



Midterm Status Report 2003 and Application for Continuation in 2004

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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

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

3. Head of project

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6. Project period (month, year)

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

7. Midterm description of the project, its results and progress, and application for continuation in 2004

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 on 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 reducing traffic intensity (i.e. low axle loads and tyre). 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.

Please consult the Midterm Report 2002 and the project description in the application for funding in order to obtain more detailed descriptions of research plans.

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	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 tillage 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 tillth 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

This workpackage concluded its activities in 2001. Some examples of results were shown in the 2002 Mid-term Status Report. The results were published in DIAS Report No. 82 (Schjønning et al., 2002),- see a full reference in section E.3 of this Status Report.

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 to 2003. The implement used was a Howard Paraplow, which loosens the soil to a depth of 35-40 cm without inverting the soil. According to the original plan, the subsoil loosening should have taken place in the lupine crop. However, in order to reduce the 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 was delayed one year (the grass/clover ley is not included in this measuring programme). Thus 2002 was the first year with a measuring programme for above-ground crop response to the treatment. Table 1 shows 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 sub-soil loosen-

ing 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 affected by the subsoil loosening. The yield data from 2002 confirms the results of the reflectance measurements with slightly lower yields in winter wheat after subsoiling at both Foulum and Flakkebjerg (Table 2). The reason for this is unknown, but may be related to a negative effect of subsoiling on the growth of the grass-clover (Table 1). This is partly confirmed by the fact that yield reductions from subsoiling were slightly higher in treatments without manure. To investigate this further, spectral reflectance measurements were conducted on the grass-clover crop at both sites in 2003. However, these data are not yet available. The measurements will be continued in 2004.

Table 1. Average ratio vegetation index (RVI) measured during the growing season in 2002 in crops with and without subsoil loosening. The effects are not significant.

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

Table 2. Effects of subsoil loosening on yield (t/ha) of winter wheat at Foulum and Flakkebjerg in 2002.

Site	Without manure		With manure	
	Without loosening	With loosening	Without loosening	With loosening
Foulum	4.2	3.8	5.8	5.6
Flakkebjerg	4.7	4.0	4.7	4.6

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 of 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. Preliminary results were shown in the 2002 Mid-term Status Report. All data has now been analysed and presented at an international scientific conference (see section E.2). Further to that, two manuscripts reporting the studies were submitted to the journal *Soil & Tillage Research* in September 2003 (see section E.1).

Figure 1 shows an index of pore continuity calculated from the soil physical measurements in the plough pan layer (~25-30 cm depth). The PO_{100} is the quotient between the air permeability measured when the soil was drained to -100 hPa water potential (~field capacity) and the air-filled pore space found at this specific potential. The index thus expresses the specific capacity of the air-filled macropores to conduct air. A high index is indicative of a high continuity of macropores. The small differences in pore continuity found between the initially loosened soil (NINV treatment) and the reference soil (CONV) in 1998 and 1999 were not statistically different. However, it appears that the combined effect from high loads during traffic and conventional, in-furrow ploughing (NINV-TH) displayed a poorer continuity than the NINV-OL treatment receiving only moderate traffic loads and on-land ploughing.

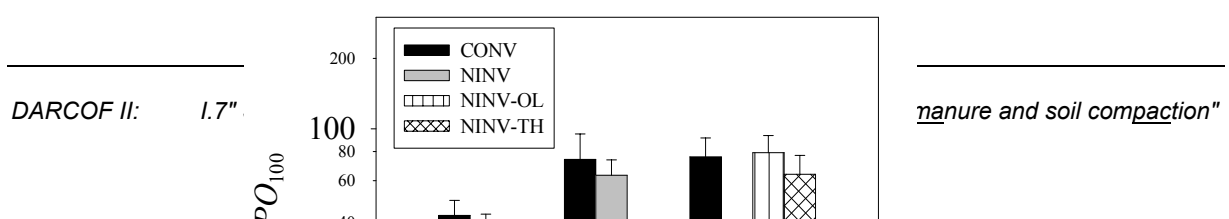


Figure 1. The $PO_{100} = ka_{100}/\epsilon_{100}$ index of pore continuity, gives the specific air permeability (ka) for air-filled pores (ϵ) at a water potential of -100 hPa (\sim field capacity). The NINV-plots were mechanically loosened in 1997. The NINV-OL and the NINV-TH plots were treated with on-land ploughing / light traffic, and conventional ploughing / heavy traffic, respectively. The CONV plots were never loosened. Bars indicate standard error of the mean.

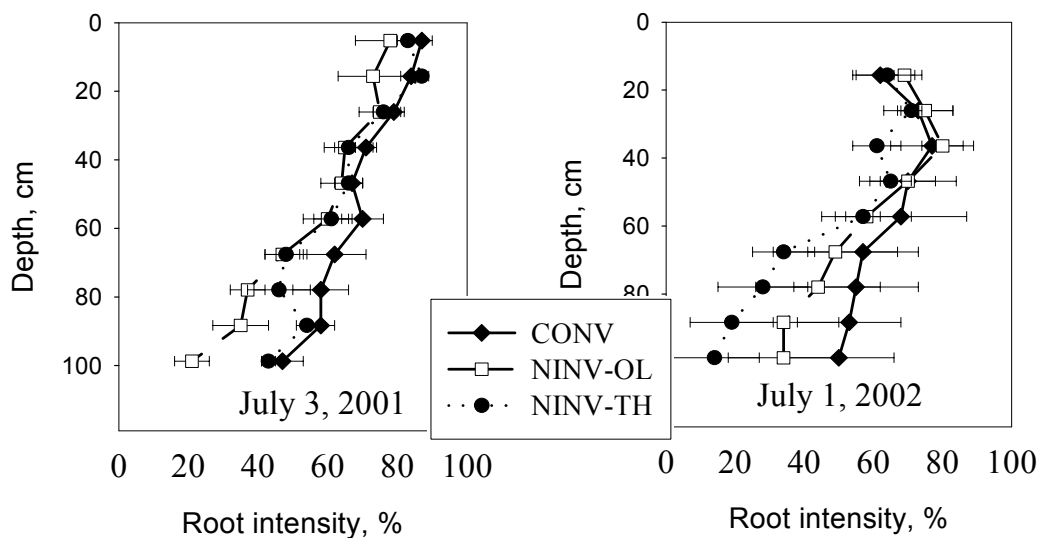


Figure 2. Root intensity (fraction of grid fields with visible roots in the transparent tubes inserted into the soil) in mid-summer for winter wheat grown in differently treated plots. Please consult the Figure 1 caption for explanation of treatments. Horizontal bars indicate standard error of the mean.

Figure 2 shows two years of root response to the different treatments. Interestingly, the highest root intensity was found for the CONV treatment that did never receive any mechanical loosening. The CONV soil also produced similar yield (data not shown). The deep rooting in the CONV soil occurred despite increased root diameters (data not shown) indicating a hampered root growth in the CONV plough pan layer. The deep rooting in the CONV soil may be due to preferential growth in biopores (earthworm and root channels). Subsoiling undoubtedly destroyed the inherent system of continuous biopores in the upper subsoil although at the same time produced new cracks and pores. These new pores were probably not as efficient pathways for roots as the inherent biopores. This also means that the index of continuity estimated and

shown in Figure 1 is probably reflecting another size of pores than those determining root growth. At least in 2002, the NINV-OL treatment displayed better root growth than the NINV-TH treatment, indicating that especially the on-land ploughing is mitigating damaging recompaction of mechanically loosened soil.

We thus conclude that on-land ploughing is an efficient means of mitigating recompaction of mechanically loosened subsoils. However, our results show that mechanical subsoiling may create even more constraints than benefits to crop development. We thus recommend that mechanical subsoiling should only take place in situations with severe compaction of subsoil layers. Our results indicate that biological amelioration induced by appropriate changes in cropping system as well as tillage and traffic intensity comprises a favourable alternative to mechanical subsoiling.

The studies in Workpackage A3 continues as planned in terms of measurements of root growth in mechanically loosened soil in the CRE trial at Foulum and Flakkebjerg (see the plans outlined in the Project Description found in the application for funding or in the 2002 Mid-term Status Report).

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. The plots targeted for sampling in 2003 were treated this way again in the autumn of 2002. For the LAM trial, an additional treatment with rotovator was included in the trial. All the planned samplings and field measurements took place in the spring 2002 and 2003. The comprehensive measuring programme in the laboratory most probably will be completed by the end of 2003 or in early 2004.

In the 2002 Mid-term Status Report, we showed two biological indicators of soil quality (microbial biomass and fungal hyphae) measured at the CRE trial at Flakkebjerg (please consult the 2002 report if you want to focus on these effects). The 2003 measurements have confirmed the 2002 data except that there was no effect of application of animal manure on the microbial biomass. In the present Status Report, we again address the Flakkebjerg trial due to its interesting 'history' as outlined below. For the present report, we have chosen to discuss a physical and a chemical parameter indicating the quality of the soil at the Flakkebjerg trial as affected by the crop rotation and the application of manure.

We reiterate from the 2002 Mid-term Status Report that the CRE field at Flakkebjerg had been grown with annuals for cash cropping (primarily small grain cereals) for a couple of decades prior to the start of the CRE trial. 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 (a soil drop test). However, it appeared that in 2002 the soil was generally too plastic and coherent to fragment when the cube was dropped as part of the method. This was probably due to very wet conditions when tilling the soil for seedbed in the autumn 2001. In the spring 2003, the soil was generally more friable and we succeeded to carry out the soil drop test, Figure 3. Although not statistically significant, there is a tendency that the poor crop rotation receiving no animal manure resulted in a less friable soil (a high mean weight diameter (MWD) of aggregates is indicative of a cloddy soil after the soil cube has been dropped).

More conspicuously, the compaction treatment has resulted in a significant decrease in friability (high MWD-values express cloddy structure). Again, there is a trend that the poor crop rotation without manure showed the strongest reduction in friability when subjected to the compaction. Hence, our results indicate that even after only ~6 years of differentiated treatment, a diversified crop rotation and/or the application of animal manure has improved this soil's quality in terms of soil workability for seedbed after having been compacted.

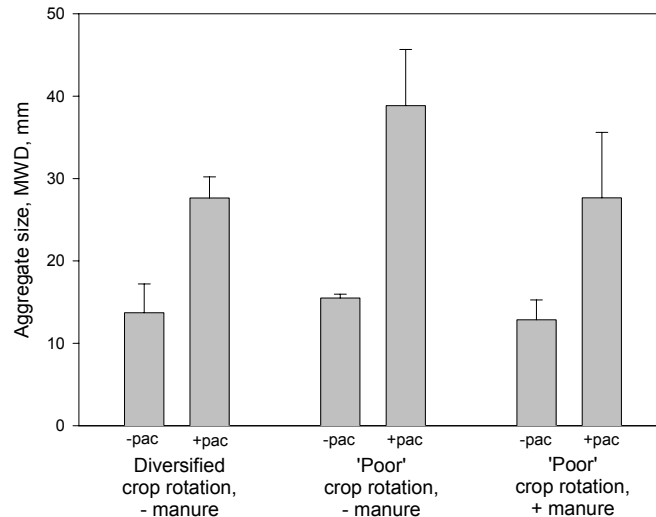


Figure 3. Aggregate size expressed as the mean weight diameter (MWD, mm) following a drop test with an undisturbed cube in the field. CRE-trial, Flakkebjerg, spring 2003. High MWD values indicate a poor friability. Bars indicate standard error of the mean.

The ROMAPAC project aims at elucidating the mechanisms in stabilisation of soil structure. Two mechanisms are active in structure stabilization, - i) enmeshment of the soil with fungal hyphae and fine roots, and ii) glueing with polysaccharides. In the 2002 Mid-term Status Report, we addressed the hyphae and showed that especially a diversified crop rotation favoured the abundance of fungal hyphae. Figure 4 shows the average results of the 2002 and 2003 measurements of polysaccharide C found in 1-2 mm aggregates derived from the differently treated trial plots. Please note that the soil grown with a 'poor' crop rotation and receiving no animal manure is displaying the smallest amount of glueing material. Although the trend is not significant at the $P=0.05$ level ($P\sim 0.11$), the same tendency was found both years. Our results thus show that both mechanisms of aggregate stabilization are enhanced by diversified crop rotations and the application of manure to the soil.

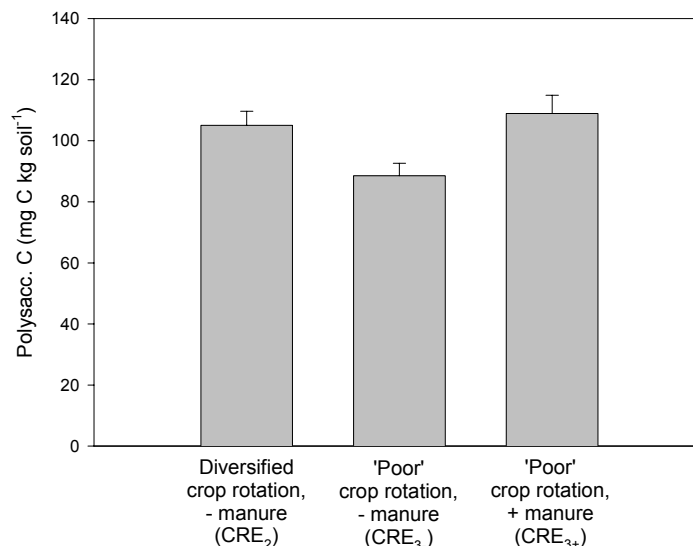


Figure 4. Hot-water extractable polysaccharide C as affected by cropping system at the CRE-trial, Flakkebjerg. Average of 2002 and 2003 and compaction treatment. Bars indicate standard error of the mean.

WP C. Project co-ordination and dissemination of results

The activities in this Workpackage have included editorial work with an upcoming book on Soil Quality (to be published in November 2003 at CAB International). Although not directly related to the results in the ROMAPAC project, this book is to a large extent based on the concepts also launched for the ROMAPAC. Further, dissemination of specific results from the project has included lectures and reports aimed at organic farmers and consultants (please consult point E of this report).

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	Fulfilled
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	Delivered
D8 International scientific paper	11/2004	(Delivered)
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	See D
5 Presentation of results at ISTRO Conference	06/2003	Fulfilled
6 International scientific paper(s) submitted	12/2004	Fulfilled

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	See D
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	Fulfilled
4 Field measurements and samplings 2003 completed	05/2003	Fulfilled
5 Presentation of results at ISTRO Conference	06/2003	See D
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. Activities concluded.

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.

Specific comments on 'Deliverables': Two manuscripts have been submitted (not yet accepted) for publication. Further to that, we expect to produce also a paper reporting the root studies in the CRE trial at Foulum.

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).

Specific comments on 'Deliverables': Due to illness, the intended presentation of preliminary Workpackage B results at the 2003 ISTRO Conference was not delivered.

Workpackage C. Project co-ordination and dissemination of results

No changes in plans.

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

**Kay, B.D. & Munkholm, L.J. 2004. Management-induced Soil Structure Degradation: Organic Matter Depletion and Tillage. In: Schjønning, P., Christensen, B.T. & Elmholt, S. (Eds). *Managing Soil Quality: Challenges in Modern Agriculture*. CABI Publishing, Wallingford, UK, pp. 185-197 (in press).

**Larsen, T., Schjønning, P. & Axelsen, J.A. The impact of soil compaction on euedaphic Collembola. *Applied Soil Ecology* (accepted).

**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. Structural vulnerability of a sandy loam exposed to intensive tillage and traffic in wet conditions. *Soil & Tillage Research* (accepted).

**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. & Rüegg, K. Mitigation of subsoil recompaction by light traffic and on-land ploughing: I. Soil response. *Soil & Tillage Research* (submitted).

Munkholm, L.J., Schjønning, P., Jørgensen, M.H. and Thorup-Kristensen, K. Mitigation of subsoil recompaction by light traffic and on-land ploughing: II. Root and yield response. *Soil & Tillage Research* (submitted).

**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.

**Schjøning, P., Elmholt, S. & Christensen, B.T. (Eds.) 2004. *Managing Soil Quality: Challenges in Modern Agriculture*. CABI Publishing, Wallingford, UK, 368 pp (in press).

**Schjøning, P., Elmholt, S. & Christensen, B.T. 2004. *Soil Quality Management – Concepts and Terms*. In: Schjøning, P., Elmholt, S. & Christensen, B.T. (Eds.) *Managing Soil Quality: Challenges in Modern Agriculture*. CABI Publishing, Wallingford, UK, pp. 1-16 (in press).

**Schjøning, P., Elmholt, S. & Christensen, B.T. 2004. *Soil Quality Management – Synthesis*. In: Schjøning, P., Elmholt, S. & Christensen, B.T. (Eds.) *Managing Soil Quality: Challenges in Modern Agriculture*. CABI Publishing, Wallingford, UK, pp. 315-334 (in press).

**Schjøning, 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.

**Van den Akker, J.J.H. & Schjøning, P. 2004. *Subsoil Compaction and Ways to Prevent It*. In: Schjøning, P., Elmholt, S. & Christensen, B.T. (Eds.) *Managing Soil Quality: Challenges in Modern Agriculture*. CABI Publishing, Wallingford, UK, pp. 163-184 (in press).

2. Papers presented at congresses, symposiums, etc.

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

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Munkholm, L.J., 2002. Bekvem jord. Den faglige baggrund - Landsbladet, 6.12.02, p. 32.

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Schjøning, 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 82. The Danish Institute of Agricultural Sciences, 45pp.

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 planteavlskonulerter 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 "Planteavl-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.
- Munkholm, L.J. 2003. Jordbearbejdning og såteknik. Contribution at course for onion growers, Middelfart, February 24., 2003.
- Munkholm, L.J. 2003. Skadelig pakning. Contribution at "Markvandring" a field day held at Foulumgård June 12., 2003.
- Munkholm, L.J. 2003. Hvordan finder man ud af om jorden skal løsnes? Contribution at a field demonstration organized by The Danish Institute of Agricultural Sciences and The Danish Agricultural Advisory Centre at Rugballegaard September 10, 2003.
- Schjøning, P. 2000. Jordstruktur og jordfrugtbarhed. Konsekvenser af almindelig markpraksis i dag. Oral presentation at a seminar organized by LØJ, Bygholm Landbrugsskole/Rugballegaard, Horsens, 19. September 2000.
- Schjøning, P. 2000. Jordstruktur, jordbehandling og udbyttevariation. Oral presentation at a course for agricultural advisors, Koldkærgård, 20. September 2000.
- Schjøning, P. 2000. Jordstruktur og mekaniske egenskaber i økologisk jordbrug. Oral presentation at visit from the Royal Veterinary and Agricultural University, 4. October 2000.
- Schjøning, P. 2000. Jordpakning i økologisk jordbrug – hvor tunge maskiner kan vi bruge. Oral presentation at Økokongres 2000, Hotel Pejsegården, Brædstrup, 1. November 2000.
- Schjøning, P. 2000. Skadelig jordpakning og jordens frugtbarhed – generelt og med henblik på pløjefri dyrkning. Oral presentation at a course organized by the Organization for Reduced Tillage in Denmark (FRDK), Scanticon-Comwell, Middelfart, 14. November 2000.
- Schjøning, 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.
- Schjøning, P. 2001. Bæredygtig jordbearbejdning og trafik i fremtidens jordbrug. Oral presentation at a workshop organized by the Dep. Agricultural Engineering, DIAS, Snavtun Færgesgaard, 22. August 2001.
- Schjøning, P. 2001. Jordpakning, jordbearbejdning og jordfrugtbarhed. Oral presentation at visit from the Royal Veterinary and Agricultural University, 3. October 2001.
- Schjøning, 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.

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. This work has now been reported in a refereed paper in *Applied Soil Ecology* (see section E).

Project participant S. Elmholt served as a member of the evaluation committee at a ph.d. defense (Janne Lagers: Soil-borne Clover Diseases in Intensive Legume Cropping) at SLU Department of Plant Pathology and Biocontrol Unit, 15th November 2002.

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. Schjøning has – together with colleagues Susanne Elmholt and Bent T. Christensen – edited 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. The book will be published by CAB International in November 2003.

P. Schjønning serves 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. Hugo Fjelsted 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. A number of Danish scientists have contributed to the book Chapters. Whether their role has been as authors or as referees, we have benefitted by this interaction. 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 still 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 5 illustrates the

concept.

The 'traditional' interdisciplinarity includes a combination of different disciplines, Figure 5. 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 5. 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.

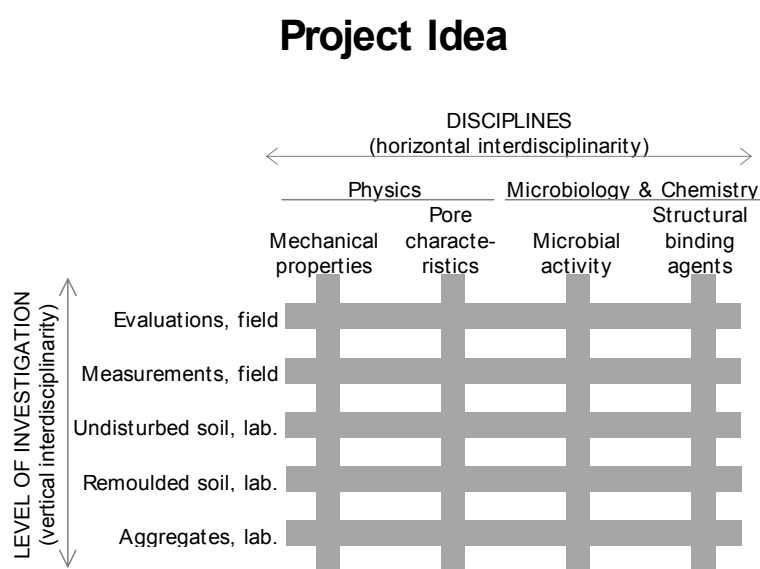


Figure 5. The approach applied for minimizing pitfalls from application of reductionistic methods in our research on soil tilth in organic farming fields.

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 6 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.

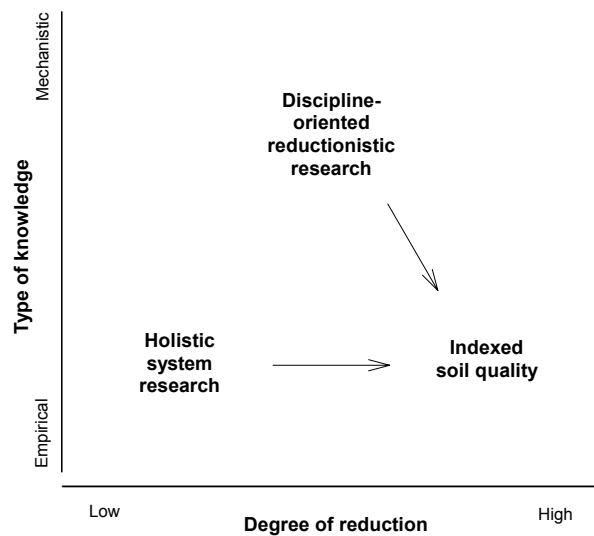


Figure 6. Different research approaches depicted as related to the degree of 'reduction' (abscisse) and the type of knowledge gained (ordinate). The arrows indicate what happens when indexing the information gained as is often done in soil quality studies (adopted from Schjøning et al., 2003).

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. The preliminary results indicate that a versatile crop rotation may prove more efficient in maintaining a high soil quality for crop production than the application of animal manure (the Flakkebjerg site).

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 (in press).

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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 2004 of a smaller part of the funds originally budgetted for 2001, 2002 and 2003.

B. Budget for the whole project (1.000 DKK)

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

Year:	Consumption before 2003	Expected consumption 2003	2004	2005	Total
Man-months					
Scientific personnel	22,5	17,25	22		61,75
Technical personnel	28,5	15,5	1,5		45,5

Year:	Consumption before 2003	Expected consumption 2003	2004	2005	Total
Salaries					
Scientific personnel	891	730	1023		2644
Technical personnel	673	400	45		1118
Other operational costs	472	111	311		894
Equipment					
Others (please specify)	30	15			45
Direct costs	2066	1256	1379		4701
Indirect costs (20% of direct costs)	406	248	276		930
Total	2472	1504	1655		5631

Comments:

9. Signatures and stamps

Name	Institute	Date	Signature
Head of project Per Schjønning		30.09.2003	