): Alternative versus conventional values and attitudes in higher agricultural education. *Biological agriculture & Horticulture* **20**, 347-363
- Rasmussen, J. (2004): Falsk såbed sparer tid til roehakning. *Økologisk Jordbrug* **24** (311), 8
- Jensen RK, Rasmussen J & Melander B (2004) Selectivity of weed harrowing in lupin. *Weed Research* **44**, 245-253
- Rasmussen J; Kurtzmann JI & Jensen A (2004) Tolerance of competitive spring barley cultivars to weed harrowing. *Weed Research* **44**, 446-452

Curriculum vitae for *Inger Bertelsen*, Danish Agricultural Advisory Service, National Centre, participation in all WPs.

Education and employment

January 1991: Master of Science in Agriculture at the Royal Veterinary and Agricultural University, Copenhagen.

1991: employment at DIAS

1993: employment at Centre of Labour Market Courses

1994: employment at Varde Farmers Union as advisor in organic and conventional farming

1999: employment at Danish Agricultural Advisory Service, National Centre as advisor in organic farming.

Key qualifications

Advisor in weed control in organic farming.

Project manager on

- *Prevention of perennial weeds in organic farming 2003-2005*
- *Simplified soil preparation in organic farming, demonstration project. 2004-2007*
- *Organic plant production, demonstration in practice 2001-2003*

Project participant in

- *Soil loosening and prevention of soil compaction in organic farming 2003-2005*
- *Farm oriented weed control. (Bichel-project) 2000-2002*
- *Organic field trials. 1999-*

Publications

Publications in Danish on the homepage www.landbrugsinfo.dk and in the agricultural press.

Significant publications during the last five years

Bertelsen I (2003). Økologisk ukrudtsbekæmpelse Fakta hæfte. Landbrugsforlaget. (Organic weed control)

Tersbøl M, Bertelsen I, Mejnertsen P (2002). Økologisk planteavl. Fakta hæfte Landbrugsforlaget. 2. Edition. (Organic plant production)

⁸Melander B., Rasmussen I.A. & Bertelsen I (2004). Common Couch-grass control with less tillage. DARCOF-news, December 2004 No. 4, 4 pp., (www.darcof.dk/enews/dec04/couch.html).