



Midterm Status Report 2002 and Application for Continuation in 2003

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The Directorate for Food, Fisheries and Agro Business
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1. Research program

Research in organic farming 2000-2005 (DARCOF II)

2. Project title and number

I.7. Soil quality in organic farming: Effects of crop rotations, animal manure and soil compaction (ROMAPAC)

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attached to the project, see point '7. F. Scientific education')

6. Project period (month, year)

Start of project:	04, 2000
End of project:	12, 2002

7. Midterm description of the project, its results and progress, and application for continuation in 2003

A. Project summary

General project summary

The ROMAPAC project will address some basic characteristics and functions of soil that are of paramount importance for organic farming. The aim is to improve the understanding of the managed soil ecosystem, and at the same time derive results that are applicable to the practical development of organic farming. The project includes two research topics, labelled A and B. Both topics were also addressed in a former DARCOF project (1996-1999) and the ROMAPAC project is a close follow-up on this. Dissemination of results to consultants and farmers has a high priority in the ROMAPAC project as we consider a higher attention to the compaction aspect included in both research topics essential for the development of organic farming.

Research topic A is concerned with the effects of subsoil compaction and loosening upon soil conditions and crop performance. It is the aim to elucidate how subsoiling of a compacted soil layer affects the growth of roots and shoots, and eventually crop yields in terms of biomass as well as nutrient uptake. The effects of weed growth are included in the studies too. It is further intended to evaluate the possibility of avoiding re-compaction of loosened soil by using on-land ploughing and by controlling axle loads and tyre pressures of vehicles trafficking the soil. Two existing field trials and three soil types are included in these studies.

Research topic B is concerned with the topsoil tilth. A stable but yet friable soil is a major concern in order to obtain optimal growing conditions for plants. The soil tilth further determines the living conditions for soil biota. Results from the former DARCOF-project indicated important long-term influence of crop rotation and application of animal manure. Further, the results indicated a pronounced negative influence of tillage and traffic intensity. Generally, therefore, the positive effects on soil fertility from cropping and fertilisation practices are prone to destructive forces from tillage and traffic. In the ROMAPAC project, further studies are performed to increase our knowledge of the relative importance of each of these basic management tools and their interactions. We address the processes involved in the formation and stabilisation of soil structure. The resulting tilth is quantified in terms of structural strength/friability and characteristics of soil pores as a habitat for microorganisms. Two field trials and two soil types are included in these studies.

The investigations in the ROMAPAC project are expected to give organic farming valuable and directly applicable conclusions on the effects of subsoiling compacted land. Another achievement will be a better understanding of the basic mechanisms in creation of a tilth optimal to soil behaviour and functions. This knowledge has general value in order to envisage consequences from different management strategies.

Overview of project structure and methodology

Conceptual framework for research topic B

As mentioned above, the ROMAPAC project includes two research topics, A and B. For the latter concerned with the tilth and tilth forming processes, we have created a conceptual framework in which we perform our investigations, Figure 1. The combined concepts of *tilth* and *tilth forming processes* as defined in the boxes overleaf constitute an extremely relevant framework for studying soil fertility and quality as related to the organic farming system. Crop rotation, animal manure and compaction by traffic are key factors in the **formation and stabilisation of soil structure** (tilth-forming processes), cf. Figure 1. The **structural strength and friability** and the **soil pores as a habitat for microorganisms** express the resulting soil tilth, cf. Figure 1.

Soil tilth

The physical condition of a soil described by its bulk density, porosity, structure, roughness, and aggregate characteristics as related to

- *water, nutrient, heat and air transport*
- *stimulation of microbial and faunal populations and processes*
- *impedance to seedling emergence and root penetration*

Tilth-forming processes

The combined action of physical, chemical, and biological processes that bond primary soil particles into simple and complex aggregates and aggregate associations that create specific structural or tilth conditions

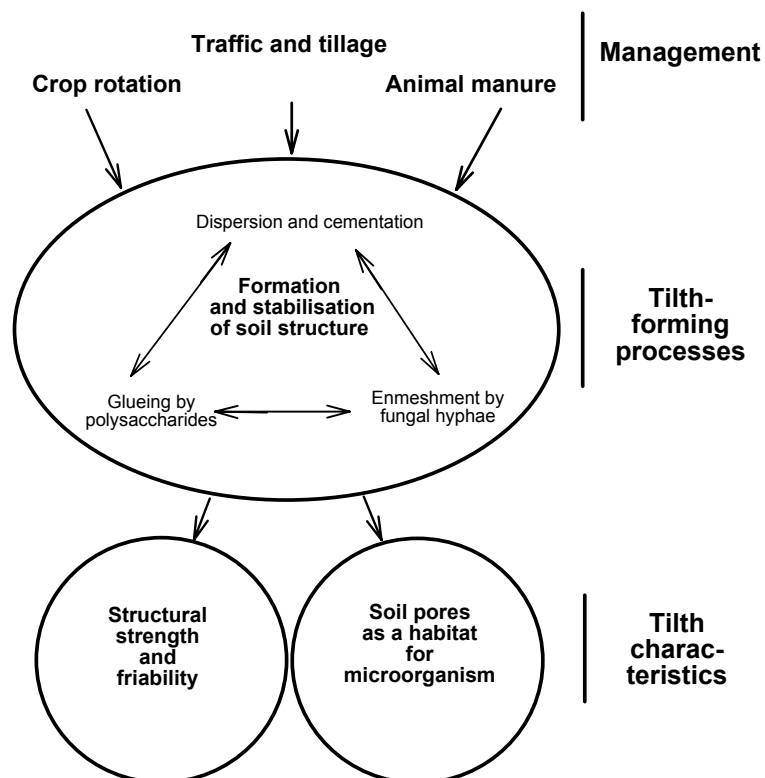


Figure 1. The conceptual framework of research topic B.

Research 'objects'

The ROMAPAC project makes use of three existing field trials as research 'objects':

- Development of tillage strategies (DTS)
- Crop rotation experiment (CRE)
- Levels of input of animal manure (LAM)

The DTS and the CRE trials were initiated in 1996 as part of the initial set-up of field experiments by DARCOF. The soils used for the trials were converted to organic farming at the initiation of the trials, and the soils at all sites have now fully adapted to the crop rotations and management strategies imposed. The LAM trial was initiated in 1987 and is run with four different levels of organic inputs to the soil. Within the CRE trial, three crop rotations are addressed and labelled CRE₁₋₃. The characteristics of the CRE rotations are explained in some detail below. Figure 2 shows how ROMAPAC uses the trials in relation to its research topics.

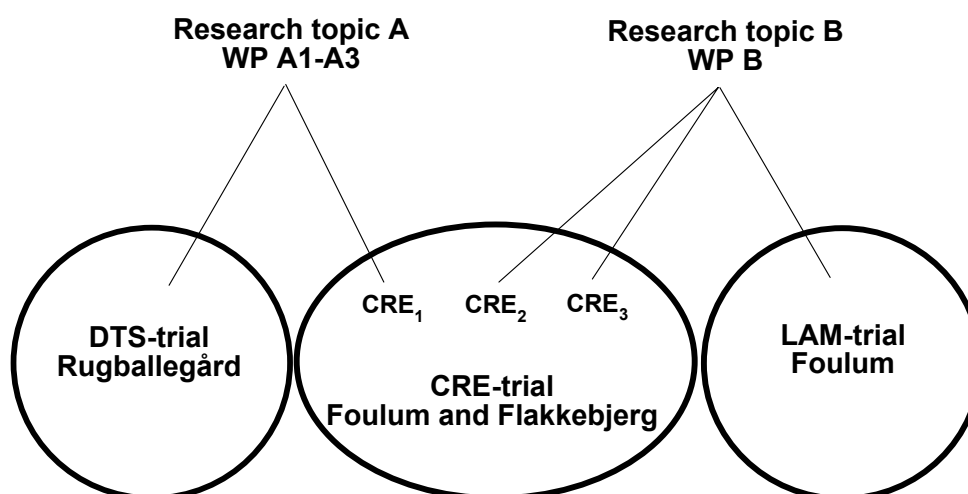


Figure 2. Project structure in terms of field trials addressed within the research topics A and B. DTS = Development of tillage strategies, CRE = Crop rotation experiments, LAM = Levels of input of animal manure

The crop rotations in the CRE trial are all four-course rotations, but they differ in their proportion of nitrogen fixing crops and the use of catch crops:

Rotation CRE₁ [WP A2, WP A3]:

- Spring barley undersown with a grass/clover mixture
- Grass/clover mixture for green manure
- Winter wheat
- Lupine

Rotation CRE₂ [WP B]:

- Spring barley undersown with a grass/clover mixture
- Grass/clover mixture for green manure
- Winter wheat with undersown catch crop of ryegrass
- Lupine with undersown catch crop of ryegrass

Rotation CRE₃ [WP B]:

- Spring barley
- Spring oats
- Winter wheat
- Lupine

Content of each workpackage

WP A1. Development of tillage strategies including recompaction evaluation

The primary task in WP A1 is to run the field trial with development of tillage strategies initiated in 1996. The trial plots will then be utilised by WP A3 for evaluation of tillage effects on soil characteristics and root growth. From year 2001, modifications were made in order to evaluate the risk of re-compaction of loosened soil by traffic and during mouldboard ploughing. These

treatments will be investigated in a crossed split-plot design for the basic treatments with non-inverting deep tillage.

WP A2. Above-ground crop response to compaction and subsoiling

When characterising the soils for the CRE trials, measurements of penetration resistance showed clear indications of compaction of the soil beneath the plough layer. The overall task in WP A2 is therefore to evaluate the effects of the existing compacted soil and the effects of subsoil loosening upon crop performance.

For each of the years 2000 through 2003, half of the plots (two subplots) grown with the recently established grass/clover crop is subjected to subsoil loosening to a depth of ~40 cm by means of a Howard Paraplow. The soil loosening is carried out after harvest of the cover crop (starting in 2000). I.e., for each location and year, four additional replicate plots will be provided for studies of the effect of subsoil loosening (two plots without manure and two plots with manure application).

For each of the years 2001 through 2003, a number of registrations are performed at the two locations in plots grown with cereals and leguminosae (i.e., excluding the grass/clover ley crop):

- Yields and content of N, P and K in the harvested material
- Total above-ground plant production, including content of N
- Above-ground weed biomass
- Weekly measurements of crop spectral reflectance for assessment of light interception.

WP A3. Soil effects and root response to compaction and subsoiling

In WP A3, the task is to evaluate the subsoiling effects on soil physical characteristics and root growth. The treatments in the DTS trial at Rugballegård as well as those in the CRE₁ rotation at Foulum are included in these investigations. For the DTS trial, the subsoiled treatments are evaluated with traditionally ploughed soil as a reference. Further, the measurements include the new treatments regarding traffic and ploughing strategy (see WP A1).

For all combinations of locations and treatments, the mechanical strength of the soil in the 0-60 cm layer is evaluated by cone penetration measurements. These measurements take place in the spring at water contents of field capacity. Soil sampling for bulk density and micro-penetrometer studies, and measurements of root growth are performed according to the plan below. These studies take place in a winter wheat crop.

	2001	2002	2003
DTS, field B3	R _s +R _r		
DTS, field B4		R _s +R _r +S+W	
CRE ₁ , Foulum			R _s +R _r +S+W

R _s :	Root studies by soil core sampling, washing and quantification of root length
R _r :	Root studies by rhizotron-studies in the field during the growing season
S:	Soil physical studies on core samples at controlled water potential
W:	Water content measurements by Time Domain Reflectometry technique during the growing season

WP B. Topsoil tilth as affected by crop rotations, animal manure and traffic

This workpackage covers all aspects in research topic B. The reason for not differentiating this work into several workpackages is the fact that the aspects included in the topic should be treated in one context all the way through the project. However, several tasks are of course included as described below.

Research objects

As already described, ROMAPAC benefits from the accumulated effects of crop rotation and animal manure amendments found in the existing CRE and LAM field trials. Samplings and measurements for this purpose took place in year 2002 in a winter wheat crop and will be repeated in 2003.

At Foulum, the effects of differentiated crop rotations are studied in the CRE trial by sampling in the CRE₂ and CRE₃ rotations. The manure effects at Foulum are studied in the LAM trial.

At Flakkebjerg, the crop rotation effects as well as the manure effects are studied in the CRE trial. The crop rotation effects are elucidated by addressing the CRE₂ and CRE₃ rotations, - both without application of animal manure. The organic manure effects are elucidated by addressing plots of the CRE₃ rotation with and without amendments with animal manure (CRE₃₊ and CRE₃₋). I.e., at Flakkebjerg the CRE₃₋ plots serve as a common reference for both main effects.

Treatments prior to sampling and measurements

In order to enable the study of the interaction between the basic crop and manure effects and the mechanical disturbance by field traffic, half of the plots selected for studies of crop and manure effects are treated as follows. In the years 2000 and 2001, the soil was trafficked 'wheel by wheel' immediately following mouldboard ploughing prior to establishing the specific crops. The traffic treatment was repeated again in 2002 at the plots to be sampled in 2003. For the CRE₂ rotation the crop preceding the winter wheat is grass/clover mixture. In this case, the traffic takes place in the crop in the spring at water contents of field capacity.

Field measurements

Field measurements and sampling for laboratory studies take place in the winter wheat crop in the spring at water contents of field capacity. The *in situ* measurements include a quantification of 'ease of fragmentation' by the soil drop method. The method involves drop from a specified height of minimally disturbed soil cubes sampled immediately before the test. Further, the shear strength is measured by the shear vane method and by the torsional shear box method. All characteristics are measured for the 6-13 cm soil layer.

Laboratory studies

Soil is sampled in minimally disturbed cubes, in minimally disturbed 100 cm³ cores and also in remoulded form. The remoulded soil is air-dried at arrival at the laboratory while the minimally disturbed samples are stored at 2°C until analyses.

Soil textural composition and content of C, P and K are analysed by standard methods. Air-dried soil is fractionated to yield aggregates in the four size-classes 8-16, 4-8, 2-4 and 1-2 mm. Aggregate tensile strength is measured on these aggregates. An index of soil friability is then estimated from the slope of an aggregate tensile strength / aggregate volume relation in a log-log presentation. Stability of wet aggregates that are sub-sampled from the minimally disturbed cubes is measured by a wet-sieving procedure. Dispersibility of clay from bulk soil derived from the same soil cubes is quantified with a turbidimetric measurement of dispersed clay following a mechanical shaking procedure.

Water retention is measured with standard technique at a number of predefined matric potentials (including -10 kPa), using the 100 cm³ minimally disturbed cores. Further, bulk soil air diffusivity and permeability are measured when equilibrated at each of the matric potentials. Finally, water retention at -100 kPa and -1.5 MPa matric potentials is measured in order to quantify the habitable and protective pore space.

Extracellular polysaccharides (EPS) are measured after extraction with hot water. Fungal hyphal lengths are determined by epifluorescent microscopy using calcofluor staining. Finally, microbial biomass C is determined by the fumigation-extraction method. Soil for the methods mentioned here is sub-sampled from the minimally disturbed soil cubes. I.e., measurements will take

place in field-moist soil.

WP C. Project co-ordination and dissemination of results

Co-ordination of the whole project including dissemination of results has been designed a separate workpackages. This is partly due to the fact that the two topics included in ROMAPAC – although generally correlated – constitute two separate task forces. Another important task included in this workpackages is dissemination of results to consultants and farmers.

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

No.	Work package title	Participants*	Budget (1.000DKr)	Start	End	Deliverable No:
A1	Development of tillage strategies including recompaction evaluation	<u>PS</u> , LJM, (TSM)	468	04/00	12/02	D1, D2, D3
A2	Above-ground crop response to compaction and subsoiling	<u>JEO</u> , PS, LJM	777	08/00	12/04	D4, D5, D6
A3	Soil effects and root response to compaction and subsoiling	<u>LJM</u> , PS, JEO	1435	01/01	12/04	D7, D8
B	Topsoil tilth as affected by crop rotations, animal manure and traffic	<u>PS</u> , SE, LJM	2679	04/00	12/04	D9, D10
C	Project co-ordination and dissemination of results	<u>PS</u> , JEO, LJM, SE	272	04/00	12/04	D11, D12, D13, D14, D15

* Responsible participants are underlined

B. Objectives and expected achievements

Aims and objectives

The general objective of the ROMAPAC project is to quantify the effects of some basic management tools upon the quality of organically managed soil. In this context, the project also addresses the existing compaction of subsoil derived from the use of heavy machinery in Danish agriculture. In order to reach this goal and to further differentiate our understanding, we set up the following specific objectives.

- Evaluate whether the widespread occurrence of subsoil compaction in Danish agricultural land generally reduces the production potential and important functions of organically managed soil [WP A1, WP A2 and WP A3]
- Determine whether mechanical loosening of a compacted soil layer may improve crop performance through better conditions for root growth and other biological processes [WP A1, WP A2 and WP A3]
- Investigate whether low axle loads and tyre pressures as well as on-land ploughing will reduce compaction and re-compaction of mechanically loosened soil [WP A1 and WP A3]
- Quantify the effects of crops and animal manure on abiotic and biotic mechanisms involved in the tilth-forming processes [WP B]
- Reveal the relative importance of mechanical disturbance in terms of soil surface traffic on the crop and animal manure effects mentioned above [WP B]
- Investigate soil behaviour in terms of strength and friability as affected by the tilth-forming processes and in turn the management tools involved [WP B]
- Investigate soil porosity as related to its function as a habitat for microorganisms in the

framework of the management tools investigated [WP B]

- Evaluate and confirm recent findings on the correlation between descriptive/integrating field methods and differentiating laboratory methods for evaluation of soil tilth [WP B]

Finally, the ROMAPAC project includes as one of its objectives to disseminate the results to consultants and farmers as the practical implications of the achievements is regarded of high importance to a successful development of organic farming [WP A1, WP A2, WP A3, WP B and WP C].

Expected achievements

Organic farming has to rely on an optimal function of all parts of the soil ecosystem. In order to achieve this, it is essential to procure a high level of understanding of soil behaviour and functions. The organic farmer should base his decisions for all management strategies on this knowledge.

Based on the studies in research topic A (WP A1-3), the ROMAPAC project will increase our insight in the effects of compacted subsoil on key aspects of crop growth. First of all, this will include the effects on the crop yields. Moreover, an increased knowledge about the effects on root growth and uptake of plant nutrients is believed to be valuable for development of organic farming. Further, knowledge about the effects of subsoiling may create the basis for general recommendations on how organic farmers should include this tillage procedure in their soil management. Finally, the results may serve as a basis for general recommendations for organic farmers concerning maximum permissible axle loads and tyre pressures.

The studies in research topic B (WP B) are anticipated to increase our knowledge on the basic mechanisms in creation of a tilth optimal to soil behaviour and functions. This knowledge has general value in order to envisage consequences from different management strategies. It further quantifies the relative effects of crop rotations and amendments with organic manures. This has practical implications as it provides an indication of the potentials and problems in specific types of organic farming.

The high impact of intensive tillage and traffic on key topsoil tilth properties that was detected in the former DARCOF-project I.3, in the present project will be studied in close connection to the effects of crops and amendments with manure. It is anticipated that this will yield the opportunity to more specifically interpret the relative effects of the management tools. The practical implications manifest themselves in terms of recommendations for traffic and tillage strategies in organic farming.

C. Midterm results and progress

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

The ROMAPAC project is running in close agreement with the plan. In this section, we give examples of the results obtained in each of the workpackages.

WP A1. Development of tillage strategies including recompaction evaluation

For two of the fields of the DTS trial at Rugballegaard, the ROMAPAC project in 2001-2002 successfully introduced new treatments on the formerly mechanically loosened soil. On-land ploughing was compared with traditional mouldboard ploughing with the tractor wheels in the furrow. In addition, the plots were trafficked with reduced and high axle loads, respectively. The effects on crop yield in year 2001 are tabulated in Tables 1 and 2. For none of the fields did the on-land ploughing affect the yield as related to traditional ploughing with the wheel in the furrow. The traffic system with low axle loads tended to give higher yields in the oat crop (Table 1), while

no effects could be detected for the winter wheat crop (Table 2).

Table 1. Yields of oats (relative numbers) for the B4 field at Rugballegaard, 2001. The differences are not statistically significant ($P>0.05$).

Traffic system	Low axle load		High axle load	
Ploughing system	On-land	In furrow	On-land	In-furrow
Relative yield	102	104	101	100

Table 2. Yields of winter wheat (relative numbers) for the B3 field at Rugballegaard, 2001. The differences are not statistically significant ($P>0.05$).

Traffic system	Low axle load		High axle load	
Ploughing system	On-land	In furrow	On-land	In-furrow
Relative yield	98	96	97	100

WP A2. Above-ground crop response to compaction and subsoiling

The subsoiling of selected plots of the CRE trials at Foulum and Flakkebjerg was performed in the autumn of 2000, 2001 and 2002. The implement used was a Howard Paraplow, which loosens the soil to a depth of 35-40 cm without inverting the soil. Table 3 gives the average ratio vegetation index (RVI) measured in 2002 in the winter wheat crops at both sites and for the grass-clover at Flakkebjerg. There were no significant effects of subsoil loosening in these results, but there were tendencies at all sites and crops for reduced RVI after loosening, indicating that crop growth may have been negatively effected by the subsoiling. The tendency in the grass-clover field is interesting because the result obtained in the winter wheat may be due to a reduced pre-crop effect rather than a direct effect of the subsoiling. Yield results are not yet available.

Table 3. Average ratio vegetation index (RVI) measured during the growing season in 2002 in crops with and without subsoil loosening. The effects are not statistically significant ($P>0.05$).

Site	Crop	RVI	
		Without loosening	With loosening
Foulum	Winter wheat	4.52	4.19
Flakkebjerg	Grass-clover	7.76	7.12
	Winter wheat	5.27	5.15

WP A3. Soil effects and root response to compaction and subsoiling

The measuring programme on soil as well as below-ground crop (root) effects at the DTS trial was concluded in mid 2002. The results include studies in winter wheat grown in field B3 in year 2001 and in field B4 in year 2002. For both years, the measuring programme included penetration resistance in the field to 60 cm depth in the spring, and a recording of root growth in mini-rhizotrons inserted slantingly into the soil to a depth 100 cm vertically below the soil surface. In year 2002 the programme also included sampling of soil cores for estimating the root length after washing out the soil, and other cores for determination of soil physical characteristics. As an example of the results, Figure 3 displays the relative frequency of roots in the soil profile of two selected treatments. The Figure to the left shows the situation in the spring, while that to the right reflect the situation later in the growing season. In the spring, the subsoiling that was performed four years prior to this growing season yielded improved rooting as compared to the reference never tilled below ploughing depth. Later on in the growing season, however, the difference be-

tween the two treatments disappeared and at the end of the growing season there was even a clear indication of a deeper rooting in the reference soil, Figure 3, right. The improved rooting in the loosened soil early in the season corresponds well with a lower penetration resistance found for this soil in the plough pan region (25-35 cm depth). The reason for the change during the growing season is yet unclear. We await the results from the 2002 measurement in field B4 to evaluate the trends found in 2001.

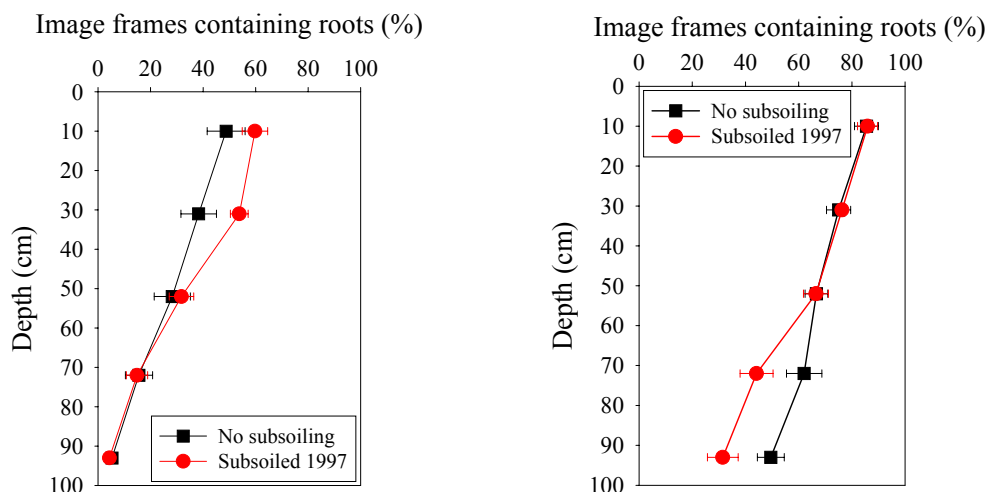


Figure 3. Relative frequency of minirhizotron image frames containing roots in spring (left) and summer (right) for soil without any subsoiling and for soil that was subsoiled in 1997. Both treatments were managed with on-land ploughing.

WP B. Topsoil tilth as affected by crop rotations, animal manure and traffic

The selected plots of the field trials CRE at Foulum and Flakkebjerg and those of the LAM trial at Foulum were compacted wheel by wheel in the spring and the autumn of 2001. For the LAM trial, an additional treatment with rotovator was included in the trial. The first field measurements and sampling for soil took place in the spring of 2002, and a comprehensive measuring programme is carried out in the laboratory at the moment (September 2002). As an example of the results obtained, we discuss below the CRE trial at Flakkebjerg.

Prior to the start of the CRE field at Flakkebjerg, the field selected for the investigation had been grown with annuals for cash cropping (primarily small grain cereals) for a couple of decades. By this management, the soil organic matter content had declined considerably, and the soil structure had degraded accordingly. In many respects, this field may thus be regarded as ideal for studies in the potential of different crop management strategies. The field measurements planned to take place at the time of sampling included a measurement of soil friability in terms of soil fragmentation caused by a selected energy input to a soil cube. However, it appeared that the soil was generally too plastic and coherent to fragment when the cube was dropped as part of the method in the spring 2002 (at field capacity). Hence, it was impossible to differentiate the structural conditions of the crop rotations selected for studies by this method. It appears, however, that something has indeed taken place in the soil in terms of microbial biomass, Figure 4. The CRE₃ rotation dominated by annuals and with no use of catch crops still exhibits a very low level of microbial biomass. The application of animal manure in terms of slurry in this crop rotation (CRE₃₊) has significantly increased the biomass. However, it appears that the alternative crop rotation (CRE₂) including grass/clover and catch crops has induced an even higher increase in the biomass of microbes in the soil.

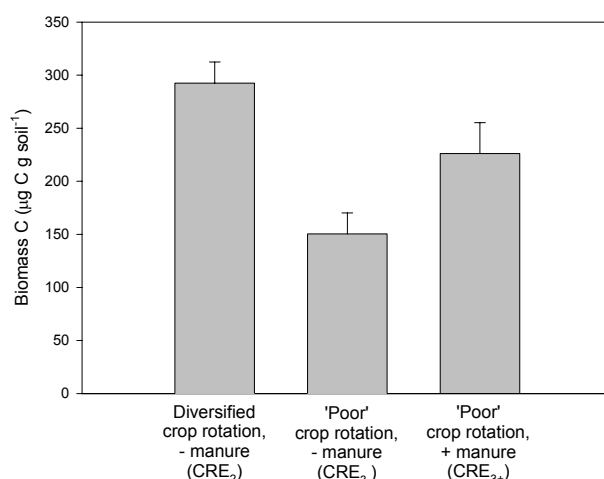


Figure 4. Microbial biomass measured in the spring 2002 for selected crop rotations in the CRE trial at Flakkebjerg. Bars indicate standard error.

The ROMAPAC project aims at elucidating the mechanisms in stabilisation of soil structure. Fungal hyphae contribute to enmeshment of mineral particles and hence the creation of stable aggregates (Figure 1). Our measurements on the amount of hyphae in the soil clearly indicate that also in this respect, soil biota has initiated changes in this degraded soil, Figure 5. However, from these our first data, application of animal manure appears to induce nearly no effect on the hyphae, while the crop rotation has a significant effect.

The only soil physical measurements completed so far (September 2002) are the tests on dispersible clay and stable macroaggregates. However, the results obtained in 2002 showed no significant effects on these parameters. We are now curious to see if the other soil physical characteristics addressed in the project will reflect the indications derived from the soil biota that the tilth of this degraded soil is being improved through the adverse management strategies.

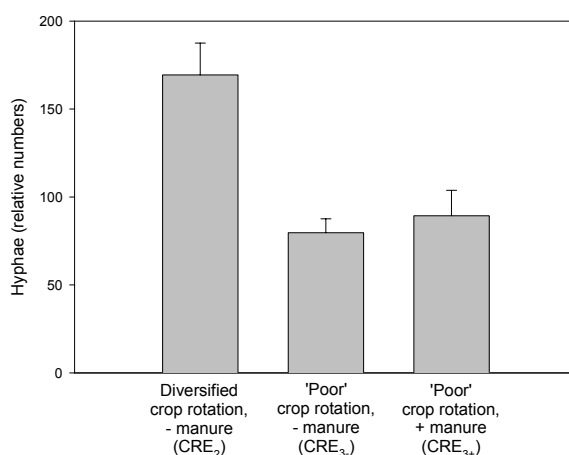


Figure 5. Fungal hyphae measured in the spring 2002 for selected crop rotations in the CRE trial at Flakkebjerg. Bars indicate standard error.

WP C. Project co-ordination and dissemination of results

Please consult point 7.E of this report for a list of lectures and reports aimed at organic farmers and consultants.

C.2 Fulfilment of deliverables and milestones

WP A1: Development of tillage strategies including re-compaction evaluation	Time schedule according to application	Deviations, if any*
Deliverables		
D1 Research objects for DARCOF project IV.3	04/2000	Delivered
D2 Research objects for WP A3	04/2001	Delivered
D3 DARCOF-report on 1997-2000 years trial results	03/2002	(delivered)
Milestones		
1 Trial performed by old plan	10/2000	Fulfilled
2 On-land plough has been procured and used first time	04/2000	Fulfilled
3 The controlled traffic strategy has been implemented	06/2000	Fulfilled
4. A DARCOF-report on tillage strategies has been publ.	03/2002	(Fulfilled)

WP A2: Above-ground crop response to compaction and subsoiling	Time schedule according to application	Deviations, if any*
Deliverables		
D4 Demonstration of effects for farmers (field-days)	06/2002-2004	Delivered
D5 Research objects for WP A3	04/2002	Delivered
D6 International scientific paper	10/2004	
Milestones		
1 All subsoiling performed	08/2003	
2 All measurements performed	10/2004	
3 International paper submitted	12/2004	

WP A3: Soil effects and root response to compaction and subsoiling	Time schedule according to application	Deviations, if any*
Deliverables		
D7 Presentation of results at international Conference	06/2003	
D8 International scientific paper	11/2004	
Milestones		
1 Rhizotron studies of roots have been implemented	04/2001	Fulfilled
2 Core sampling completed at Rugballegård, field B3	06/2001	see D
3 Measurements and samplings completed at Rugb. B4	06/2002	Fulfilled
4 Measurements and samplings compl. Foulum and Fl.	06/2003	
5 Presentation of results at ISTRO Conference	06/2003	
6 International scientific paper(s) submitted	12/2004	

WP B: Topsoil tilth as affected by crop rotations, animal manure and traffic	Time schedule according to application	Deviations, if any*
Deliverables		
D9. Presentation of results at international Conference	06/2003	
D10. International scientific paper(s)	11/2004	
Milestones		
1 Compaction treatments in sub-plots completed	10/2001 and 10/2002	Fulfilled
2 Field measurements and samplings 2002 completed	05/2002	Fulfilled
3 Laboratory measurements for 2002 samplings compl.	01/2003	
4 Field measurements and samplings 2003 completed	05/2003	
5 Presentation of results at ISTRO Conference	06/2003	

6 International scientific paper(s) submitted	12/2004	
WP C: Project coordination and dissemination of results	Time schedule according to application	Deviations, if any*
Deliverables		
D11 Project manual	09/2000	Delivered
D12 1. 2. 3. 4. Annual status report	11/2001 – 11/2004	(Delivered)
D13 Papers in farmers' magazines	no specific date	Delivered
D14 Oral presentations at seminars and meetings	no specific date	Delivered
D15 Final status report	10/2004	
Milestones		
1 Project manual completed	10/2000	Fulfilled
2 Annual status reports completed	11/2000 – 11/2004	(Fulfilled)
3 Final status report completed	10/2004	

* Deviations are to be further discussed in D

D. Description of deviations and subsequent adjustments of plans

Workpackage A1. Development of tillage strategies including recompaction evaluation

No changes in plans.

Workpackage A2. Above-ground crop response to compaction and subsoiling

According to the original plan, the subsoil loosening should have taken place in the lupine crop. However, in order to reduce risk of recompaction from tractors and tillage implements in the treated plots, it was decided to apply the treatments to the young grass/clover ley crop about one month after the harvest of the cover crop. Because of this the measuring programme on above-ground crop response is delayed one year (the grass/clover ley is not included in this measuring programme).

Workpackage A3. Soil effects and root response to compaction and subsoiling

In 2001 the minirhizotron technique was not supplemented by root studies on core samples as originally planned. The soil was simply too dry for core sampling at the time of sampling (middle of July).

The washing of roots found in soil cores has proved to be a very labour-demanding procedure. Hence, we have decided to concentrate the 2003 studies solely on the CRE Foulum trial. In the original plan, we aimed at a sampling also at the Flakkebjerg location.

Workpackage B. Topsoil tilth as affected by crop rotations, animal manure and traffic

In the project description, we planned to have only one sampling in the LAM-trial at Foulum (in spring 2002). However, in order to increase the basis on which we base our conclusions, it has been decided to sample also in this trial in 2003. The sampling and measuring programme will hence be identical both sampling years (2002 and 2003).

Workpackage C. Project co-ordination and dissemination of results

The report on the 1997-2000 results of the DTS trial was scheduled for publication in March 2002. However, due to unforeseen circumstances, it will be published late October 2002 (it is in press pt [September 2002]).

E. Project publications and other products

Papers and reports labelled with one and two asterisks (* **) have been produced with 25-75% and 5-25%, respectively, of the costs paid by the ROMAPAC project. Non-labelled papers have been fully paid by the project.

1. Articles in international, scientific journals with review procedures

**Munkholm, L.J. & Kay, B.D. 2002. Effect of water regime on aggregate tensile strength, rupture energy and friability. *Soil Science Society of America Journal* 66, 702-709.

**Munkholm, L.J., Schjønning, P., Deboz, K., Jensen, H.E. & Christensen, B.T. 2002. Aggregate strength and mechanical behaviour of a sandy loam under long-term fertilization treatments. *European Journal of Soil Science* 53, 129-137.

**Munkholm, L.J., Schjønning, P. & Kay, B.D. 2002. Tensile strength of soil cores in relation to aggregate strength, soil fragmentation and pore characteristics. *Soil & Tillage Research* 64, 125-135.

**Munkholm, L.J., Schjønning, P. & Petersen, C.T. 2001. Soil mechanical behaviour of sandy loams in a temperate climate: case-studies on long-term effects of fertilization and crop rotation. *Soil Use and Management* 17, 269-277.

**Munkholm, L.J., Schjønning, P. & Rasmussen, K.J. 2001. Non-inversion tillage effects on soil mechanical properties of a humid sandy loam. *Soil & Tillage Research* 62, 1-14.

**Schjønning, P., Elmholt, S., Munkholm, L.J. & Deboz, K. 2002. Soil quality aspects of humid sandy loams as influenced by organic and conventional long-term management. *Agriculture, Ecosystems & Environment* 88, 195-214.

**Schjønning, P., Munkholm, L.J., Moldrup, P. & Jacobsen, O.H. 2002. Modelling soil pore characteristics from measurements of air exchange: the long-term effects of fertilization and crop rotation. *European Journal of Soil Science* 53, 331-339.

2. Papers presented at congresses, symposiums, etc.

*Elmholt, S., Munkholm, L.J., Deboz, K. & Schjønning P. 2000. Biotic and abiotic binding and bonding mechanisms in soils with long-term differences in management. pp. 53-62 In: Elmholt, S., Stenberg, B., Grønlund, A. & Nuutinen, V. (eds), *Soil Stresses, Quality and Care. Proceedings from NJF Seminar 310, 10-12 April 2000, Ås. DIAS Report 38, Danish Institute of Agricultural Sciences, Foulum.*

Munkholm, L.J., Schjønning, P. & Elmholt, S. 2002. Soil structure dynamics: Effects of management and water content. Abstract, *Advances in Soil Structure Research workshop, Prince Edward Island, Canada, July 7-9, 2002.*

**Munkholm, L.J., Schjønning, P., Heckrath, G. & Jørgensen, M.H. 2000. Pløjefri dyrkning: effekter på jordens frugtbarhed. *Tidsskrift for Landøkonomi* 4/00, 306-309.

**Munkholm, L.J., Schjønning, P. & Rasmussen, K.J. 2000. Non-inverting tillage: Early-stage effects on soil mechanical behaviour. *Proceedings, 15th ISTRO Conference, Texas.*

Schjønning, P. 2000. Jordens frugtbarhed og kvalitet. *Tidsskrift for Landøkonomi* 4/00, 290-292.

*Schjønning, P. Munkholm, L.J., Deboz, K. & Elmholt S. 2000. Multi-level assessment of soil quality - linking reductionist and holistic methodologies. pp. 43-52 In: Elmholt, S., Stenberg, B., Grønlund, A. & Nuutinen, V. (eds), *Soil Stresses, Quality and Care. Proceedings from NJF Semi-*

nar 310, 10-12 April 2000, Ås. DIAS Report 38, Danish Institute of Agricultural Sciences, Foulum.

Schjønning, P., Munkholm, L.J., Elmholt, S., Deboz, K., Mikkelsen, G.H. & Trautner, A. 2000. Den danske dyrkningsjords tilstand og kvalitet – konsekvenser af trafik og jordbearbejdning. Tidsskrift for Landøkonomi 4/00, 293-300.

3. Reports, articles in agricultural journals, etc.

*Elmholt, S., Stenberg, B., Grønlund, A. & Nuutinen, V. (eds), Soil Stresses, Quality and Care. Proceedings from NJF Seminar 310, 10-12 April 2000, Ås. DIAS Report 38, Danish Institute of Agricultural Sciences, Foulum, pp 179.

Munkholm, L.J. 2001. Fragmentering og smuldringsegenskaber i jord: effekter af vandindhold og dyrkningssystem. Forskningsnytt om Økologisk Lantbruk i Norden 4, 17.

Munkholm, L.J. 2001. Jordens smuldreevne har stor betydning. Økologisk Jordbrug 244, 8.

**Munkholm, L.J., 2001. Soil fragmentation and friability: Effects of soil water and soil management. Ph.D. Dissertation, Department of Agricultural Sciences, The Royal Veterinary and Agricultural University, Copenhagen. DIAS Report No. 73, The Danish Institute of Agricultural Sciences, Tjele, Denmark. 59 pp.

Schjønning, P., Rasmussen, K.J., Munkholm, L.J. & Nielsen, P.S. 2002. Jordbearbejdning i økologisk jordbrug – pløjedybde og ikke-vendende jordløsning (*Soil tillage in organic farming – ploughing depth and non-inversion tillage*). DIAS Report XX. The Danish Institute of Agricultural Sciences (in press).

4. Oral presentations, public meetings, field days, etc.

The topic and the results of the ROMAPAC project have been presented for farmers and agricultural consultants at quite a number of occasions. Most lectures have been performed for organic growers. However, we take the chance of disseminating our results also to conventional farmers at all occasions possible. The list below serves primarily as a documentation of these activities. We apologize for the title of most presentations being in Danish.

Munkholm, L.J. 2000. Field demonstration of the Spade analysis. LØJ-seminar, Bygholm Landbrugsskole/Rugballegård, Horsens, 19 September 2000.

Munkholm, L.J. 2000. Oral presentation and field demonstration of the Spade analysis, Kursus for økologisk planteavlskonsulenter Koldkærgård, 5. October 2000.

Munkholm, L.J. 2001. Jordbehandling med omtanke - Hvordan undgås tryk- og strukturskader? Contribution at the course "Jordbehandling med omtanke". A course for organic farmers held at Landbogården Åbenrå February 7., 2001.

Munkholm, L.J. 2001. Ødelægges jordens struktur ved intensiv jordbehandling og trafik? Contribution at course for conventional and organic farmers held by Samsø Landboforening March 15., 2001.

Munkholm, L.J. 2001. Spadeprøve og jordbearbejdning. Contribution at course for organic farmers held by Landbogården Åbenrå at Rugballegaard Research Station June 6., 2001.

Munkholm, L.J. 2001. Jordløsning på grovsandet jord. Contribution at "Regions-markvandring" a field day held for crop advisors in Ribe County June 12., 2001.

Munkholm, L.J. 2001. Spadeprøven. Contribution at "Markvandring" a field day held at Foulumgård June 14., 2001.

Munkholm, L.J. 2001. Jordpakning og jordstruktur. Contribution at a course for lecturers held at Hovborg Kro June 19., 2001.

Munkholm, L.J. 2001. Spadeprøve og jordbearbejdning. Contribution at field day for advisors and lectures held by The Danish Agricultural Advisory Centre June 26, 2001.

Munkholm, L.J. 2001. Jordbearbejdning og trafik – effekter på jordstruktur og funktion. Oral presentation at the seminar "Planteavls-efterårskonferencen" held by The Danish Agricultural Advisory Centre October 2nd. 2001.

Munkholm, L.J. 2002. "Skadelig pakning". Contribution at "Markvandring" a field day held at Foulumgård June 13th, 2002.

Munkholm, L.J. 2002. "Skadelig pakning og rodvækst". Contribution at field trip held by Landbrugsrådgivning Nord for organic farmers, Ålegårds Mark, June 24th, 2002.

DARCOF II

1.7. Soil quality in organic farming: Effects of crop rotations, animal manure and soil compaction (ROMAPAC)

Schjønning, P. 2000. Jordstruktur og jordfrugtbarhed. Konsekvenser af almindelig markpraksis i dag. Oral presentation at a seminar organized by LØJ, Bygholm Landbrugsskole/Rugballegård, Horsens, 19. September 2000.

Schjønning, P. 2000. Jordstruktur, jordbehandling og udbyttevariation. Oral presentation at a course for agricultural advisors, Koldkærgård, 20. September 2000.

Schjønning, P. 2000. Jordstruktur og mekaniske egenskaber i økologisk jordbrug. Oral presentation at visit from the Royal Veterinary and Agricultural University, 4. October 2000.

Schjønning, P. 2000. Jordpakning i økologisk jordbrug – hvor tunge maskiner kan vi bruge. Oral presentation at Økokongres 2000, Hotel Pejsegården, Brædstrup, 1. November 2000.

Schjønning, P. 2000. Skadelig jordpakning og jordens frugtbarhed – generelt og med henblik på plojefri dyrkning. Oral presentation at a course organized by the Organization for Reduced Tillage in Denmark (FRDK), Scanticon-Comwell, Middelfart, 14. November 2000.

Schjønning, P. 2001. Jordpakning og jordløsning. Status på forskning og udvikling. Oral presentation at a workshop organized by the The Danish Agricultural Advisory Centre, Skejby, 9. February 2001.

Schjønning, P. 2001. Bæredygtig jordbearbejdning og trafik i fremtidens jordbrug. Oral presentation at a workshop organized by the Dep. Agricultural Engineering, DIAS, Snaptun Færgegaard, 22. August 2001.

Schjønning, P. 2001. Jordpakning, jordbearbejdning og jordfrugtbarhed. Oral presentation at visit from the Royal Veterinary and Agricultural University, 3. October 2001.

Schjønning, P. 2002. Reduceret jordbearbejdning og jordens frugtbarhed. Oral presentation at a course for agricultural advisors, Koldkærgård, February 2002.

F. Scientific education

L.J. Munkholm concluded his Ph.D. study ‘Soil fragmentation and friability’ in 2001. This work was an integrated part of a former DARCOF project ‘Soil fertility and soil tillage as influenced by organic farming practices and soil tillage’ (1996-1999). The conclusion of the Ph.D. work has further strengthened and contributed to the work in the ROMAPAC project.

Torben S. Madsen (TSM) carries out a Ph.D. study on the technical aspects of optimization of tillage procedures in organic farming. The ROMAPAC project leader serves as an assistant supervisor for TSM. The Ph.D. project includes aspects of different ploughing systems. Therefore, TSM has been attached to the project group. Part of TSM’s studies is carried out in the field trial of WP A1.

The project leader has served as an assistant supervisor for the M.Sc. student Thomas Larsen in his work on the effects of soil structure on soil mesofauna.

G. National and international cooperation

International

L.J. Munkholm has initiated a post-doc project on ‘Soil fragmentation in tillage – understanding and prediction’ funded by the Danish Agricultural and Veterinary Research Council (2002-2004). In this context, he will co-operate with Associate Professor Ed Perfect at University of Tennessee. The project will include a study stay at Tennessee.

P. Schjønning is – together with colleagues Susanne Elmholt and Bent T. Christensen – currently editing an international book on soil quality as related to the major challenges in modern agriculture. In this context there is contact to the senior authors of 16 chapters addressing most soil quality indicators of relevance for sustainable agriculture. A general scope of the book project is to identify ‘management thresholds’ rather than solely ‘soil indicator thresholds’ for sustainable management. The contributors are experts in their field and selected from all over the world. A contracted agreement exists stating that the book will be published by CAB International.

P. Schjønning has agreed to serve as a consultant for a recently initiated Norwegian project on organic farming at the Norwegian Crop Research Institute (contact person: Hugh Riley).

National

During the project, we have collaborated with Jørgen A. Axelsen at the National Environmental

Research Institute in terms of a mutual coordination of a M.Sc. study.

The abovementioned work with an international book on soil quality and sustainability has also increased the national cooperation of relevance to the ROMAPAC project. First, Hugo Fjellsted Alrøe (HFA) at DARCOF has contributed to our understanding of the terminology used in systems theory and to our growing awareness of the role of values in science. This has been obtained through frequent consultations and through HFA's informal review of our introductory Chapter to the book. Second, a number of Danish scientists have contributed to the book Chapters as authors and we have benefitted very much by this interaction. These colleagues are Margrethe Askegaard, Kirsten Brandt, Bent T. Christensen, and Lars J. Munkholm, all employed at the Danish Institute of Agricultural Sciences. The expertise contributed to a large extent is related to work carried out in the context of DARCOF and the cooperation has thus clearly strengthened the interaction among participants in DARCOF.

H. Critical reflection on the project

It is a pleasure to work with our ROMAPAC project. In the project group, we are very pleased with the research strategy that was launched when we wrote the project description. As mentioned elsewhere in this Mid-Term Report, the ROMAPAC project is based on a previous project in the context of DARCOF. The former project followed the case-study approach. I.e., we addressed a number of farmers' fields and monitored a range of soil quality indicators for interpretation in relation to the management at the specific fields. We learned a lot from this. Specifically, it appeared that traffic in the field had a major influence on soil functions and interfered the long-term positive effects of diversified crop rotations and application of organic manures. Hence, we included this interaction for quantification in the ROMAPAC project.

More generally, the work in the former project revealed that reductionistic methods applied in the laboratory may well reflect the soil behaviour in the field. This finding is a great support for our research in the ROMAPAC project. Nevertheless, to confirm our earlier findings, we still include field as well as lab methods in our research. Another lesson learned in the former project was the need to increase our understanding of the dynamics in the system. The case study approach did not allow a differentiation of the relative importance of the crop rotation effect and the effect of organic manures. In this section, we discuss our considerations on these and related topics.

Vertical and horizontal interdisciplinarity

Much concern has been addressed to the use of reductionistic methods when addressing systems like organic farms and fields. Any method applied to a soil system will simplify the system because the output and results will be interpreted in a framework reflecting the observer's conception of a soil. This is particularly true when 'reducing' the system. In the context of the ROMAPAC project, an air-dried soil aggregate (aggregates are used for several lab methods) is indeed a reduced soil system. On the other hand, science has to do with quantification of the object studied. Hence, what is important is to keep a high awareness of the pitfalls when applying a specific (reductionistic) methodology. In our former DARCOF project, this was done by securing a 'horizontal' as well as a 'vertical' interdisciplinarity in our studies. Figure 6 illustrates the concept.

The 'traditional' interdisciplinarity includes a combination of different disciplines, Figure 6. This is important to allow a general understanding of the system and the interaction between properties and functions addressed by the different disciplines. We secured that in the former project and continue the approach also in the ROMAPAC project.

The 'vertical' interdisciplinarity has to do with evaluation of soil behaviour, properties and functions at different levels of investigation, Figure 6. In the context of the former DARCOF

project and again in the ROMAPAC project, we evaluate the soil behaviour by holistic methods in the field as well as by reductionistic methods in the laboratory. The former DARCOF project gave a clear indication that the 'classical' scientific methods relevant in this context (soil tilth) gave reliable estimates of soil behaviour and function in the field. The results of the former DARCOF project is thus a good basis for concluding on the results obtained in the ROMAPAC project.

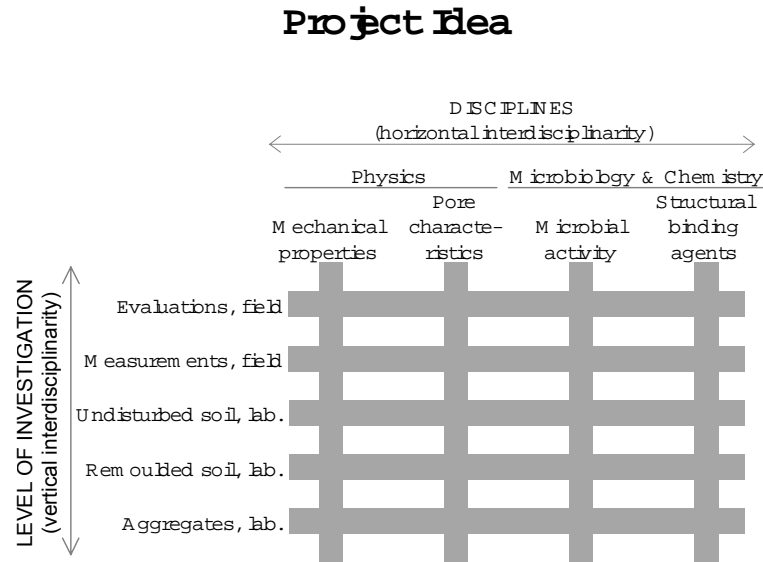


Figure 6. The approach applied for minimizing pitfalls from application of reductionistic methods in our research on soil tilth in organic farming fields.

Emergent properties and development of organic farming systems

Some scientists involved with research in organic farming claim the need to address only the whole system. The reason is a high awareness of 'emergent' properties defined as *'the functional interaction of system components that are not observable from those smaller units of organization characteristic of reductionist approaches'* (Carter et al., 2003). A case-study approach necessarily will include such emergent properties. However, in order to increase our understanding of the system function, it may be necessary to differentiate the management options included in the system. Our approach in the ROMAPAC project is a good example of this. Figure 7 illustrates the benefits and drawbacks of holistic (case study approach) versus reductionistic research (factorial field trials). Holistic research involves per definition a low degree of reduction of the system. However, the knowledge gained may be rather empirical. In contrast, the discipline-oriented, reductionistic approach may reduce the complexity of the system, however, may provide understanding of mechanistic system dynamics of importance for further development of the system towards a sustainable function.

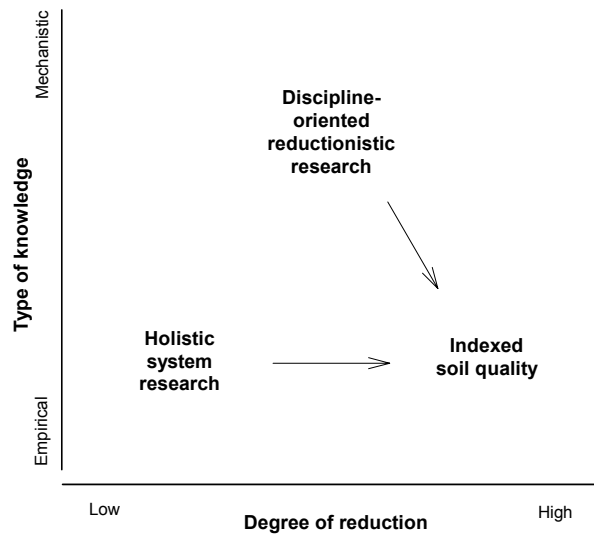


Figure 7. Different research approaches depicted as related to the degree of 'reduction' (abscisse) and the type of knowledge gained (ordinate). The arrows indicate what happens when indexing the information gained as is often done in soil quality studies (adopted from Schjøning et al., 2003).

The former DARCOF project was not able to identify whether a diversified crop rotation rather than application of organic manures was the more important management tool inducing a healthy soil of the organically managed fields. The field trials investigated in the ROMAPAC project provide an opportunity to differentiate the relative effects of these management options available to the organic farmer. Hence, in order to provide the basis for improving the management in organic farming systems, we have decided to address these two important management tools separately. This is a deliberate action and we are well aware that some emergent properties of a 'full' organic system may not be elucidated in our project. However – at least for Danish conditions – organic systems exist that base a continued soil health on crop rotations without applying animal manure. For a future evaluation of the sustainability and improvement of such systems, it is important to provide quantitative knowledge on the relative effects of the management options considered.

Literature cited in Section H:

Carter, M.R., Andrews, S.S. & Drinkwater, L.E. 2003. Systems Approaches for Improving Soil Quality. In: Schjøning, P., Elmholt, S. & Christensen, B.T. (eds.) *Managing Soil Quality – Challenges in Modern Agriculture*. CAB International, Wallingford, UK (submitted).

Schjøning, P. Elmholt, S. & Christensen, B.T. 2003. Soil Quality Management – Concepts, Terms and Delimitations. In: Schjøning, P., Elmholt, S. & Christensen, B.T. (eds.) *Managing Soil Quality – Challenges in Modern Agriculture*. CAB International, Wallingford, UK (submitted).

8. Budget

A. Account for any change in budgets

The changes in plans for WP A2 and WP B (see section D) have caused a need for carry forward to year 2003 of a smaller part of the funds originally budgetted for 2001 and 2002. This amounts to 3.75 scientific and 1.00 technical man-months. Also 41 KKr of the operational costs have been carried forward to 2003.

B. Budget for the whole project (1.000 DKK)

Total consumption of funds from DARCOF and expected consumption this year and coming years

(The budget has been corrected for the carry forward to 2003 that has been asked for)

Year:	Consumption before 2002	Expected consumption 2002	2003	2004	2005	Total
Man-months						
Scientific personnel	10.5	12	17,25	22		61,75
Technical personnel	9.5	19	15,5	1,5		45.5

Year:	Consumption before 2002	Expected consumption 2002	2003	2004	2005	Total
Salaries						
Scientific personnel	381	510	730	1023		2644
Technical personnel	215	458	400	45		1118
Other operational costs	154	318	381	41		894
Equipment						
Others (please specify)	15 ¹	15 ¹	15 ¹			45 ¹
Direct costs	765	1301	1526	1109		4701
Indirect costs (20% of direct costs)	150	256	302	222		930
Total	915	1557	1828	1331		5631

¹Consultative service from Department of Fruit, Vegetable and Food Science (root studies)

9. Signatures and stamps

Name	Institute	Date	Signature
Head of project Per Schjønning			

Appendix I. Detailed budget

A. Budget for each participating institute (1.000 DKr)

Name of Institute: Danish Institute of Agricultural Sciences (DIAS)

(The budget has been corrected for the carry forward to 2003 that has been asked for)

Year:	Consumption before 2002	Expected consumption 2002	2003	2004	2005	Total
Man-months						
Scientific personnel	10.5	12	17,25	22		61,75
Technical personnel	9.5	19	15,5	1,5		45.5

Year:	Consumption before 2002	Expected consumption 2002	2003	2004	2005	Total
Salaries						
Scientific personnel	381	510	730	1023		2644
Technical personnel	215	458	400	45		1118
Other operational costs	154	318	381	41		894
Equipment						
Others (please specify)	15 ¹	15 ¹	15 ¹			45 ¹
Direct costs	765	1301	1526	1109		4701
Indirect costs (20% of direct costs)	150	256	302	222		930
Total	915	1557	1828	1331		5631

Comments:

¹Consultative service from Department of Fruit, Vegetable and Food Science (root studies)

B. Budget for each participating department (1.000 DKK)

Name of Institute and department:

DIAS, Department of Crop Physiology and Soil Science

(The budget has been corrected for the carry forward to 2003 that has been asked for)

Year:	Consumption before 2002	Expected consumption 2002	2003	2004	2005	Total
Man-months						
Scientific personnel	10	12	17,25	22		61,25
Technical personnel	4	16	15,5	1,5		37

Year:	Consumption before 2002	Expected consumption 2002	2003	2004	2005	Total
Salaries						
Scientific personnel	362	510	730	1023		2625
Technical personnel	90	386	400	45		921
Other operational costs	132	313	381	41		867
Equipment						
Others (please specify)	15 ¹	15 ¹	15 ¹			45 ¹
Direct costs	599	1224	1526	1109		4458
Indirect costs (20% of direct costs)	117	241	302	222		882
Total	716	1465	1828	1331		5340

¹Consultative service from Department of Fruit, Vegetable and Food Science (root studies)

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

Name of Institute and department:
DIAS, Department of Agricultural Engineering

Year:	Consumption before 2002	Expected consumption 2002	2003	2004	2005	Total
Man-months						
Scientific personnel	0.5	0	0	0		0.5
Technical personnel	5.5	3	0	0		8.5

Year:	Consumption before 2002	Expected consumption 2002	2003	2004	2005	Total
Salaries						
Scientific personnel	19	0	0	0		19
Technical personnel	125	72	0	0		197
Other operational costs	22	5	0	0		27
Equipment						
Others (please specify)						
Direct costs	166	77	0	0		243
Indirect costs (20% of direct costs)	33	15	0	0		48
Total	199	92	0	0		291

Comments: