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

FØJOII-6. Cultivation in ridges and mixed cropping - new approaches to organic row crop production (CARMINA)

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

Slutrapporten vedlægges et dansk resumé.

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6. Project period (month, year)

Start of project: 09 2000
End of project: 12 2004

7. Final report

A. Project summary

The aim of the project was to investigate the possibilities to increase the efficacy of row crop production by improving nutrient cycling at the field level and strengthening prophylactic measures against plant pathogens. Ridge tillage and catch crops were chosen to manipulate nutrient cycling and mixed cropping and catch crops were chosen to manipulate pathogens and pests. There was focus on potato but other crops were considered as well. Crop yield and nitrogen leaching were used as key indicators in relation to nutrient cycling and reduction of late blight (*Phytophtora infestans*) and *Rhizoctonia* stem canker in potato were used along with tuber yield and quality as success indicators in relation to prophylactic measures. Ridges were established in autumn and winter to test to what extent residual nitrogen can be protected against leaching in winter. Furthermore catch crops and subsoiling were integrated into the ridge tillage system to improve its performance. Interactions between catch crops and *Rhizoctonia* stem canker were assessed based on the assumption that catch crop holds the possibility to reduce attack. For mixed cropping two types of mixtures were used: Mixtures of potato varieties and mixtures of potato and faba beans (*Vicia faba*). It was tested whether mixed cropping can reduce late blight in potatoes and aphid problems in faba bean. By running the project we tested our assumptions, that ridge tillage as an alternative to ploughing and mixed cropping may improve organic row crop production in terms of higher yields, better quality and lower impacts on the environment.

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

No.	Work package title	Participants*	Budget (1.000DKK)	Start	End	Deliverable no(s):
WP1	Protecting nitrogen from leaching in ridge tillage systems	CBH, JPM, JR	1029	1/9 2000	31/12 2004	D1-D5
WP2	Growing row crops in ridge tillage systems with and without catch crops	CBH, JR	1824	1/9 2000	31/12 2004	D1-D5
WP3	Growing row crops in ridge tillage systems with and without catch crops with emphasis on stem canker (*R. solani*) in potato	LB (BJN)	494	1/9 2001	31/12 2003	D1-D4
WP4	Improving crop growth by subsoiling in different tillage systems	CBH, JR	229	1/9 2000	30/6 2004	D1-D3
WP5	Mixing potato varieties	LM (BJN)	708	1/3 2001	31/12 2002	D1-D3
WP6	Mixing potato and faba beans	JPM	416	1/3 2001	31/12 2004	D1-D5

* Responsible participants are underlined

B. Objectives and expected achievements

The overall objective of the project was to contribute to better growing systems in organic row crop production resulting in higher yield, better quality and lower nutrient losses.
The project focuses on ridge tillage as an alternative to ploughing and mixed cropping to improve nutrient cycling and growth conditions at the field level and to strengthen prophylactic measures against serious diseases and pests. The project focuses on potatoes as a model crop but other crops are considered as well. In potatoes, late blight and stem canker is selected as model diseases.
The project is approached from an innovative point of view. That means that ridge tillage and mixed cropping are adapted and developed into the context of organic row crop production. Our key question is: If we develop the techniques of ridge tillage and mixed cropping in the context of organic agriculture, how far will it then bring us? By running the project a number of hypotheses concerning ridge tillage and mixed crops are tested:

1) Ridge tillage can protect nitrogen from leaching in winter through
   - higher immobilisation of nitrogen
   - reduced percolation through the ridges

2) Ridge tillage can increase crop yield through
   - earlier and better establishment of the crop
   - higher mineralisation in spring
   - increased crop nitrogen uptake in the growing season
   - reduced disease severity of *Rhizoctonia* stem canker

3) Catch crops can improve yield and quality of potato through
   - improved nutrient cycling in ridge tillage systems
   - reduced disease severity of *Rhizoctonia* stem canker

4) Subsoiling can improve crop growth in ridge tillage systems

5) Mixing potato varieties can slow down the epidemic development of potato late blight

6) Mixing potato and faba beans can reduce attack of late blight in potato and reduce attack of aphids in faba beans and thereby increase yields

C. Progress and results

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

Short summary

The project has given the following main results: 1) Ridge tillage as an alternative to ploughing can protect nitrogen from leaching in winter, but the effect is highly dependent on timing of ridging and soil type, 2) ridge tillage increased crop yield in spring barley established on flat soil after winter ridges and maintained crop yield in potatoes, 3) ridges established in early autumn increased mineralization during autumn and increased the N-leaching potential, 4) catch crops reduced N-leaching on sand and sandy loam but were only able to increase yield on sand, 5) inter-row subsoiling improved crop growth on sand, but the effect was dependent on timing and soil water status, 6) maize grown on ridges established in spring on ploughed soils showed im-

proved growth and yield, 7) there were insignificant effects of mixing potato varieties on the epidemic development of potato late blight, 8) there were insignificant effects of mixing potato and faba bean on potato late blight and faba bean aphids, but ridge tillage intermittently increased nitrogen fixation in faba bean and 9) different catch crops reduced severe attack of *R. solani* by about 50% but tillage had no effect on *R. solani*..

Elaboration

Tracer studies supported the hypothesis that ridges set up in winter can protect nitrogen from leaching by reducing percolation through the ridges. However, field and lysimeter experiments showed that the effect on soil nitrogen was highly dependent on timing of ridging and soil type. Since carbon-rich residues (straw) were not incorporated in any of the experiments, the proposed mechanism of N-immobilization was not observed. Instead the results showed increased mineralization and leaching risks during winter when ridges were set up in early autumn (late August). This was especially pronounced on sandy soil. The increased mineralization in autumn was reflected in lower amounts of plant available nitrogen in spring and lower potato crop yield on sandy soil. There were no significant effects on sandy loam. Ridging in winter (December/January) increased plant available nitrogen in spring, especially on sand, but this benefit was not reflected in potato yield.

On sand, the potatoes were planted directly in the ridges established in winter but on sandy loam it was necessary to harrow and re-establish the ridges in spring in order to obtain a sufficiently loose soil for planting.

Even if it was not measured, the field experiments indicate that leaching after winter ridges set up in November were lower than after ploughing conducted at the same time. This was verified in two lysimeter experiments, where solid animal manure was either incorporated in ridges or ploughed in. Ridges reduced N-leaching from sand and sandy loam and increased the yield of a subsequent barley crop planted on flat soil.

It was assumed that the risk of increased N-leaching from ridges set up in early autumn could be compensated by the use of catch crops establish on ridges. Catch crops established on ridges, however, were not able to compete with undersown catch crops in spring barley, which were used in combination with winter ridges. Therefore, ridges set up in winter after undersown catch crops were better to preserve nutrients from leaching than ridges set up in autumn with catch crops established on ridges. As expected there were significant effects of using catch crops, but there were no interactions between tillage (ploughing versus ridges) and catch crops. Catch crops increased total and marketable potato yields on sand, but not on sandy loam, and reduced N-leaching on both soil types.

In conclusion, there was found no evidence in this project that ridging in early autumn (August) is able to reduce leaching during winter. Ridges, which have been set up in winter (November/December/January), however, reduced N-leaching and increased crop yield in spring barley and maintained crop yield in potatoes.

Inter-row subsoiling in the growing season increased the marketable yield of potatoes with 49% in 2001, whereas there was no effect in 2002 and 2003. Precipitation before and after subsoiling, which was significantly lower in 2001, is considered to play a central part of this result but several unaccounted factors such as timing may influence crop responses to inter-row susoiling in the growing season.

The main emphasis on tillage in this project has been on ridges as an alternative to ploughing. Experiments with maize grown on ridges established in spring on

ploughed soils, however, have also been conducted. In 2003, crop emergence was improved, root growth was increased and the dry matter of aboveground maize biomass harvested in August was increased by 49%. In a similar experiment at St. Jyndevad in 2004 maize also responded positively to ridge planting and the yield was increased from 8.0 t/ha to 12.8 t/ha compared with planting on flat soil. The reasons for the observed improvements in maize growth conditions are not fully understood, but a combination of increased soil temperature, increased mineralization, increased root growth and reduced downwards movement of nutrients in the growing season may all contribute to the highly positive crop responses. In collaboration with the Danish Agricultural Advisory Service and Sejet Planteforædling, a project has been initiated in 2005 to investigate the mechanisms behind the observed yield increases and perform a preliminary evaluation of ridge planting of maize for both silage and grain production.
Also faba beans were grown on ridges in this project, which intermittently increased nitrogen fixation and promoted a deeper root system at the flowering stage. Consequently, the amount of fixed N at flowering was significantly greater in ridges than in flat soil. However, during the period from flowering until harvest, when the major part of the N uptake and N_2 fixation took place, the differences between the treatments disappeared.
The effect of mixing potato varieties on late blight development was insignificant. Even if minor reductions in late blight development have been observed, there have been no positive yield responses. Valuable scientific knowledge about the epidemics of late blight has been achieved. It has not been possible to show positive effects of mixing potato and faba beans as regard to late blight and aphids on faba beans, and it has not been possible to prove any impacts of soil tillage, manure and catch crop on *R. solani* in field experiments with low and natural infestations. However, different catch crops reduced severe attack of *R. solani* by about 50% in experiments with artificial inoculation. Lack of aphid response in faba beans grown in potato mixtures may be due to low aphid occurrence.

WP1: Protecting nitrogen from leaching in ridge tillage systems

The effect of ridge tillage on N-leaching in winter was investigated in three separate series of experiment. In the first one, the hypothesis that ridge tillage protects nitrogen from leaching by reducing percolation through the ridges was tested on sandy loam at KVL. Bromide and Brilliant Blue FCF was used as to simulate nitrate transport in ridges. The experiment showed that bromide and Brilliant Blue FCF was more protected in the middle of the ridge than on the side of the ridge and in the furrow. In untrafficked furrows leaching below the furrows was 104% higher than below the ridges, but if the furrows were compacted due to traffic, leaching below furrows was only 18% higher than below ridges. The study supports the hypothesis that ridge tillage protects nitrogen from leaching by reducing percolation through the ridges.To get direct measurements of leaching on both sand and sandy loam the second study was conducted in lysimeters. In November, solid farmyard manure was incorporated into ridges or ploughed in. Lysimeter leachate was sampled continuously from November to April and subsequently a barley crop was sown on flat soil after levelling the ridges in spring. Ridges reduced leaching by 29% on sandy loam and 14% on sand during the wet winter of 2001-2002. In the very dry winter of 2002-2003 leaching was reduced by 13% on sandy loam, whereas there was no effect on sand. Spring barley yield after ridges was 20% higher on sandy loam and 13% higher on sand in 2002. In 2003 ridging increased yield by 10% on sandy loam, whereas there was no effect on sand. The experiments showed a positive relationship between precipitation during au-

tumn and winter and the advantages of ridges.

The third study was conducted to study the main effects and interactions between soil tillage (ridging and ploughing), timing of soil tillage (early autumn, winter and spring), catch crops (none, ryegrass and brassicas) and soil type (sandy loam and sand). Soil inorganic nitrogen was assessed in November and April and the experiments were conducted in two years. The experiment showed that early autumn ridging in late August increased the N-leaching potential on sand and to a minor degree on sandy loam. Since N-leaching potential was only determined in November before winter ridging we cannot say whether winter ridging also reduced N-leaching potential in this study. However, winter ridging in December/January increased nitrogen availability in spring on sand and had a tendency to increase nitrogen availability on sandy loam. Catch crops reduced N-leaching potential on both soil types, reduced nitrogen availability on sandy loam and increased nitrogen availability on sand. There were no interactions between soil tillage and catch crop.

Based on the three studies it is concluded that ridging in winter can be used as a measure to reduce N-leaching on sandy loam, whereas ridging in early autumn cannot be recommended as it increases N-leaching potential, especially on sand.

WP2: Growing row crops in ridge tillage systems with and without catch crops

In the field experiment conducted to investigate the effects of soil tillage (ridges and ploughing), timing of soil tillage (early autumn, winter and spring) and catch crops (none, ryegrass and brassicas) the yield and quality of a subsequent potato crop was determined.

The experiment showed that there was a significant effect of both timing of ridging and catch crops on total and marketable potato yield on sand, but not on sandy loam. Averaged over two years, ridging in December/January resulted in a total yield of 279 hkg/ha and a marketable yield of 142 hkg/ha. Correspondingly, ridging in August resulted in a total yield of 264 hkg/ha and a marketable yield of 131 hkg/ha. Ploughing in spring gave the same total and marketable yield as ridging in winter on both sand and sandy loam. Catch crops increased total yield on sand, but not on sandy loam. There was no tillage x catch crop interaction on either soil type.

Tuber quality (determined at the sandy soil location St. Jyndevad) was only weakly affected by the treatments employed in this study. On sandy loam it was necessary to harrow and re-establish the ridges in spring in order to obtain a sufficiently loose soil, but on sand the potatoes could be planted directly in the winter ridges in spring. Since ridging in winter gave the same potato yield and quality as ridging in spring it is concluded that ridging in winter is an alternative to traditional potato production, especially on sand.

A field experiment with sugar beet was established at KVL in autumn 2000 to investigate how ridge size and placement of animal manure influenced yield. Animal manure was either placed in strings and incorporated in ridges (50 cm and 75 apart) or broadcasted at the surface before ridging. The experiment showed that deep incorporation of farmyard manure was important to avoid that manure was harrowed up to soil surface in spring. Ridging resulted in poor seedbed quality in 2001 due to shallow incorporation of manure. The experiment was replicated in 2001-2002 with a more powerful ridger, which succeeded in placing the manure deep enough to avoid problems with a poor seedbed the following spring. However, there were no significant main effects of soil tillage and placement of manure in any of the years. In 2001 sugar beet grown after ridges yielded 17%-23% more at 50 cm row spacing than at 75 cm row spacings. In 2002 spring ploughing yield 6% higher than ridges and sugar beet grown

after ploughing yielded 7%-10% higher at 50 cm row spacing than at 75 cm row spacings. It is concluded that there are no advantages of using ridge tillage for sugar beet production.

Three pilot studies with incorporation of clovergrass in ridges and cereals established on ridges were conducted at St. Jyndevad (sandy soil) in 2002 to achieve answers to some practical questions about the ridge tillage system. The studies showed that clovergrass incorporated in ridges in autumn strongly reduced yield of winter rye and oats as compared with spring ploughing. This was most likely caused by increased leaching from decomposed clovergrass in ridges. The pilot studies also showed that seedbed preparation in ridge tillage systems need to be further improved. Yields of rye and oats were reduced when sown on ridges compared with sowing in a flat seedbed. Further pilot studies were initiated in 2003 to compare the growth of different crops on ridge tops, on ridge shoulders and in flat seedbeds. At St. Jyndevad maize and faba bean showed promising results when grown on ridges, whereas soybean, sugar beet, lentil, oats, barley, lupin and pea did not seem to benefit by ridges. At KVL soybean emergence on ridge shoulders was increased by 32% compared with soybean emergence on ridge tops and in the flat seedbed. Dry matter production of maize harvested in August was increased by 79% on ridge shoulders and 49% on ridge tops compared with a flat seedbed. Following this study a special ridge planter was developed in collaboration with Research Centre Bygholm. In 2004 the planter was used for ridge planting of maize, sugar beet and soybean at St. Jyndevad Research Station. In this experiment ridge planting increased the dry matter yield of silage maize from 8,0 t/ha to 12,8 t/ha compared with traditional planting. The reasons for the observed improvements in maize growth conditions are not fully understood, but a combination of increased soil temperature, increased mineralization, increased root growth and reduced downwards movement of nutrients in the growing season may contribute. Based on these results a new project has been initiated in collaboration with the Danish Agricultural Advisory Service and Sejet Planteforædling to investigate the mechanisms behind the observed yield increases and perform a preliminary evaluation of ridge planting of maize for both silage and grain production.

WP3: Growing row crops in ridge tillage systems with and without catch crops with emphasis on Rhizoctonia stem canker in potato

The effect of manure, soil tillage, timing and catch crops on occurrence of *Rhizoctonia* stem canker was studied in the field trial under WP2 at St. Jyndevad. In 2001, there was a high natural level of *R. solani* (anamorph:*Thanatephorus cucumeris*) in the field. However, there were no significant effects on the natural occurrence of *R. solani* regardless of method used for scoring stem canker. There were however, indications of effect of some of the treatments. Based on all these tendencies, the study was repeated in 2002 but unfortunately, the natural level of infestation of *R. solani* this year was very low all over the field in all treatments and therefore nothing could be concluded from the second year trial. To avoid a similar experience the third year, a field experiment with artificial inoculum was set up at Flakkebjerg August 2002. However, it was necessary to produce large quantities of artificial inoculum of *R. solani* for inoculation of the field experiments. Several growth media (infected tubers, mixture of wheat bran and saw dust, potato dextrose agar and malt extract agar) and containers (sterile glass bottles and plastic bags) for producing inoculum were investigated. Malt extract agar as growth medium was selected based on a pilot field experiment to test the effect of the different inoculum types produced under laboratory conditions. After artificial infestation, with *R. solani* in autumn 2002, oat and a seed mix-

ture was sown as catch crop on either bare soil or on ridges. In June 2003, the potatoes showed rather severe attack of *R. solani* in the plots that were artificial inoculated in the autumn. There was, however, no effect of ridging but oat and the seed mixture from WP 2 sown as catch crops on bare soil reduced the attack of Rhizoctinia stem canker with 41 % and 55 %, respectively. These results are very promising and in line with the literature showing a disease suppressive effect of catch crops with cruciferous crops on Rhizoctonia stem canker. Despite the negative result from 2001 in the Jyndevad trial, the positive results from the Flakkebjerg trial need further verification in farmer's fields.

The field trials have given a valuable experience in field infestations with *R. solani*, which are very difficult and time consuming.

WP4: Improving crop growth by subsoiling in different tillage systems

A series of field experiment was conducted on sandy soil from 2001-2003 to determine the effect of autumn ridging and inter-row subsoiling on potato yield and quality. Autumn ridging showed comparable yields to ploughing and significantly reduced the incidence of black scurf from 2.5% to 2.2%. Inter-row subsoiling in the growing season significantly increased marketable potato tuber yield from 84.4 hkg/ha to 96.3 hkg/ha and reduced the percentage of malformed potatoes from 9.3% to 7.5%, irrespective of tillage treatment and irrigation level. There was no significant interaction between autumn ridging and subsoiling. The beneficial effect of subsoiling on marketable yield was driven by a 48.5% increase in the dry year 2001. It is concluded that at least three factors may modify the effects of subsoiling: Soil water status in the growing season, precipitation immediately before and after the subsoiling operation, and crop growth stage at the time of subsoiling.

A field experiment with total soil loosening by digging was conducted at KVL in 2001-2002. Before crop establishment plots were a) totally loosened to a depth of 90 cm by digging, b) subsoiled with a commercial subsoiler and c) untreated with respect to subsoiling. In 2001 there was found positive correlations between loose soil and plant growth in spring barley and winter rapeseed. In 2001, crop yield in barley-pea and oat-lupin mixtures were unaffected and in 2002 a clover-grass mixture was unaffected by soil structure.

WP5: **Mixing potato varieties**

The influence of potato variety mixtures on late blight development was studied in field experiments at research stations at St. Jyndevad and Borris in 2001 and in 2002. Four varieties (Kuras, Danva, Oleva, Producent) with different levels of partial resistance were grown in pure stands and the 4-way mixture. Due to the nature of this study, exceptional large plots (24x24 m) were used in 2001, however detailed studies allowed for a reduction in the size of plots of the varieties in pure stands, which were reduced to 12x10.5 m in 2002. In addition to the weekly assessments of late blight severity throughout the growth season, more detailed studies were undertaken at St. Jyndevad: In 2001, it included late blight severity assessments in 25 subplots per plot and foci development, and in 2002, assessments of disease on individual randomly selected plants and by remote sensing. Slightly lower disease levels (measured as Area Under Disease Progress Curve) were found in three of the four trials, but only a significant reduction was found in the trial at Borris in 2001, where the disease reduction (calculated as the percent late blight reduction in the mixture compared to the mean of late blight in the pure stands) was 13 percent. The rate of disease development, measured as the 'apparent infection rate' was significantly reduced in mixtures for all trials,

resulting in a delay of the epidemic by 2-3 days for the late blight severity to reach a level of 50% diseased foliage. The small disease reductions in the mixtures were not reflected in the tuber yield or in the amount of blight infected tubers. Tuber yield and also percent late blight infected tubers of the mixture equalled the mean of yield and tuber blight found in the 4 component varieties. The assessments of foci expansion patterns of late blight revealed no clear differences between the mixture and the pure stands. Given the insignificant reductions of late blight in the mixture, this study provides strong evidence to say that potato mixtures used in practical organic farming in Denmark today do not improve control of late blight. However, other mixing strategies, like alternating rows, together with other control measures should not be ruled out.

The design and the performance of the trials were a success and a large amount of useful data of high quality was obtained. The different detailed assessment methods have been evaluated and will set down a standard for future studies. However, it should be noted that this kind of experiment is laborious. The involved partners including the two master students have obtained valuable knowledge concerning late blight behaviour in mixtures and practical experience with potato mixture trials. One of the students was soon after graduation employed at the International Potato Centre (CIP) in Ecuador.

WP6: **Mixing potato and faba beans**

Field experiments have been conducted with inter-cropping of potatoes and faba bean with 4 rows of each crop in alternating order to delay late blight development. In 2001 and 2002 mixtures have contributed with minor reductions of late blight without any influence on crop yield. In 2003 mixtures had no influence on late blight. In order to investigate the effect of the row direction the rows have been oriented both north-south and east-west in large 24 x 24 m plots. Reference plots with potatoes and faba beans in pure stands have been established for comparison in a randomised block design. In order to investigate in detail the effect of the intercropping system and row direction the establishment and spread of blight infections in the plots have been carefully observed and mapped. Likewise the attacks of aphids on faba beans have been recorded. Results show no clear differences on blight infection or yield between the treatments. Aphid attacks in the faba beans has been insignificant and therefore no difference between treatments could be observed. Mixing potatoes and faba beans within the same row increased late blight attack, probably due to unfavourable microclimate.

In 2001 it was observed that the root system of faba beans developed more vigorously when grown on ridges compared to flat soil. To investigate these observations further, the possible advantage of ridge planting of faba bean was compared with traditional planting on flat soil in the following two growing seasons. Differences in soil physical parameters resulted in a significantly greater microbial activity and a deeper root system at the flowering stage when faba bean was grown in ridges than on flat soil. Consequently, the amount of fixed N at flowering was significantly greater in ridges than on flat soil. However, during the period from flowering until harvest, when the major part of the N uptake and N2 fixation took place the differences between the treatments disappeared.

C.2 Fulfilment of deliverables and milestones

WP1 Protecting nitrogen from leaching in ridge tillage systems	Time schedule according to application	Deviations, if any*	Full filled
Deliverables			
1 Evaluation of ridges set up in autumn as an alternative to autumn ploughing for reducing nitrate leaching			Full filled
2 Paper in international journal on the effects of shape, size and orientation of ridges		Deviation – note	Not fulfilled
3 Paper in international journal on the effects of timing of different soil tillage operations and placement of crop residues/animal manure			Full filled
4 Paper in popular magazine summarising the results in this workpackage			Full filled
5 Paper in popular magazine describing a guideline for setting up ridges in autumn			Not fulfilled
Milestones			
1. Field experiments finished	09 2003	Achieved	
2. The effects of shape, size and orientation of ridges has been determined	11 2003	Achieved	
3. The effects of type and placement of crop residues and animal manure has been determined	11 2003	Achieved	
4. The effects of timing of setting up ridges has been determined	11 2003	Achieved	
5. The effects of growing catch crops on ridges has been determined	11 2003	Achieved	
6. Final evaluation of ridge tillage as an alternative to mouldboard ploughing for reducing nitrate leaching	06 2004	Achieved	
7. Papers have been written	06 2004	Papers published, submitted or in preparation	

WP2: Growing row crops in ridge tillage systems with and without catch crops	Time schedule according to application	Deviations, if any*	Full filled
Deliverables			Full filled
1. Evaluation of ridge tillage for organic row crop production			Full filled
2. Evaluation of the interaction between tillage system and catch crops			Full filled
3. Evaluation of the effects of ridge tillage and catch crops on stem canker			Full filled
4. Evaluation of the effects of soil tillage and type/timing of animal manure on potato yield and quality			Full filled

5. Paper(s) in international journal(s) on the ridge tillage system for organic row crop production 6. Paper in international journal on the effects of soil tillage and timing/type of animal manure on potato yield and quality 7. Several papers in popular magazines describing the progression and results of this workpackage		Papers combined with papers in WP1	Full filled Full filled Full filled
Milestones			
1. Field experiments finished	09 2003	Achieved	
2. The performance of tillage systems based on ploughing and ridges with and without catch crops has been determined	11 2003	Achieved	
3. The effects of soil tillage and timing/type of animal manure has been determined	11 2003	Achieved	
4. The energy consumption and economy of ridge tillage for organic row crop production has been determined	02 2004	Not achieved. Instead pilot studies with ridge planting of different crops have been made	
5. Final evaluation of ridge tillage for organic row crop production	06 2004	Achieved	
6. Papers have been written	06 2004	Papers published, submitted or in preparation	

WP3: Growing row crops in ridge tillage systems with and without catch crops with emphasis on *Rhizoctonia* stem canker in potato	Time schedule according to application	Deviations, if any*	Full filled
Deliverables			
1. Evaluation of ridge tillage with organic soil amendments on *Rhizoctonia* stem canker			Full filled
2. Evaluation of the importance of soil-borne inoculum in ridge tillage with organic amendments.			Full filled
3. Paper in international journal on catch crops in a ridge tillage system with emphasis on *Rhizoctonia* stem canker in potato. 4. Paper in popular magazine describing a guideline for Danish farmers for using organic soil amendments in organic potato production with emphasis on the control of *R. solani* stem canker		Deviation – note	Not full filled
Milestones			
1. Methods have been developed for producing large amount of artificial inoculum of *R. solani*. Several growth media and containers have been investigated (Primo 2001)	05 2001	Achieved	

2. The effect of manure, soil tillage, timing and catch crops on occurence of *Rhizoctonia* stem canker has been studied in the field trial under WP2 at St. Jyndevad (Medio 2001).	06 2001	Achieved
3. Field experiment has been conducted at Flakkebjerg to test the effect of the different inoculum types (Medio 2001).	07 2001	Achieved
4. The effect of manure, soil tillage, timing and catch crops on occurence of *Rhizoctonia* stem canker has been studied once more in the field trial under WP2 at St. Jyndevad (Medio 2002).	06 2002	Achieved
5. Artificial inoculation with *R. solani* of field experiment at Flakkebjerg and sowing of catch crops and establishment of ridge tillage systems have been performed (Medio 2002).	08 2002	Achieved
6. Healthy seed tubers have been planted in the field experiment at Flakkebjerg (Primo 2003).	05 2003	Achieved
7. The disease severity of *Rhizoctonia* stem canker has been scored and field experiment at Flakkebjerg finished (Medio 2003)	07 2003	Achieved
8. Papers have been written (Ultimo 2003)	12 2003	Not achieved

** Deviations are to be further discussed in D*

WP4: Improving crop growth by subsoiling in different tillage systems	Time schedule according to application	Deviations, if any*	Full filled
Deliverables			
1. Evaluation of subsoiling for potato production in ridge tillage systems			Full filled
2. Paper in international journal on the effects of subsoiling on potato yield and quality in different tillage systems.			Full filled
3. Paper in popular magazine summarizing the results in this work package			Full filled
Milestones			
1. Field experiment finished	07 2003	Achieved	
2. The effects of subsoiling on potato yield and quality in different tillage systems have been determined (	12 2003	Achieved	
3. Papers have been written	06 2004	Achieved	

** Deviations are to be further discussed at D*

WP5: Mixing potato varieties	Time schedule according to application	Deviations, if any*	Full filled
Deliverables			

1. Evaluation of the efficacy of using potato mixtures as a late blight control measure in organic grown potatoes in Denmark			Full filled
2. Paper in international journal on the effect of potato mixtures on late blight development		Deviation – note	Not full filled
3 Papers in popular magazines or proceedings			Full filled
Milestones			
1. A method for assessing late blight in potato mixtures has been developed	07 2001	Achieved	
2. First years field trials have been analysed and possible adjustments of design of the field trials can be decided	12 2001	Achieved	
3. AUDPC measurements in two years field trials completed	11 2002	Achieved	
4. The efficacy of organic grown potato mixtures as a late blight control measure is determined	12 2002	Achieved	

** Deviations are to be further discussed at D*

WP6: Mixing potato and faba bean	Time schedule according to application	Deviations, if any*	
Deliverables			
1. Evaluation of intercropping of potatoes and faba bean as a growing system			Full filled
2. Evaluation of the possibility to reduce attack of late blight in potatoes using intercropping			Full filled
3. Evaluation of the possibility to reduce colonisation of aphids in faba bean using intercropping 4. Paper in international journal describing the potato faba bean intercropping and effect on pests and diseases. 5. Paper in popular magazine summarising the results of this work package			Full filled Not full filled Full filled
Milestones			
1. Field experiments finished	12 2003	Achieved	
2. Influence of intercropping on potato late blight epidemiology has been determined	12 2003	Achieved	
3. Influence of intercropping on aphid abundance in faba bean has been determined	12 2003	Achieved	
4. Final evaluation of possibilities and perspectives of potato intercropping with faba bean	06 2004	Achieved	
5. Papers have been written	06 2004	Achieved	

** Deviations are to be further discussed at D*

D. Description of deviations and subsequent adjustments of plans

The project has been based on an innovative approach, which means that adjustments have been a part of the project. A balance between adjustments and repetition of experiments in at

least two years to ensure the possibilities of publication has been attempted. As it was very expensive, and more expensive than expected, to run field experiment with potatoes and sugar beet, some experimental plans in WP1 and WP2 have to be reduced according to the Midterm Status Report 2002. Consequently some of the papers in WP1 and WP2 have been combined. However, the greatest modifications of the original plans have been in WP3 (Growing row crops in ridge tillage systems with and without catch crops with emphasis on *Rhizoctonia* stem canker in potato) as described and justified in the Midterm Status Report 2002. Instead of natural occurring infections of *R. solani* in the field experiments at St. Jyndevad there has been applied artificial inoculum in field experiments at Flakkebjerg in 2003. This modification gave high quality data. Encouraging results with growing various crops on ridges in pilot studies at KVL and St. Jyndevad in 2003 implied that it was prioritized to conduct further pilot studies in 2004 instead of the planned calculations on energy consumption and economy. The project as a whole has produced material for five publications in peer-reviewed scientific journals and contributed significantly to two other publications in peer-reviewed scientific journals. At the time of writing this final report one paper has been published, another is in press, two have been accepted, a fifth publication has been submitted, and two more publications are in preparation and will be submitted during 2005. (The delay in publication is primarily caused by the leave granted in 2003).

In WP1 a scientific paper is in preparation: C: Henriksen, C.B. & Rasmussen, J. (200x): The effect of autumn incorporation of animal manure in ridges on nitrate leaching and subsequent barley and sugar beet yields. Soil Use and Management

In WP5 a scientific paper is in preparation: Munk, L., Kromann, P., Bjerre, KD and Bødker, L., 200x. Influence of variety mixtures on late blight in organic potato production. European Journal of Plant Pathology

E. Project publications and other products

Peer-reviewed and accepted

English

Henriksen CB, Rasmussen J, Søgaard, C (2005) Kemink subsoiling before and after planting. *Soil & Tillage Research* 80:pp. 59-68.*

Henriksen CB, Mølgaard, JP, Rasmussen, J (2004) The effect of autumn ridging and inter-row subsoiling on potato tuber yield and quality. *Soil & Tillage Research*. (in print).

Henriksen CB, Rasmussen J, Søgaard C (2005) Ridging in autumn as an alternative to mouldboard ploughing in a humid-temperate region. *Soil & Tillage Research* (in print).

Rasmussen J (2003) Punch planting, flame weeding and stale seedbed for weed control in row crops. *Weed Research* 43:pp. 393-403.**

Vinther FP, Dahlmann-Hansen L (2004) Effects of ridging on crop performance and symbiotic N2 fixation of fababean (Vicia faba L.). *Soil Use and Management* (in print).

Submitted for peer-review but not yet accepted

English

Henriksen, CB, Rasmussen J, Mølgaard, JP (2005) The effect of timing of ridging on soil inorganic nitrogen and potato tuber yield and quality .

Not peer-reviewed

English

Bugge Henriksen, Christian; Mølgaard, Jens Peter and Rasmussen, Jesper (2004) Inter-row subsoiling increases marketable yield in potatoes. *Darcof e-news*. Online at <http://www.darcof.dk/enews/june04/subsoiling.html>

Henriksen, Christian Bugge; Rasmussen, Jesper; Jørgensen, Martin Heide and Thomsen, Henning Carlo (2005) Ridge planting of maize shows promising yield increase. *DARCOFenews*. Online at <http://www.darcof.dk/enews/mar05/maize.html>

Dansk - Danish

Henriksen, Christian Bugge (2004) Dybe jordløsninger i kartofler. In *Økologisk Jordbrug*, 6. August, Volume 24, No 317, page 6. Økologisk Landsforening.

Bugge Henriksen, Christian (2003) Alternativ til pløjning - Erfaringer med kamme som alternativ til pløjning [Alternative to ploughing - Experiences with ridges as an alternative to ploughing]. In *Økologisk Jordbrug*, 18. April, Volume 23, No 287, page 6.

Bugge Henriksen, Christian (2000) Er kamme et alternativ til pløjning?. [oral] Presentation at *Det Kgl. Danske Landhusholdningsselskabs Akademiråds efterårsseminar*, Foulum, Denmark, November 8. 2000.

Christian Bugge, Henriksen (2000) Kamme - et alternativ til pløjning?. Paper presented at Det Kgl. Danske Landhusholdningsselskabs Akademiråds Efterårsseminar, Foulum, Denmark, November 8, 2000; Published in P. Dam, Hans, Eds. *Tidsskrift for Landøkonomi* 187(4), page pp. 311-314. Det Kgl. Danske Landhusholdningsselskab.

Dahlmann-Hansen, Lisbeth (2002) *Hestebønnes tidlige rodudvikling ved dyrkning i kamme [Early root growth in faba bean grown on ridges]*. Bachelor, Department of Agricultgural Sciences, Den Kgl. Veterinær- og Landbohøjskole. KVL.*

Henriksen, C.B. and Rasmussen, J. (2002) Kamdyrkning (drill) – et økologisk alternativ. Paper presented at Den nasjonale kongres for økologisk jordbrug, Hamar, Norway, 21/2-22/2 2002; Published in Cottis, T., Eds. *Den nasjonale kongres for økologisk jordbrug, Rapport nr. 3 - 2002*, page pp. 61-68. Høgskolen i Hedmark.

Henriksen, Christian Bugge (2005) Positiv effekt af kamdyrkning [Positive effect of ridge planting]. *Økologisk Jordbrug* 25(238):4.

Henriksen, Christian Bugge (2003) Erfaringer med kamme som alternativ til pløjning [Experiences with ridging as an alternative to ploughing]. *FØJOenyt*. Online at <http://www.foejo.dk/foejo/enyt2/enyt/juni03/kamme.html>

Henriksen, Christian Bugge; Rasmussen, Jesper; Jørgensen, Martin Heide and Thomsen, Henning Carlo (2004) Majs på kamme viser lovende merudbytte. *FØJOenyt*. Online at <http://www.foejo.dk/enyt2/enyt/dec04/kam.html>

Kildested, Lars (2005) Vilde merudbytter til forbavsede forskere. In *Agrologisk*, January, Volume 23, No 1, page pp. 6-8. Dansk Agrar Forlag.

Larsen, Lone Urbrand (2003) Langtidseffekter af dyb jordløsning [Long-term effects of deep soil loosening]. Report, Den Kgl. Veterinær- og Landbohøjskole, Institut for Jordbrugsvidenskab.**

Mølgaard, Jens Peter (2004) Kamdyrkning af hestebønner. *FØJOenyt*. Online at <http://www.foejo.dk/enyt2/enyt/jan04/kamme.html>

Thomsen, Henning C. (2001) Kan hestebønner forsinke skimmelangreb. *Kartoffelproduktion* 27(4):pp. 6-7.

Kromann P, Koch T, Bødker L and Munk L, 2003. Kartoffelblandingers betydning for udvikling af kartoffelskimmel (*The influence of potato mixtures on late blight development*). DJF-rapport nr. 89: 77-84.

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

Rasmussen, Jesper (2000) Alternative jordbearbejdningsmetoder. [oral] Presentation at *Seminaret "Jordbearbejdning og jordfrugtbarhed", Landsforeningen Økologisk Jordbrug*, Bygholm Landbrugsskole, 19. september 2000.

Rasmussen, Jesper and Henriksen, Christian Bugge (2002) Kamdyrkning i stedet for pløjning. [oral] Presentation at *Nasjonal kongress for økologisk landbruk*, Hamar, Norge, 21.-22. februar.

Rasmussen, Jesper and Henriksen, Christian Bugge (2000) Jordløsninger - er det svaret? . [oral] Presentation at *Økologikongres 2000. Troværdighed og succes*, Hotel Pejsegården i Brædstrup, 1. og 2. november 2000.

F. Scientific education

Grossmann, Freya (2002) *Forbedring af jordkvaliteten efter jordpakning - er løsning løsningen?*. MSc thesis, Institut for Jordbrugsvidenskab, KVL**

Dahlmann-Hansen, L. (2002): Hestebønners tidlige rodudvikling ved dyrkning på kamme (The initial development of root in faba beans grown on ridges) B.Sc.-project, Institut for Jordbrugsvidenskab,. KVL (available at http://dvjb1.kvl.dk/ALEPH)**

Kock, T & Kromann, P (2002): Blandingskulturer til bekæmpelse af kartoffelskimmel / udført af: Torben Koch, Peter Kromann. MSc thesis. Institut for Plantebiologi. KVL (available at http://dvjb1.kvl.dk/ALEPH)*

Mathiasen, K. (2002) Effekter af midlertidige kamme på temperatur, vandindhold, volumenvægt og fremspiring i såbed til majs. MSc thesis. Institut for Jordbrugsvidenskab, KVL (available at http://dvjb1.kvl.dk/ALEPH)**

Larsen, L. U. (2003): Langtidseffekten af dyb jordløsning – samt indflydelse på samdyrkning. B.Sc-project, Institut for Jordbrugsvidenskab, KVL (available at http://dvjb1.kvl.dk/ALEPH)**

G. National and international cooperation

The project has coorporated closely with Martin Heide Jørgensen and the project 'Teknologiudvikling I Økologisk Jordbrug', in which the ridge planter has been developed. The project has also cooperated with Finn Pilegaard Vinther and the DARCOF-project 'Dinitrogen fixation and nitrous oxide losses in organic grass-clover pastures: An integrated experimental and modelling approach (DINOG)' and the EU-project 'Greenhouse gas mitigation for organic and conventional dairy production (MIDAIR)' on investigating the nitrogen fixation in faba beans grown on ridges compared to flat soil.

WP 5 and WP 6 are closely co-ordinated with the research conducted in the EU project 'Development of a system-approach for the management of late blight in EU-organic potato production' (Blight MOP) in which Bent J. Nielsen and Jens Peter Mølgaard have been participating. Where possible, the same varieties and design have been used.

H. Critical reflection on the project

General reflections for the project as a whole

The project has been running fairly close to the initial plans described in the application, but in the last part of the project the focus has been shifted from potatoes grown in ridge tillage systems without preceding ploughing to ridge planting of other row crops after ploughing.

It is considered to be disappointing from an applied perspective that the project has not shown any strengthening of the possibilities to control late blight by mixing potato varieties or mixing potato and faba bean. This disappointment is counterbalanced by valuable scientific knowledge on the epidemics of late blight and knowledge about the required plot size to make conclusions about potato mixtures relevant in a practical context.

It was hypothesized that catch crops were able to reduce *Rhizoctonia* stem canker. This was supported by field experiments in 2003 where a new experimental approach based on artificial inoculum was used. Previous findings in this project could not support the hypothesis, most likely due to methodological problems by using natural infestation of *R. solani*. Considerations about developing a new experimental technique were discussed in the Midterm Status Rapport 2002.

The project has shown potential for ridging in winter without preceding ploughing as an alternative to traditional potato production based on ridging in spring after ploughing. It requires, however, good workmanship and appropriate machinery to establish ridges on wet soils with relatively high clay content in late autumn and winter.

Ridge planting of row crops (especially maize) has given encouraging results in pilot studies at KVL and St. Jyndevad. This aspect has been emphasized in the last part of the project and has directly fostered an initiative to perform a thorough investigation of the potential for ridge planting of maize in Denmark in collaboration with the Danish Agricultural Advisory Service and Sejet Planteforædling.

Reflections on tillage systems

The factorial field experiments with catch crops and incorporation of animal manure in WP1 and WP2 were found to be significantly more expensive than budgeted. In consequence, the most expensive experiments were terminated after two years and the main efforts in the last experimental year were concentrated on 1) the lysimeter experiment (WP1), 2) pilot studies comparing various crops grown on ridges (WP2), 3) the subsoiling experiment at St. Jyndevad (WP4) and 4) a pilot study with subsoiling in different growth stages of potato (WP4).

Regarding nitrogen management, the experiments have so far confirmed that ridging may hold the potential to decrease leaching and increase plant available nitrogen. Measurements of bromide transport, and nitrate in lysimeter samples have demonstrated decreased leaching and measurements of soil inorganic nitrogen has demonstrated increased nitrogen availability in spring. At the same time, the higher yield of barley grown after ridging in the lysimeter experiment indicates that barley is capable of utilizing the extra nitrogen. Since yield advantages in barley have also been found in previous studies at KVL, but not consistently in other crops in this study, it could be hypothesized that ridging is more successful in crops with a high nitrogen requirement early in the growing season than in crops with a more sustained nitrogen requirement during the growing season.

It has been difficult to establish Brassica catch crops on ridges. Catch crops are almost solely established in the furrows between ridges. This may not have a negative impact on leaching but a better establishment would stabilize the soil, increase soil porosity and secure competition against weeds. Using the ridge planter developed at Research Centre Bygholm has partly solved this problem.

Our experiments show that ridge-incorporated ryegrass is not fully decomposed in spring and may reduce seedbed quality in spring.

Weed control in autumn after early autumn ridging is challenging. It is not advisable to flatten out ridges and rebuild them in late autumn because mineralization will be enhanced. Weed seedlings, however, may be controlled efficiently by repeated harrowings. Perennial weeds, however, cannot be controlled without levelling the ridges.

In this project, ridging is used as a one-year treatment in an existing arable system based on ploughing. Ridges have been set up after spring barley at KVL and after winter rye at St. Jyndevad. Results have to be interpreted in this context. Timing of setting up ridges, weed pressure and residual soil nitrogen would be different if the experiments had been established in a vegetable cropping system.

Reflections on mixed cropping

The experiments have been conducted according to the plans. The results in terms of postponing the epidemic development of late blight have been somewhat disappointing. One possible explanation for the lack of treatment effects in the year 2001 was very strong winds, which blew at the time of the first blight infections in the trial field. However, in 2002 and 2003 (only potato-faba bean mixtures conducted) we had usual weather conditions, which indicate that the mixed cropping does not have the presumed positive effect on late blight. We therefore have to conclude that under the given conditions a mixture of potatoes and faba bean and mixtures of potato cultivars did not postpone the development of late blight as expected. It should be noted that the results of the potato mixture trials are not in agreement with results from a French study (Andrivon et al. (2003) Plant Pathology 52, 586-594) where late blight was significantly lower in a susceptible variety grown in alternating rows with a partially resistant variety. Other mixing strategies might also reduce disease under Danish conditions. The faba bean mixture may still have a positive effect in terms of reducing aphid attacks in faba beans, but due to inferior prevalence of aphids no conclusion can be drawn on this point. The experiments have revealed a positive effect of growing faba beans on ridges. In collaboration with two other projects the nitrogen fixation in faba beans on ridges is being investigated. The preliminary results are promising. This has inspired us to establish a pilot project investigating the possibilities of growing other nitrogen fixing crops as well as non-fixing crops on ridges.

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	Consumption 2004	Total
Man-months	82,5	61	12	12,5	85,5
Scientific personnel	63,5	43	7	12,5	62,5
Technical personnel	24,0	18	6	0	24

Year:	Original budget	Consumption before 2003	Consumption 2003	Consumption 2004	Total
Salaries	2655	1833	360	504	2697
Scientific personnel	2081	1403	216	504	2123
Technical personnel	574	430	144	0	574
Other operational costs	1257	1041	164	100	1305
Equipment					
Others (please specify)					
Direct costs	3912	2874	524	604	4002
Indirect costs (20% of direct costs)	783	574	105	121	800
Total	4700	3448	629	725	4802[1)]

Comments:
The additional expenditure on 102.000 DKK compared to the budget has been funded by KVL. The additional expenditure was made in 2004.

9. Signatures and stamps

Name	Institute	Date	Signature
Head of project Jesper Rasmussen	Department of Agricultural Sciences, KVL	10 April 2005	

Appendix I. Detailed budget

A. Budget for each participating institute (1.000 DKr)

Name of Institute: KVL

Year:	Original budget	Consumption before 2003	Consumption 2003	Consumption 2004	Total
Man-months	43	29	1	11	41
Scientific personnel	43	20	1	11	41
Technical personnel	0	0	0	0	0

Year:	Original budget	Consumption before 2003	Consumption 2003	Consumption 2004	Total
Salaries	1376	915	48	454	1417
Scientific personnel	1376	915	48	454	1417
Technical personnel	0	0	0	0	0
Other operational costs	746	611	137	45	793
Equipment					
Others (please specify)					
Direct costs	2122	1526	185	499	2210
Indirect costs (20% of direct costs)	428	305	37	100	442
Total	2550	1831	222	599	2652

Comments:

B. Budget for each participating department (1.000 DKK)

Name of Institute and department: DJF

Year:	Original budget	Consumption before 2003	Consumption 2003	Consumption 2004	Total
Man-months	44,5	32	11	1,5	44,5
Scientific personnel	20,5	14	5	1,5	20,5
Technical personnel	24,0	18	6	0	0

Year:	Original budget	Consumption before 2003	Consumption 2003	Consumption 2004	Total
Salaries	1280	918	312	50	1280
Scientific personnel	706	488	168	50	706
Technical personnel	574	430	144	0	574
Other operational costs	512	430	27	55	512
Equipment					
Others (please specify)					
Direct costs	1792	1348	339	105	1792
Indirect costs (20% of direct costs)	358	269	68	21	358
Total	2150	1617	407	126	2150

Comments: