Danish Research Centre for Organic Farming

Final Report

For DARCOF II research projects financed by grants from
The Directorate for Food, Fisheries and Agro Business
under the Danish Ministry of Food, Agriculture and Fisheries

1. Research program

Research in organic farming 2000-2005 (DARCOF II)

2. Project title and number

Band heating for intra-row weed control (I.9)

3. Head of project

Martin Heide Jørgensen
Project Researcher
Danish Institute of Agricultural Sciences
Dept. of Agricultural Engineering

4. Participating institutes

Danish Institute of Agricultural Sciences (DIAS)
The Royal Veterinary and Agricultural University (RVAU)

5. Other project staff

Erik Fløjgaard Kristensen, DIAS, Dept. of Agricultural Engineering.
Bo Melander, DIAS, Dept. of Crop Protection
Hans-Werner Griepentrog, RVAU, Agrotechnology

6. Project period (month, year)

Start of project: 04, 2000
End of project: 12, 2004

Slutrapporten sendes elektronisk til Forskningscenter for Økologisk Jordbrug *foejo@agrsci.dk* senest 3 måneder efter projektets afslutning.

Slutrapporten vedlægges et dansk resumé.

7. Final report

A. Project summary

The project covers two fields of activity: One concerning “Thermal band heating” and one concerning “Precision sowing”. Below are summaries regarding the two areas.

Thermal band heating:

The initial objective for the project has been to develop a new integrated machinery system for thermal soil treatment in a narrow band around the crop rows, by means of which, the germination of in-row weeds between the crops can be limited effectively. As an overall result, a prototype that has been analysed and documented under field conditions has now been established. The results have shown that the prototype is capable of controlling weeds effectively at a consumption of about 400 l of oil/ha. The system was approved for use in organic production in February 2005 by the Danish Plant Directorate. The first full-scale system is under construction and will be put into service within carrot production in the spring of 2005.

During the initial phase of the project, the principle for the process has been analysed under laboratory conditions. A special setup is designed to simulate field conditions. At the analysis, a batch of soil is placed in a rotating plate designed with a ditch, where the soil volume is heated by steam injection to simulate the process. The temperature process is well-controlled and documented. The treated soil batches are afterwards analysed for surviving weed seeds that are capable of germinating. The analysis covers several soil types and weed populations that are all naturally and artificially controlled by adding seeds to the soil.

The biological studies in the laboratory have shown that soil type, soil moisture content and soil structure (aggregate size) influence the lethal effect of soil steaming when the maximum soil temperatures are below 70°C. Steaming was more effective in a sandy soil than in a loamy soil, and increasing soil moisture content generally increased the susceptibility of weed seeds. More weed seeds survived the lethal effect of steam in soil containing many large aggregates as compared with soil having fewer large aggregates, presumably due to poorer steam penetration of the large aggregates. However, all the factors mentioned no longer had any effect when maximum soil temperature reached more than 70°C.

In general, seedling emergence from natural weed species was reduced by 99% when the maximum soil temperature reached 71°C, but added and non-imbibed seeds of Lolium perenne and Brassica napus generally required higher temperatures.

Studies of sowing crop seeds immediately after steaming showed that seeds of sugar beets, maize, leek, onion and partly carrots were surprisingly tolerant to the heat. This implies that crop sowing might be integrated with steaming so that steaming and sowing can be done in the same pass provided that crop sowing is done after steaming.

Analyses of the energy uptake have shown that at a maximum temperature of 70°C, the theoretical energy input without any loss will be equivalent to 204 l of oil per ha at a soil water content of 20% at 12cm row width and 50cm row spacing.

Field trials were carried out in the years of 2002-2004. During the first two years, a first-generation prototype was analysed. The principle of the system was for a number of slim

pipes to be placed in a frame for injection of the steam into the soil. The weed effect obtained from using this system was analysed to be acceptable, i.e. better than 95%, even if the maximum surface temperature would have to be at the level of 85-90°C to obtain a good performance. In 2003-04, a new prototype was designed and established. This new version is designed with a longitudinal closed chamber, from where the steam is conducted through a number of inlets at the top. The soil is lifted from the ground by a set of rotating mechanical tines, as will be seen for a rotary cultivator. The system has been analysed in field tests in 2004. The weed effect will still be better than 95%. The practical performance of the system has proved so good and so reliable that a commercial company has taken over the sales and production of the system.

The energy consumption for field application at a row width of 12 cm and a row spacing of 50 cm will be approximately 400 l of oil/ha. The difference between this value and the theoretical consumption can be partly explained by the loss in the steam generator and the operational stops of the system including the losses of steam in relation to soil energy transfer. There has been great focus on optimising the energy input, but it has not been possible to obtain further reductions. The energy consumption of the system is rather high, but in relation to the effect of in-row weed removal, it is rated to be acceptable. In the evaluation of the energy consumption, it is important to bear in mind that many growers make use of surface flaming for weed control purposes. There are great variations in the energy consumption for this operation, but a consumption corresponding to approximately 75 l of oil per ha is quite normal. The flaming will affect the weeds to such an extent that the need for manual weeding can be reduced by app 30%. Many growers spend about 100 manual hours per ha on weed control. The evaluation of the thermal band heating must be looked upon in this perspective.

Precision Sowing

New information based technologies in agriculture will lead to the possibility of individual plant care cropping systems. These systems will particularly contribute to reduce labor costs in organic farming as well as reduce herbicide use in conventional farming. Individual plant care embodied in farming systems will in general lead to new opportunities in agricultural crop management. The objective of this WP was to develop and evaluate a data logging system attached to a conventional precision seeder to enable high accuracy seed position mapping of a field of sugar beet. A seed map allows optimising the energy input of thermal soil treatment (spot treatment) and allows a guidance of weeding tools between and within crop rows.

An RTK GPS, optical seed detectors and a data logging system were retrofitted on to a precision seeder to map the seeds as they were planted. To minimize the displacement of seed from where it was dropped to where it remained and germinated, a seeder was chosen that dropped the seed into the furrow with a horizontal speed equal and opposite to the vehicle. This technique is well known (zero-ground-speed effect) and machines with this feature achieve a higher evenness of longitudinal seed and plant spacing. Although a high accuracy positioning system was used, results from field operations were initially poor due to small dynamic inclinations during the sowing operation. In order to correct this effect, an inclinometer was attached to the GPS antenna pole for measuring pitch and roll. In the post processing of the data, a kinematic model provided the heading information, eliminated the inclination errors and calculated the seed drop positions.

Field tests were conducted to check the performance of the seeder and to verify the data logging and processing system. The first experiment investigated the effect of seed bed quality

and soil type on the deviation between seed position and position where the plants emerged at the field surface. In the second experiment, the seed spacing and vehicle speed were altered to check the influence of these parameters on the seeder's performance.

The results showed that soil conditions of a field have an influence on where plants emerge related to their seed position. The range of mean deviations was 11.2 mm to 17.4 mm. These fully random errors will always occur because they appear due to normal and unavoidable soil structure conditions. The results showed that the seed bed quality has an effect on the deviations at least on heavy soil types.

The range of the overall mean deviation between measured seed positions and true plant positions was 16 mm to 43 mm. Higher vehicle speeds always resulted in higher deviations compared with the values from the small seed spacing. Furthermore, as expected, the smaller seed spacing always gave higher deviations compared with the larger (202 mm) seed spacing. This can be explained by the zero-ground-speed effect when using the 202 mm spacing.

The results showed that the overall accuracy of the estimated plant positions was acceptable for the guidance of vehicles and implements as well as potential individual plant treatments. The control of inter-row and intra-row hoes could be based on seed map data.

Work Package organisation.

The activities are organised in the following five work packages (WP):

1. Technical process analysis
2. Basic biological analysis (lab. test)
3. Establishment of prototype and technical field validation
4. Biological field validation
5. Precision sowing in treated bands and determination of seed positions

The timing of the activities is as follows: WP 1 & 2 have been carried out in close connection with each other, and likewise have WP 3 & 4. The activities in WP 5 have followed their own plan. This WP has been aiming at developing a system for precision seeding within the treated bands. WP 5 also involves a system for geo-positioning of each individual seed in order to control the following operations very precisely. The results of this package can be used independently, but the WP also involves a potential future improvement of the steam system, where the band treatment may be developed into spot treatment.

Table A.1: Work package list (from application)

No.	Work package title	Participants*	Budget (1.000 DKK)	Start	End	Deliverable No.(s):
1	Technical process analysis	MHJ, EFK	978	4/00	12/02	1a,1b
2	Basic biological analysis (lab. test)	BM, TH	990	4/00	12/04	2a,2b
3	Establishment of prototype and technical field validation	MHJ, EFK	1.246	1/01	12/04	3a,3b
4	Biological field validation	BM, TH	810	4/02	12/04	4a,4b
5	Precision sowing in treated bands and determination of seed positions	HWG	976	4/00	3/02	5a,5b

* Responsible participants are underlined

B. Objectives and expected achievements

The aim of the project is to develop a system for thermal soil treatment in close bands covering the crop rows. The system has to be optimised for minimum energy consumption and effective weed control within the intra-row area. In relation to the development of the system, it is of high demand to respect the structure of the soil and its positive biological activity.

The objective will be achieved through the following activities:

- Establishment of a prototype of an implement that will permit the performance of thermal soil treatment in narrow bands covering the crop rows. The prototype will be a result of a detailed analysis of the thermal processes involved
- Establishment of basic biological knowledge for impeding the germination capacity of weed seeds in soil
- Realisation of the adaptation of precision sowing equipment to special demands involved with band treatment. Modification and investigation of particular tools to achieve good seed placements and good covering in treated bands. Determination of the position of each placed seed by means of high-precision GPS. Utilisation of the position data to optimise the energy input on thermal soil treatment (spot treatment) and to allow guidance of weeding tools between crop rows and plants in order to remove unwanted plants (inter and intra-row weeding).

C. Progress and results

C.1 Description (summary) of main results and conclusions

- The band steaming concept is evaluated in a series of lab tests, where batches of soil are treated under controlled conditions. The heating process to a max. temperature and the cooling are controlled. Hereby, a series of equally treated batches is produced and tested for the germination capability of the contained weed seeds. The results show that under lab conditions, the effect will be higher than 98% when heating to a temperature higher than 70^{o}C followed by a cooling procedure where the temperature is decreased by approximately 10^{o}C after 10 min.

- Two generations of field implements is are and the analysed in field tests. Results show that it is possible to obtain results similar to what is seen in the lab, but the max. processing temperature will have to be raised to approximately 80^{o}C in order to attain an effective weed control, as described for the lab tests.

- In the laboratory, the necessary energy consumption for an oil heated system with a normal efficiency is calculated and documented to be about 204 l oil per ha (12 cm row width, 50 cm row spacing). The field tests with the 2nd.-generation prototype show an oil consumption of approximately 400 l oil per ha. The higher oil consumption is partly due to the system efficiency from the burner in the steam generator to the soil uptake, and partly to the higher process temperature.

- A cost benefit analysis has been composed by an external consultant. Results show an economical break-even in at a 4 ha production area with carrots or onions.

- On the basis of experiences with the first prototype, collaboration with the company "Carl Oluf Madsen – specialmaskiner" has been established. The company has supported the construction of the second generation machines and is in the process of taking over the rights for production and sales.

- The implementation of the system raises some questions concerning environmental impact. The process requires a substantial energy consumption that has to be balanced against the benefits of the process. Another aspect will be the effect on sterilised soil, resulting in eradication of the soil flora and fauna in the treated band. This problem has been analysed in 2003 in a combined test, where a parallel project analysed this problem. The project was headed and carried out by senior researcher Lars Elsgaard, DIAS, Foulum. Results show that there is a measurable impact on the ecological environment in the processed soil volume. The effect is measurable throughout the growth season, but no indication of permanent damage is shown.

- The activities concerning precision seeding and (RTK) geo-positioning is finished. Results confirm that the system is practicable. The results showed that the overall accuracy of the estimated plant positions was acceptable for the guidance of vehicles and implements as well as potential individual plant treatments. The control of inter-row and intra-row hoes could be based on seed map data. The conclusion is that the system needs more research to obtain a reliability proving that the system is ready for marketing. The RVAU continues the work in other projects (e.g. 'Robotic Weeding').

C.2 Fulfilment of deliverables and milestones

(To be completed for each work package)

WP number and title **WP1: Technical process analysis**	Time schedule according to application	Deviations, if any*	Full filled
Deliverables			√
1.a: A setup for producing batches of thermally treated soil with a well-defined and documented treatment history.	(08/00)		√
1.b: Documentation of the possibility of designing thermal soil treatment systems to give the soil a treatment with a given temperature history. The technical documentation includes heating source, temperature of transfer medium (heated air). The tillage/handling system is interacting with the soil.	(06/01)		√
1.c: The theoretical energy consumption for different technical systems analysed under laboratory conditions.	(12/01)		√
Milestones			√
1.1 Establishment of laboratory processing rig capable of producing batches of heat-treated soil.	(06/00)		√

1.2 Ready to carry out methodology test.	(09/00)		√
1.3 1 phase of methodology investigations to be completed.	(06/01)		√
1.4 Supplementary investigations and publication to be finished.	(08/01)		√

** Deviations are to be discussed further in D*

WP number and title **WP2: Basic biological analysis**	Time schedule according to application	Deviations, if any*	Full filled
Deliverables			
2.a: Draft paper for international publication on the basic model.	(06/02)		√
2.b: Draft papers on 1) model extension and 2) crop establishment in pre-heated soil for international publication.	(06/04)	See 1) in D	√
2.c: National publication, as required.	(year 02-04)		√
Milestones			
2.1 Preliminary structure of the basic biological model	(09/01)		√
2.2 Completion of model extension to explain the impact of major factors affecting the biological effect of band-heating on weed seed germination	(09/02)		√
2.3 Final results on crop establishment in heated soil and statements on the agronomic consequences	(04/03)		√

** Deviations are to be discussed further in D*

WP number and title **WP3: Establishment of prototype and technical field validation**	Time schedule according to application	Deviations, if any*	Full filled
Deliverables			√
3.a: Establishment of an operative prototype for field test.	(02/01)		√
3.b: Establishment of an optimised prototype for technical field validation and validation of the basic biological knowledge.	(02/02)		√
3.c: Documentation of the technical system	(11/04)		√
Milestones			√
3.1 Prototype 1 ready for field test.	(04/01)		√

** Deviations are to be discussed further in D*

WP number and title **WP4: Biological field validation**	Time schedule according to application	Deviations, if any*	Full filled
Deliverables			

4.a: Draft papers on the perspectives of a weed control system for row crops based on band-heating for intra-row weeding and automatically row-guided hoeing for inter-row weeding.	(Year 03-04)	See 2) and 3) in D	√
4.b: Arrangement of demonstrations and seminars.	(Year 03-04)		√
Milestones			
4.1 Final plans for field experimentation.	(02/02)		√
4.2 Finalising field experimentation with band-heating including validation of the performance of the band-heater prototype.	(08/03)		√
4.3 A final description of the potential and practical implementation of band-heating techniques in organic as well as in conventional row-cropping systems for herbicide saving purposes.	(09/04)		√

** Deviations are to be discussed further in D*

WP number and title **WP5: Precision sowing in treated bands and determination of seed positions**	Time schedule according to application	Deviations, if any*	Full filled
Deliverables			
5.a: Conference paper about RTK GPS and precision sowing.	(10/01)		
5.b: Good adaptation of precision seeder to equipment of band treatment.	(01/02)		
5.c: Optimised seed placement tools of precision seeder with regard to special soil properties of treated bands .	(08/02)		
5.d Draft paper about determination accuracy of row and seed positions for international publishing.	(08/02)		

D. Description of deviations and subsequent adjustments of plans

In general, the activities have progressed as planned, according to the tables of deliverables and milestones described in C2. The prototype optimisation has involved a supplementary innovation. The reason for this is that the idea of an alternative design concept arose in the collaboration with the company Carl Oluf Madsen. It has been possible to implement this extension of the activities without compromising the overall goals and plans.

As the prototype 1 has principally been functioning satisfactory, it was possible to support the parallel project in 2003 headed by senior scientist Lars Elsgaard, DIAS. The project focused on the analysis of the negative impact from band steaming on soil microbiology. To obtain effective benefit from the field activities, the test plots for the microbiological analysis was collocated with the demonstration plots for the season.

1) A peer-reviewed journal paper is planned for submission by the end of August 2005
2) A peer-reviewed journal paper is planned for submission by the end of December 2005
3) Two peer-reviewed review papers, one in a book (published) and one in a journal (in press), have been produced as a consequence of international interests in the project and results provided in previous DARCOF-funded projects on intra-row weeding

E. Project publications and other products

http://www.okoforsk.dk/projekt/index.html

Products from Organic Eprints archive

Peer-reviewed and accepted

English

Griepentrog, Hans W.; Nørremark, Michael; Nielsen, Henning and Blackmore, Simon (2005) Seed Mapping of Sugar Beet. *journal* 6(2). Online at <http://www.ingentaconnect.com/content/klu/prag/2005/00000006/00000002/00001032;jsessionid=1s3t73ohdg6a6.victoria>

Griepentrog, Hans W.; Nørremark, Michael; Nielsen, Henning and Blackmore, Simon (2003) Individual plant care in cropping systems. Paper presented at 4th European Conference on Precision Agriculture, Berlin, Germany, July 2003, page pp. 247-251. Wageningen Academic Publishers.

Melander, B. and Jørgensen, M.H. (2005) Soil steaming to reduce intrarow weed seedling emergence. *Weed Research*.

Melander, Bo (2004) Nonchemical weed control: New Directions, in Goodman, Robert M., Eds. *Encyclopedia of Plant and Crop Science*, page pp. 1-3. Marcel Dekker, Inc., New York.

Melander, Bo; Rasmussen, Ilse A and Barberi, Paolo (2005) Integrating Physical and Cultural Methods of Weed Control – Examples from European Research. *Weed Science*.

Nørremark, Michael and Griepentrog, Hans W. (2003) A method for high accuracy geo-referencing of data from field operations. Paper presented at 4th European Conference on Precision Agriculture, Berlin, Germany, July 2003, page pp. 463-467. Wageningen Academic Publishers.

Submitted for peer-review but not yet accepted

English

Jørgensen, M.H.; Kristensen, J.K.; Melander, B. and Kristensen, E.F. (2004) Thermal Band Heating for Intra-Row Weed Control. *Biosystems Engineering*.

Not peer-reviewed

English

Bo Melander, Scientist ; Torben Heisel, Scientist and Martin Heide Jørgensen, Scientist (2002) Aspects of steaming the soil to reduce weed seedling emergence. Paper presented at 12th EWRS Symposium 2002, Papendal, Arnhem, The Netherlands, 24-27 June 2002; Published in *Proceedings of the 12th EWRS Symposium 2002*, page pp. 236-237.

Griepentrog, Hans W. and Nørremark, Michael (2004) Seed mapping of sugar beet to guide weeding robots. Poster presented at 6th Workshop of the EWRS Working Group 'Physical and Cultural Weed Control', Lillehammer, Norway, 8th March 2004.

Jørgensen, M.H.; Kristensen, E.F.; Kristensen, J.K. and Melander, B. (2004) Thermal Band Heating for Intra-Row Weed Control. Paper presented at AgEng2004 Engineering The Future, Leuven, Belgium, 12 - 16 September 2004; Published in De Baerdemaaker, Josse, Eds. *AgEng 2004, Leuven, Belgium. Book of Abstracts, ISBN 90-76019-258. Paper on CD 287, 8 pp*. Technological Institute, Belgium.

Melander, Bo and Barberi, Paolo (2004) PHYSICAL AND CULTURAL WEED CONTROL IN MINOR CROPS. Paper presented at 4th International Weed Science Congress, Durban, 20-24 June 2004, page 14.

Melander, Bo; Heisel, Torben and Jørgensen, Martin Heide (2002) Band-steaming for intra-row weed control. Paper presented at 5th Workshop of the EWRS Working Group: Physical and Cultural Weed Control, Pisa, Italy, 11 – 13 March 2002, page pp. 216-219.

Melander, Bo; Jørgensen, Martin H. and Elsgaard, Lars (2004) Band-steaming reduces laborious hand-weeding in vegetables. *DARCOFenews*(3). Online at <http://www.darcof.dk/enews/sep04/steam.html>

Melander, Scientist Bo (2003) INTERGRATING PHYSICAL AND CULTURAL METHODS OF WEED CONTROL – EXAMPLES FROM EUROPEAN RESEARCH. Paper presented at North Central Weed Science Society's annual meeting, December 2003, Lousville, USA, 1-4 December 2003.

Melander, Scientist Bo and Heisel, Scientist Torben (2002) Band-steaming for intra-row weed control. Paper presented at 5th Workshop of the EWRS Working Group: Physical and

Cultural Weed Control, Pisa, Italy, 11 – 13 March 2002; Published in *Proceedings of the 5th Workshop of the EWRS Working Group: Physical and Cultural Weed Control*, page pp. 216-219.

Melander, Scientist Bo and Heisel, Scientist Torben (2002) Prospects and limitations for agricultural engineering in the development of sustainable weed control methods – examples from European research. Paper presented at Australian Conference on Agricultural Engineering, Charles Sturt University, Wagga Wagga, September 2002. CD-ROM available from the Danish Institute of Agricultural Sciences.

Melander, Scientist Bo; Jørgensen, Scientist Martin Heide and Elsgaard, Scientist Lars (2004) Recent results in the development of band steaming for intra-row weed control . Paper presented at 6th EWRS Workshop on Physical and Cultural Weed Control, Lillehammer, 8-10 March; Published in *Abstracts 6th EWRS Workshop on Physical and Cultural Weed Control*, page 21.

Melander, Senior scientist Bo (2003) Visit to Australia and New Zealand. Report, Crop Protection, Danish Institute of Agricultural Sciences.*

Melander, Senior scientist Bo and Jørgensen, Scientist Martin Heide (2003) Band steaming for intra-row weed control in direct-sown vegetables. Paper presented at EWRS working group workshop: "Weed Management Systems in Vegetable Crops", Skierniewice, Poland, 26-27 June 2003; Published in Dobrzanski, Dr. Adam, Eds. *Abstracts, EWRS, Skierniewice, 2003*, page pp. 13-15. Research Institute of Vegetable Crops, Instytut Warzywnictwa.

Dansk - Danish

Griepentrog, Hans W. and Nørremark, Michael (2002) Positionering af frø og afgrøderækker med RTK-GPS [Referencing of crop plants and rows by RTK-GPS]. Paper presented at Teknik i Landbruget, SCC Aarhus, Denmark, 21-22 March, 2002; Published in *Proceedings*, page pp. 51-52. Landbruget Rådgivningscenter, Skejby.

Jørgensen, Martin H. and Melander, Bo (2004) Stribedampning virker mod ukrudt. *FØJOenyt*(3). Online at <http://www.foejo.dk/enyt2/enyt/juni04/damp.html>

Melander, Bo; Jørgensen, Martin H. and Elsgaard, Lars (2004) Effekter af damp på ukrudt og mikroliv . *FØJOenyt*(1). Online at <http://www.foejo.dk/enyt2/enyt/jan04/damp.html>

Melander, Bo; Rasmussen, Ilse A.; Host, Niels and Bertelsen, Inger (2004) Ikke-kemisk ukrudtsbekæmpelse - mekanisk og termisk, in Madsen, Kathrine H., Eds. *Ukrudtsbogen*, chapter 4, page pp. 207-226. Danmarks JordbrugsForskning.**

Melander, Forsker Bo (2002) Hårde betingelser for Vestaustraliens økologer. In *Økologisk Jordbrug*, December, page pp. 4-4.

Melander, Scientist Bo (2004) Ukrudtsbekæmpelse med rækkedampning. In *Planteproduktion 2004, Månedsmagasinet MARK, Danske Landbrugs Medier 15 januar 2004*, page 51.

Melander, Scientist Bo; Heisel, Scientist Torben and Jørgensen, Scientist Martin Heide (2002) Stribedampning og andre teknologiske nyheder til bekæmpelse af ukrudt i økologiske grønsager . Paper presented at Den nasjonale kongress for økologisk landbruk 2002, Hamar,

Norge, Februar 2002; Published in Thomas Cottis, , Eds. *Den nasjonale kongress for økologisk landbruk 2002*, page pp. 9-16. Høgskolen i Hedmark.

Melander, Scientist Bo; Heisel, Scientist Torben and Jørgensen, Scientist Martin Heide (2001) Stribedampning mod ukrudt i højværdiafgrøder. In *Forskningsnytt om økologisk landbruk i Norden*, November, No 6, page pp. 13-13.

Nørremark, Michael and Griepentrog, Hans W. (2003) Den digitale mark [The digital field]. In *magazine*, July, No 15, page pp. 10-11. KVL.

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1. Other products (oral presentations, public meetings, field days, etc.)

Griepentrog, H. W.; Nørremark, M. (2001): Bestandesführung mittels kartierter Pflanzenpositionen. In: Proceedings VDI-Tagung Landtechnik, 2001 Hanover, VDI Verlag, Düsseldorf, p.285-290

Melander B. *Physical and cultural weed management*. Three lectures at the Agricultural University in Copenhagen on 21 Nov. 2000, 23 Nov. 2001 and 1 Nov. 2003

Melander B. *Danish research on physical weed control in bulb onion (Allium cepa L.) and leek (*Allium porrum *L.)*. Oral presentation at the EWRS working group meeting, Weed Management Systems in Vegetables, at Zaragosa, Spain, 4 June, 2001.

Melander B. *Integrating physical and cultural methods of weed control – examples from European research*. Keynote speaker at the North Central Weed Science Society Annual Meeting 1-4 Dec. 2003, Louisville, Kentucky USA.

Melander B. *Physical and Cultural Weed Control in Minor Crops*. Invited speaker at the session on "Minor Crops" at the 4th International Weed Science Congress, Durban 20-24 June 2004, South Africa.

Melander B. *Weed management in organic arable crops*. Postgraduate course SLU, Alnarp, Sweden, 22 September 2004

* 25-75% financed by DARCOF
** 5-25% financed by DARCOF

F. Scientific education

The principle of seed mapping was used at RVAU as a basis for student projects:

i) International course Ecological Agriculture I, Socrates Curriculum. The student group submitted the following project report:
Cavalieri, A.; Janssen, S.; Smithson, A.; Buisman, T. (2001): Economic viability of weeding strategies in organically grown sugar beet. KVL Socrates Course, 24 ECTS

ii) Seed mapping used to guide an autonomous tractor for inter-row hoeing. The student group finished the following Bachelor thesis:
Gulhol-Hansen, T.; Kristensen, H. (2004): Ruteplanlægning og præcision for en autonom traktor. BSc thesis, 18 ECTS

G. National and international cooperation

Since 2003, collaboration has been made with the company Carl Oluf Madsen concerning prototyping and commercialisation of the steam injection implement.

Since 2001 an intensive collaboration with
i) Kverneland Accord GmbH, Coesterweg 42, D-59494 Soest, Germany and
ii) Trimble Navigation Europe Ltd, Meridian Office Park, Osborn Way, Hook, Hampshire, RG27 9HX, England
to achieve the objectives within the WP5 Precision Sowing.

The Agro-Technology group on the Swedish Agricultural University (SLU) has been inspired by the project, and it has been possible to attract funding to test the system under Swedish conditions. Together with a farmer, a nine row implement based on the concept from the 1. Prototype in this project has been built. The Swedish results confirm the conclusions from this project.

Grower unions from Germany and Norway have visited Bygholm to get information and to discuss the concept.

From 8 Sep. to 12 Oct. 2002, Bo Melander visited Australia and New Zealand (based on an invitation) and gave 16 seminars on various subjects of weed control within organic farming and farming systems aiming at reducing herbicide dependence. Also, more general information about the development of organic farming in Denmark and the Danish pesticide policy was given to the audiences comprising researchers, advisors, farmers and authorities.

H. Critical reflection on the project

As described, the progress and the results of the technical and agronomic aspects of the project is satisfactory according to the described plans. There a functional and documented prototype has been established. The system was approved for use in organic production in February 2005 by the Danish Plant Directorate. The decision for approval has required an overall balancing of the positive and negative effects.

As mentioned, the thermal band heating system eliminates the need for extensive manual weeding, and therefore, it is considered an attractive system. In spite of that – especially in the organic perspective – there are two negative side effects that require special focus, namely the influence on the microbiology in the treated soil and the energy consumption.

In the initial planning of the project, it was decided to focus on the weeding process in order to establish a well-documented system. In this perspective, the analysis of especially the in-

fluence on the microbiology in the soil was left out; even it is very interesting and important. Therefore, the project group was happy to be able to support the additional project focusing on the analysis of these aspects during the growing season of 2003.

When analysing the negative side effects, one should also pay attention to the positive elements. When the microbiology is repealed, the disease carrying fungi will also be eliminated. This could be expected to have a positive effect on some germination problems. Another fact is that thermal band heating has proved to be an almost 100% effective weed control method, the result being that weeding damage on the crop will not occur, and that the row crops may again be the crucial element in a rotation where weeds can be removed effectively.

As mentioned, the required energy input under laboratory conditions is 204 l of oil per ha. Under field conditions by use of the developed implement, the consumption have been approximately 400 l oil per ha. In the analysis of the energy input, it is important to bear in mind that the use of the system will eliminate the normal requirement for one, perhaps two flaming operations and a manual weeding activity, which will often require more than 100 hours per ha. In this perspective, a consumption of 204 l/ha seems to be reasonable.

The idea of precision seeding was to generate precise position maps for localisation of every single plant in the field. In principle this goal is reached. The overall deviation is analysed to vary in the range 16-42 mm (std. deviation). This is acceptable for guidance of coarse implements. But other systems as computer vision can give more precise positioning data and would bee preferred to guide precision tools. Perhaps more benefit could be obtained by combining these two positioning principles.

In the evaluation of the concept of precision seeding it is important to keep in mind, that the potential use covers a big variety of possibilities. One of these is to design the placement of plant in the field in grids instead of rows. Grid – seeding can obviously lead to a better soil coverage implying more benefits. It also opens the possibility of joint growing of more different crops in the same field. The different crops could f.etc. be combined to give a more environmental friendly production or the quality of the products could be improved. One of the effects of seed mapping in such a system is that it opens the possibility of selective harvesting.

8. Budget

A. Account for any change in budgets

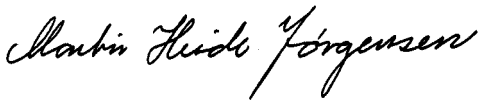
B. Budget for the whole project (1.000 DKK)

Year:	Original Budget	Consumption before 2003	consumption 2003	2004	Total
Man-months					
Scientific personnel	68	39	11	14	68
Technical personnel	47	33	9	4	47

Year:	Original budget	Consumption before 2003	Consumption 2003	2004	Total
Salaries					
Scientific personnel	2.180.000	745.000	375.000	490.000	2.180.000
Technical personnel	1.176.000	855.000	231.000	100.000	1.176.000
Other operational costs	561.000	405.000	84.000	72.000	561.000
Equipment					
Others (please specify)					
Direct costs	3.917.000	2.665.000	690.000	662.000	3.917.000
Indirect costs (20% of direct costs)	783.000	513.000	138.000	132.000	783.000
Total	**4.700.000**	**3.078.000**	**828.000**	**794.000**	**4.700.000**

Comments:

9. Signatures and stamps

Name	Institute	Date	Signature
Head of project Martin Heide Jørgensen	Danish Institute of Agricultural Sciences Dept. of Agricultural Engineering	13. April 2005	

Appendix I. Detailed budget

A. Budget for each participating institute (1.000 DKr)

Name of Institute: Danish Institute of Agricultural Sciences

Year:	Original Budget	Consumption before 2003	Consumption 2003	2004	Total
Man-months					
Scientific personnel	49	24	11	14	49
Technical personnel	45	32	9	4	45

Year:	Original Budget	Consumption before 2003	Consumption 2003	2004	Total
Salaries					
Scientific personnel	1.683.000	818.000	375.000	490.000	1.683.000
Technical personnel	1.116.000	785.000	231.000	100.000	1.116.000
Other operational costs	506.000	350.000	84.000	72.000	506.000
Equipment					
Others (please specify)					
Direct costs	3.305.00	1.953.000	690.000	662.000	3.305.00
Indirect costs (20% of direct costs)	660.000	390.000	138.000	132.000	660.000
Total	**3.965.00**	**2.352.000**	**828.000**	**794.000**	**3.965.00**

Name of Institute: The Royal Veterinary and Agricultural University

Year:	Original Budget	Consumption before 2003	Consumption 2003	2004	Total
Man-months					
Scientific personnel	19	19			19
Technical personnel	2	2			2

Year:	Original Budget	Consumption before 2003	Consumption 2003	2004	Total
Salaries					
Scientific personnel	497.000	497.000			497.000
Technical personnel	60.000	60.000			60.000
Other operational costs	55.000	55.000			55.000
Equipment					
Others (please specify)					
Direct costs	612.000	612.000			612.000
Indirect costs (20% of direct costs)	123.000	123.000			123.000
Total	**735.000**	**735.000**			**735.000**

Comments:

B. Budget for each participating department (1.000 DKK)

Name of Institute and department:

Year:	Original budget	Consumption before 2003	Consumption 2003	Consumption 2004	Total
Man-months Scientific personnel Technical personnel					

Year:	Original budget	Consumption before 2003	Consumption 2003	Consumption 2004	Total
Salaries Scientific personnel Technical personnel					
Other operational costs					
Equipment					
Others (please specify)					
Direct costs					
Indirect costs (20% of direct costs)					
Total					

Comments:

C. Budget for co-financing from each participating institute (1.000 DKK)

Name of Institute:

Year:	**Original budget**	**Consumption before 2003**	**Consumption 2003**	**Consumption 2004**	**Total**
Man-months Scientific personnel Technical personnel					

Year:	**Original budget**	**Consumption before 2003**	**Consumption 2003**	**Consumption 2004**	**Total**
Salaries Scientific personnel Technical personnel					
Other operational costs					
Equipment					
Others (please specify)					
Direct costs					
Indirect costs (20% of direct costs)					
Total					

Comments: