Danish Research Centre for Organic Farming

Progress Report 2004 and Application for Continuation in 2005

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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

Senior Scientist Per Schjønning
Department of Agroecology
Research Centre Foulum, P.O. Box 50
DK-8830 Tjele
Phone: 8999 1766
Fax: 8999 1619
E-mail: Per.Schjonning@agrsci.dk

4. Participating institutes

Danish Institute of Agricultural Sciences
Department of Agroecology
Research Centre Foulum, P.O. Box 50
DK-8830 Tjele

and

Department of Agricultural Engineering
Research Centre Bygholm, P.O. Box 536
DK-8700 Horsens

5. Other project staff

Senior Scientist Susanne Elmholt, Department of Agroecology, Research Centre Foulum, P.O. Box 50, DK-8830 Tjele, Phone: 8999 1858, Fax: 8999 1619,
E-mail: Susanne.Elmholt@agrsci.dk

Research Professor Jørgen E. Olesen, Department of Agroecology, Research Centre Foulum, P.O. Box 50, DK-8830 Tjele, Phone: 8999 1659, Fax: 8999 1619,
E-mail: JorgenE.Olesen@agrsci.dk

Senior Scientist Lars J. Munkholm, Department of Agroecology, Research Centre Foulum, P.O. Box 50, DK-8830 Tjele, Phone: 8999 1768, Fax: 8999 1619,
E-mail: Lars.Munkholm@agrsci.dk

6. Project period (month, year)

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

*See section 7D

7. Midterm description of the project, its results and progress, and application for continuation in 2005

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 desciption 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	PS, LJM	468	04/00	12/02	D1, D2, D3
A2	Above-ground crop response to compaction and subsoiling	JEO, PS, LJM	777	08/00	12/04	D4, D5, D6
A3	Soil effects and root response to compaction and subsoiling	LJM, PS, JEO	1435	01/01	12/04	D7, D8
B	Topsoil tilth as affected by crop rotations, animal manure and traffic	PS, SE, LJM	2679	04/00	12/04	D9, D10
C	Project co-ordination and dissemination of results	PS, 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

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 E1 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. The subsoiling treatment was applied to the young grass/clover ley crop about one month after the harvest of the cover crop.

The results from 2002 indicated a tendency of reduced yield of winter wheat for subsoiled plots (see Progress Report 2003). This was interpreted as a potential direct damage to the young clover plants during subsoiling. A poor grass-clover crop could potentially give rise to a poor winter wheat crop afterwards. Table 1 shows average ratio vegetation index (RVI) measured in 2003 at both sites and for three crops in the rotation (including grass-clover). Although the results (especially at Foulum) indicate a reduced growth of grass-clover, there is no clear trend in the data for the other crops. Neither the yield data from 2003 is confirming a damage from subsoiling on plant growth. Hence, at present, there is no clear conclusion regarding the effect of the

subsoiling. Hopefully, a clear conclusion will arise when putting together the results of all years' measurements (including 2004).

Table 1. Average ratio vegetation index (RVI) measured during the growing season in 2003 in crops with and without subsoil loosening.

Site	Crop	RVI			
		Without manure		With manure	
		- Loosening	+ Loosening	- Loosening	+ Loosening
Foulum	Grass-clover	8.9	8.1	8.1	7.6
	Lupine/barley	4.9	4.8	5.0	5.0
	Winter wheat	5.1	5.0	7.7	7.8
Flakkebjerg	Grass-clover	11.2	11.1	10.5	9.9
	Lupine/barley	5.6	5.8	5.4	5.6
	Winter wheat	5.5	7.5	6.6	6.6

Table 2. Effects of subsoil loosening on yield (t/ha) of winter wheat at Foulum and Flakkebjerg in 2003.

	Without manure		With manure	
Site	- Loosening	+ Loosening	- Loosening	+ Loosening
Foulum	5.5	5.5	6.6	6.5
Flakkebjerg	5.4	5.7	5.4	5.6

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

About half-part of the activities in this WP was concluded in 2002 (the DTS trial) and the results have been published (Munkholm et al., 2004ab [see section E1]). The results of the measurements in the CRE trial at Foulum have been concluded as planned except the penetration resistance for year 2004 (see section 7D). The evaluation of all these results is thus awaiting a full data set. An international publication will produced in 2005. Below, we summarize some of the results from the DTS trials, which have already been published.

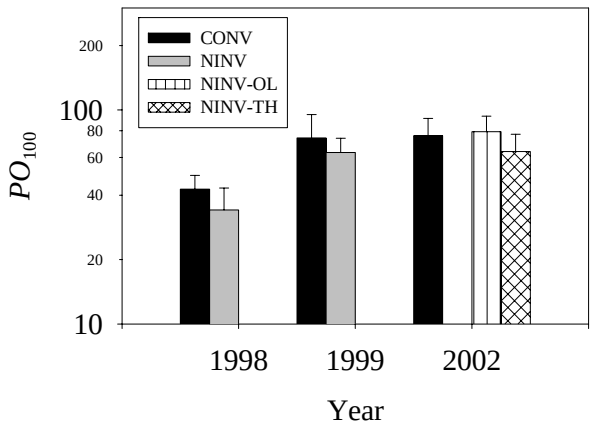

Figure 1. The $PO_{100} = ka_{100}/\varepsilon_{100}$ index of pore continuity, gives the specific air permeability (ka) for air-filled pores (ε) at a water potential of –100 hPa (~field capacity). The NINV-plots were mechanically loosened in 1997. The NINV-OL and the NINV-TH plots were treated with 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 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.

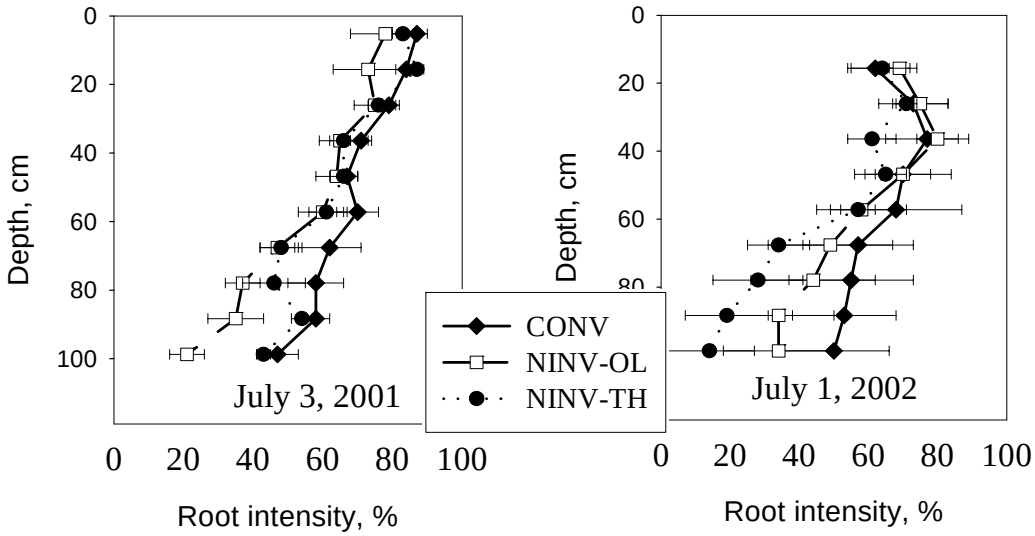

Figure 2. Root intensity (fraction of grid fields with visible roots in the transparent tubes inserted into the soil) in mid-summer for winter wheat grown in differently treated plots. Please consult the Figure 1 caption for explanation of treatments. Horizontal bars indicate standard error of the mean.

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.

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

The WP B adapted a conceptual approach including two different aspects of soil properties: *tilth forming processes* and *tilth characteristics* (see the original Project Description). The aim was to evaluate the effects of soil management on both aspects in order to better understand the mechanisms active in the creation of a high-quality soil.

Tables 3 and 4 summarize the parameters addressed regarding the *tilth-forming processes*. From Table 1 it appears that 16 years of annual application of animal manure in the LAM trial has given rise to significantly higher soil carbon content. The effect is, however, most clear when measuring on 1-2 mm aggregates rather than on 'whole soil' samples. This is an interesting observation in itself and will receive full focus also when reporting the results in international journals. Interestingly, the many years of application of animal manure has not given a significant increase in length of fungal hyphae.

Table 3. Long-term management effects (LAM-trial, Research Centre Foulum) on fractions of organic carbon extracted by different means from whole soil samples or samples of 1-2 mm aggregates. Hyphal length was determined by direct microscopy in soil suspensions. Average of four plots per treatment (2002 and 2003).

Sample type / parameter	Units	Management system		Probability of significance[1]
		REFERENCE	MANURE	
Whole soil				
Hot-water extract. C	mg kg^{-1}	169	186	ns (P=0.07)
Microbial biomass C	mg kg^{-1}	205	223	ns (P=0.17)
Total organic C	G kg^{-1}	16.0	17.0	* (P=0.044)
1-2 mm aggregates				
Hot-water extract. C	mg kg^{-1}	164	178	*** (P=0.001)
Total organic C	g kg^{-1}	17.1	18.7	** (P=0.003)
Hyphal length	m g^{-1}	12.1	10.5	ns

[1]ns = not significant at the P=0.05 level; the value of P is given in paranthesis if less than 0.20

Table 4. Short-term management effects (CRE-trial at Flakkebjerg) on fractions of organic carbon extracted by different means from whole soil samples or samples of 1-2 mm aggregates. Hyphal length was determined by direct microscopy in soil suspensions. Average of six plots per treatment (2002 and 2003).

Sample type / parameter	Units	Management system			Probability of significance[1]
		REFERENC.	MANURE	FORAGE	
Whole soil					
Hot-water extract. C	mg kg^{-1}	101	107	109	ns
Microbial biomass C	mg kg^{-1}	193	204	288	ns (P=0.11)
Total organic C	g kg^{-1}	9.1	10.6	10.9	ns (P=0.09)
1-2 mm aggregates					
Hot-water extract. C	mg kg^{-1}	89	109	105	ns (P=0.11)
Total organic C	g kg^{-1}	9.6	11.0	12.2	ns (P=0.11)

Hyphal length	m g^{-1}	6.6	7.9	12.7	* (P=0.022)

[1]ns = not significant at the P=0.05 level; the value of P is given in paranthesis if less than 0.20

Six years of manure application and forage cropping in the CRE-trial at Flakkebjerg have induced a tendency of higher content of organic carbon as compared to the unmanured cereal cropping system (Table 4). The forage system showed a significant increase in hyphal length compared with the cereal cropping systems.

In combination, the results from the LAM- and CRE-Flakkebjerg trials show that organic carbon fractions in 1-2 mm aggregates are sensitive indicators of changes in soil quality (Tables 3 and 4). This is especially true for the hot-water extractable carbon. The structural binding mechanism

delivered by the fungal hyphae seems to be active primarily in systems with a versatile crop rotation.

Figure 3 shows medium- (6 years; CRE trial) and long-term (16 years LAM trial) management effects on *tilth characteristics*. 16 years of manure application in the LAM trial significantly increased soil macroporosity, air permeability at –100 hPa water potential and fragmentation in the soil drop test

. Six years of forage cropping as compared to growing of small grain cereals at the CRE-trial at Flakkebjerg tended to increase soil macroporosity, while air permeability was significantly lowest in the manure amended system

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Traffic-induced soil compaction significantly affected most tilth characteristics and may overshadow the positive effects of improved cropping or manuring procedures

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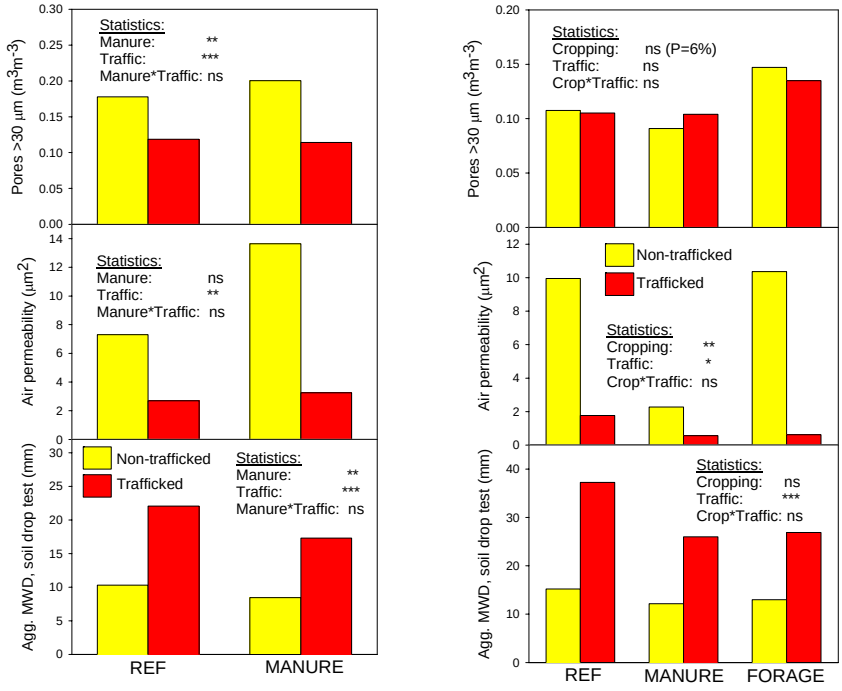

Figure 3. Management effects on pores >30 µm, air permeability at –100 hPa water potential, and fragmentation of soil using the soil drop test in the field (friability). Left part figure: LAM-trial, Foulum; right part figure: CRE-trial, Flakkebjerg.

WP C. Project co-ordination and dissemination of results

The activities in this Workpackage have included editorial work with an international book on Soil Quality (Schjønning et al., 2004,- see section E1). 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. A conceptual paper on soil quality and its potential role for promoting sustainability considerations in agricultural science was presented at the 4th International Conference of the European Society for Soil Conservation (ESSC) in Budapest, Hungary, May 2004. Further, dissemination of specific results from the project has included lectures and reports aimed at organic farmers and consultants (please consult section 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	See D
Milestones		
1 All subsoiling performed	08/2003	Fulfilled
2 All measurements performed	10/2004	Fulfilled
3 International paper submitted	12/2004	See D

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	Delivered

D10. International scientific paper(s)	11/2004	See D
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	See D

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	Postponed
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	Postponed

** 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).
The plan for 2005 is writing of the scheduled paper in an international Journal (see Milestones). This is one major reason for the delay in conclusion of the project (we have asked for carry-over of some funding to 2005).

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 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 to the journal 'Soil and Tillage Research' and are at present (September 2004) in 'queue' for printing. Further to that, we expect to produce also a paper reporting the root studies in the CRE trial at Foulum. This has to await the final measurements of penetration resistance in the plots of the crop rota-

tion trials. The apparatus for measuring this parameter broke down during the measurements in the spring 2004. The Department of Agroecology has now build a new apparatus (for use in a range of projects and not payed for by the ROMAPAC project). This apparatus is about ready for taking the measurements in the ROMAPAC field plots, which will hence take place in October or November 2004.
The plan for 2005 is thus the writing of an international paper on the studies in the CRE-trial (mentioned above). This is one reason for applying for carry-over of some funding from 2004 to 2005 (see section 8A).

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 was decided to sample also in this trial in 2003. The sampling and measuring programme was hence identical both sampling years (2002 and 2003).

The measurements on the pore characteristics were not concluded until mid 2004. This is one reason that we have asked for carry-over of funding from 2004 to 2005 (see section 8A). Another reason is the ROMAPAC link to the DARCOF project ØKOVAND regarding some measurments in the crop rotation experiments at Research Centre Foulum. Part of the measurements in ROMAPAC is planned for publication together with some of the ØKOVAND results. The ØKOVAND project has decided to sample additional soil cores in November 2004 (see the Progress Report of that project, section C.1 [p. 5] and section D [p. 13]) and this will cause delay for the conclusion of the ROMAPAC project.

Specific comments on 'Deliverables': Due to illness, the intended presentation of preliminary Workpackage B results at the 2003 ISTRO Conference was not delivered. In stead the project results were displayed at the EUROSOIL 2004 Conference in Freiburg, Germany in September 2004.
The plan for 2005 is writing of (at least) two international papers on the measurements in this workpackage (see Milestones).

Workpackage C. Project co-ordination and dissemination of results
No changes in plans. It may be relevant to summarize here the plans for 2005 for the whole project. All resources in 2005 will be used for the publication process. All four members of the project group will be involved in this task (with responsibilities according to the summary in Table A.1). At least four international papers are expected as outcome of this endeavour. Please note that this in addition to those already delivered (see section E.1). In addition, results will be described in farmers magazines, FØJO-Enyt and DARCOF-Enews.

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. Products from Organic Eprints archive

Peer-reviewed and accepted

English

Munkholm, L.J. and Schjønning, P. and Jørgensen, M.H. and Thorup-Kristensen, K. (2004a) Mitigation of subsoil recompaction by light traffic and on-land ploughing. II: Root and yield response. [in press]

Munkholm, L.J. and Schjønning, P. and Rüegg, K. (2004b) Mitigation of subsoil compaction by light traffic and on-land ploughing. I. Soil response. [in press]

Schjønning, P. and Elmholt, S. and Christensen, B.T., Eds. (2004) *Managing Soil Quality: Challenges in Modern Agriculture*. CABI Publishing, Wallingford, UK.**

Kay, B.D. and Munkholm, L.J. (2004) Management-induced Soil Structure Degradation: Organic Matter Depletion and Tillage, in Schjønning, P. and Elmholt, S. and Christensen, B.T., Eds. *Managing Soil Quality: Challenges in Modern Agriculture*, chapter 11, page 185-197. CABI Publishing, Wallingford, UK.**

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2. Other products (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 conventonal 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.
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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.
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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.
Munkholm, L.J. 2004 "Jordens frugtbarhed". Contribution at the course Guldkorn 9. Agrogården, Ringe 12 January 2004.
Munkholm, L.J. 2004 "Spadeprøve". Contribution at a Farm4U day at Agrobusiness Park Foulum for students at Næsgaard agricultural college. 22 January 2004.
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.
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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.
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Schjønning, P. 2004. Jordkvalitet er hvor godt en jord gør det, som vi ønsker den skal gøre. Projektgruppemøde for SOUND-projektet, Kursuscenter Rørvig, 19. maj 2004.

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 tilth 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.

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 continued the activities in the above mentioned subject in a Research Council – funded project 'Soil fragmentation in tillage – understanding and prediction'. In this context he was a guest researcher at the University of Tennessee (Ass. Professor Ed Perfect) for the period April-July 2004. These post-doc training activities strengthen the ROMAPAC project in terms of an improved interpretation of the tilth characteristics observed in the field plots studied.

P. Schjønning 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 was 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 was 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 was published by CABI Publishing in early 2004.

P. Schjønning serves as a consultant for a Norwegian project on organic farming at the Norwegian Crop Research Institute (contact person: Hugh Riley). In this context, a visit of the Norwegian group has been planned to take place at Research Centre Foulum in August 2005.

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. We have had a very fruitful cooperation with the group at the Danish Institute of Agricultural Sciences, Research Centre Aarslev (K. Thorup-Kristensen and co-workers) on root studies.

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 Progress 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 4 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 4. 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.

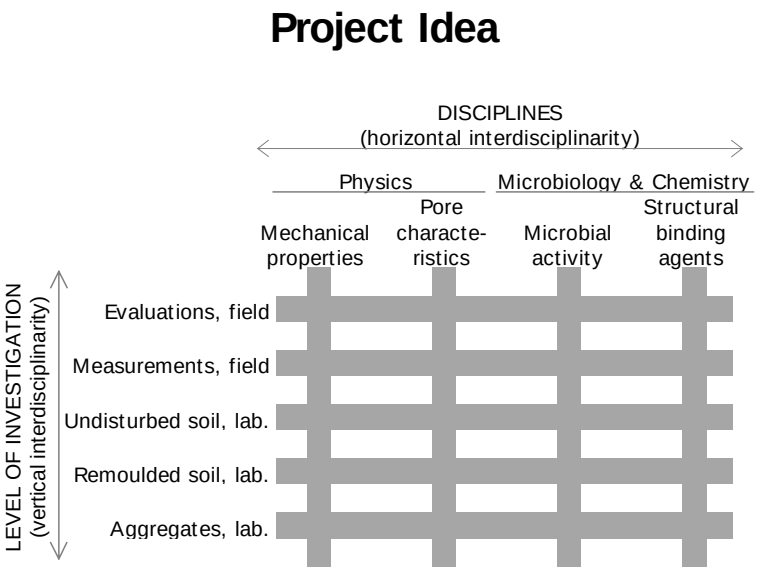

Figure 4. The approach applied for minimizing pitfalls from application of reductionistic methods in our research on soil tilth in organic farming fields.

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., 2004). 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 5 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.

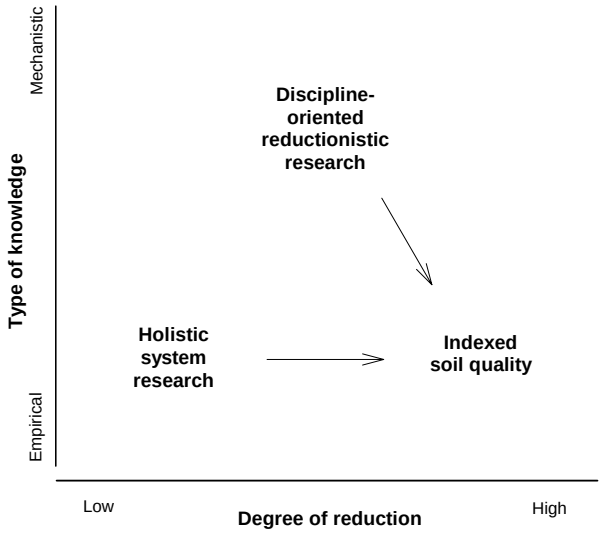

Figure 5. Different research approaches depicted as related to the degree of 'reduction' (abscisse) and the type of knowledge gained (ordinate). The arrows indicate what happens when indexing the information gained as is often done in soil quality studies (adopted from Schjønning et al., 2004).

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.

Changes in plans

As described in sections 7C and 7D, the project has been delayed to some extent for the workpackages A2, A3 and B. The reason for this has been described in the sections mentioned. This will not however imply that the objectives of the project will not be fulfilled. We have taken the consequence and moved the necessary financial resources to 2005. This will allow all results to be included in the dissemination of results in international journals as well as in articles to farmers and consultants.

Literature cited in Section H:

Carter, M.R., Andrews, S.S. & Drinkwater, L.E. 2004. Systems Approaches for Improving Soil Quality. In: Schjønning, P., Elmholt, S. & Christensen, B.T. (eds.) *Managing Soil Quality – Challenges in Modern Agriculture*. CAB International, Wallingford, UK.

Schjønning, P. Elmholt, S. & Christensen, B.T. 2004. Soil Quality Management – Concepts and Terms. In: Schjønning, P., Elmholt, S. & Christensen, B.T. (eds.) *Managing Soil Quality – Challenges in Modern Agriculture*. CAB International, Wallingford, UK.

8. Budget

A. Account for any change in budgets

The changes in plans for WP's A2, A3 and B (see section D) have caused a need for carry forward to year 2005 of a part of the funds originally budgetted for 2001, 2002, 2003 and 2004.

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	Consumption 2003	Expected consumption 2004	Budget 2005	Total
Man-months					
Scientific personnel	22,5	17.25	11	13	63,75
Technical personnel	28,5	15,5	2,9	1,1	48

Year:	Consumption before 2003	Consumption 2003	Expected consumption 2004	Budget 2005	Total
Salaries					
Scientific personnel	891	730	528	611	2760
Technical personnel	673	400	61	30	1164
Other operational costs	472	111	85	64	732
Equipment					
Others (please specify)	30	15			
Direct costs	2066	1256	674	705	4701
Indirect costs (20% of direct costs)	406	248	135	141	930
Total	2472	1504	809	846	5631

Comments:

9. Signatures and stamps

Name	Institute	Date	Signature
Head of project Per Schjønning		30.09.2004	