I.7

Soil quality in organic farming:
Effects of
crop rotations, animal manure and soil compaction

Acronym: ROMAPAC

Application for funding of research in the context of

The Danish Research Centre for Organic Farming

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1. Summary

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

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

2. Research group

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3. Introduction

In organic farming, plant production relies on the inherent properties of the soil and the state of these properties as affected by the history of farming practice for the specific soil. Crop rotation, organic amendments and soil tillage are basic management tools with a heavy impact on soil conditions and functions. Development of organic farming requires better understanding of the relative importance of these basic management tools.

In this project, we intend to address **subsoil compaction** as related to important soil functions. We further aim at elucidating **topsoil tilth** as related to crop rotation, organic manure amendments and traffic-induced compaction. The work suggested should be regarded as a close follow-up to a recent project also within the context of The Danish Research Centre for Organic Farming (DARCOF project I.3, cf. Kristensen, 1996). In that project - closing ultimo 1999 – we conducted a number of paired case studies of organically and conventionally managed soils. We further initiated a comprehensive field trial on development of tillage systems particularly relevant to organic farmers.

3.1 Subsoil compaction

The increasing mechanisation of modern agriculture has introduced very high inputs of energy to soil during traffic and tillage. This affects the soil in several ways. One important consequence of traffic with heavy tractors and implements is compaction of the soil. Based on the experience obtained during a life span of research, Håkansson (1994) regards subsoil compaction as the most severe threat to the fertility and continued productivity of soils. As organic farming relies completely on optimum soil fertility, subsoil compaction may be regarded as a basic threat to the possibility of conducting this farming system. Recent results clearly showed that organic farmers are generally faced with the same problems of compacted subsoils as conventional farmers (Schjønning et al., submitted). This important finding stresses the need for more focus on subsoil compaction also in organic farming.

3.2 Topsoil tilth

The tilth of the upper part of the soil is of paramount importance for the establishment and growth of crops. The soil biota in terms of microorganisms and fauna live almost exclusively in the upper soil layers. Soil functions like decomposition of organic matter, aggregate formation and transport processes for air, water, heat and nutrients are highly dependent on the physical constitution of this soil layer. Soil tilth also determines soil friability and ease of fragmentation, which are important for the creation of a suitable seedbed. These soil functions as well as soil behaviour are fundamental for the soil as a medium for agricultural use. Our recent results from DARCOF- I.3 quantified important long-term influence on soil quality of crop rotation and application of animal manure (Schjønning et al., submitted). Further, our results indicated a pronounced 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 this project we suggest further studies in order to increase our knowledge of the relative importance of each of these basic management tools and their interactions.

3.3 Basic and applied research

In an outlook for future research in organic farming, Niggli & Lockeretz (1996) highlight the need for *short-term, user-oriented, highly applied research* as well as *the long, slow search for a better understanding of the fundamental natural processes on which any agricultural system rests*. Based on our recent research we claim that a combination of these two aims is possible and provides a great potential for progress and success in the development of organic farming. A related aspect of great importance in future research in organic farming systems is the link between quantitative, scientific measures of system characteristics and the farmers' qualitative impression and judgement of the same characteristics. In DARCOF-I.3, we found a clear correlation between descriptive methods in the field and quantifying field tests. Furthermore we found a correlation between the field tests and classical laboratory methods. There is a need of further testing and evaluating these correlations, as they will enable an evaluation of soil quality in the field by agricultural consultants and farmers.

3.4 Reference state of the soil ecosystem

Soil behaviour and functions fluctuate as affected by climate (time of year), soil water content, soil temperature, and crop growth and soil management in terms of *e.g.* tillage and organic matter amendments. A key idea in the 'topsoil tilth' part of this project is to analyse the soil when it has arrived at a reference 'state', considering the effects listed above. We approach this situation by sampling the soil for analyses at a water content near field capacity in the spring and lagging as far as possible behind tillage events and application of organic residues to the soil. This is important for comparison of long-term management effects.

3.5 ROMAPAC project structure

The project includes two separate, although generally related research topics, A and B. Research topic A will address the problem of subsoil compaction, the potential amelioration by mechanical loosening and the risk of re-compaction by heavy traffic and during ploughing. This activity may be termed highly user-oriented although general knowledge on the soil ecosystem will also be obtained. The continued research into topsoil tilth will be denoted Research topic B and aim to increase our knowledge on the relative effects of crop rotations and animal manure as well as their interaction with short-term effects of tillage and traffic.

4. State of the art

Research topic A:

Subsoil compaction: effects on soil and crops and the potential amelioration by mechanical loosening

Soane & van Ouwerkerk (1994) concluded a comprehensive review on compaction problems in agriculture by stating that *there is urgent need to relate technical and economic benefits of overcoming compaction problems to the costs of alternative systems of mechanisation on a whole-farm scale*. This statement is based on research and experience in conventional farming. The compaction problem may be anticipated to have even higher influence in organic farming, in which the use of mineral fertilisers and pesticides is excluded.

4.1 Compaction effects

Soil compaction is a process of densification in which porosity and permeability are reduced, strength is increased and many changes are induced in the soil fabric and in various behaviour characteristics (Soane & van Ouwerkerk, 1994). A large number of important soil functions will be affected directly or indirectly. The decrease in permeability reduces drainage of excess water (Horton et al., 1994) and exchange of air to the root environment (Stepniewski et al., 1994). Ponding water may trigger surface runoff and erosion (e.g. Schjønning et al., 1995). Anoxic conditions in the bulk soil may be more frequent and lead to loss of gaseous nitrogen following denitrification (Bakken et al., 1987). The conditions for turnover of organic matter are reduced with the potential effect of reducing nutrient supply to the crop and the resulting yields (Hansen, 1996). Root penetration and proliferation in the bulk soil volume are hampered (Munkholm et al., 1998) and the uptake of nutrients is reduced (Bennie, 1996). Ultimately, the yields of crops are reduced. Håkansson (1994) reported a comprehensive series of field trials in the northwestern Europe, In Canada and in the northern USA. From these studies, it was concluded that traffic with 10 tonnes axle loads machinery decreased the yield of small grain cereal crops up to 15% the first year after the compaction event. It further appeared that there was a persistent reduction in yield even 20 years after the compaction event.

4.2 Occurrence and persistence of compaction

Numerous reports have described the existence of compacted soil layers below ploughing depth in modern, mechanised agriculture (e.g. Håkansson, 1994; Soane & van Ouwerkerk, 1994; Håkansson et al., 1996; van den Akker, 1999). For Danish conditions, a number of studies have indicated that the compaction problem is widespread in the agricultural land (Schjønning, 1989; Schjønning, 1992; Rasmussen et al., 1995; Munkholm et al., 1998; Djurhuus & Olesen, in prep.). Further, several investigations have indicated that compaction effects in soil layers not mechanically tilled may be persistent (Håkansson, 1994; Sharratt et al., 1998).

4.3 Compaction in organic farming

Recent results have shown that soil on farms, which had been organically managed for decades, also exhibited severe compaction of the soil below ploughing depth (Schjønning et al., submitted). Due to the fact that organic farmers have to rely on the natural fertility of their soils, the compaction problem should be given special attention in the future development of organic farming. During the work within DARCOF-I.3, we observed restricted root growth in soil layers below ploughing depth (Munkholm, 2000; Schjønning et al., submitted). Compaction has been observed to reduce *Rhizobium* nodulation of pea plants (Grath & Håkansson, 1992). In accordance with this, Munkholm (2000) found an increased amount of *Rhizobium* nodules in a mechanically loosened subsoil layer as compared with traditionally ploughed soil. Subsoil compaction and the amelioration by mechanical loosening therefore seems very important to the performance of legume crops and thereby to organic farming, which relies to a large extent on nitrogen fixation.

4.4 The plough pan

Several investigations have reported a significant densification of the soil layer just below the ploughing depth (e.g. Ehlers, 1973; Rydberg, 1987; Francis et al., 1987). There are numerous reports that the use of tractors of ever-increasing weight and power and the continued ploughing with these tractors for decades have created critical conditions for soil functions in these ’plough-pans’ (Teiwes & Ehlers, 1987; Schjønning, 1989; Comia et al., 1994; Ball et al., 1998). The direct pressure from the tractor wheel in the furrow combined with smearing of soil due to the shearing forces of the drawing wheel cause harmful compaction and structure deterioration below ploughing depth.

4.5 Mechanical loosening of subsoil

Subsoiling, i.e. mechanical loosening of soil below normal tillage depth, has frequently been suggested as a means of improving soil functions in compacted soil (e.g. McEven & Johnston, 1979). Braim et al. (1984) improved root growth and yield of direct-drilled soil by using the Howard Paraplow. The same implement has been reported by Hipps & Hodgson (1988) to decrease significantly the mechanical strength of a considerable part of a compact soil layer. Barraclough & Weir (1988) documented a substantial effect of loosening a panned sandy loam mechanically when speaking in terms of root development in the soil profile. For Danish conditions, Schjønning & Rasmussen (unpublished data) compared the effect of several subsoiling machineries on a loamy sand that had been subjected to repeated traffic with a heavy sugarbeet harvester in wet conditions. Significantly increased yields of winter wheat were obtained by subsoilers acting to a depth of approximately 60 cm, while no effects were found for machines only loosening the soil to ~40 cm depth. Schjønning & Rasmussen (1994) found a significant increase in the yield of monoculture spring barley when loosening soil, that had been trafficked with ten tonnes axle load machinery.

However, no yield increase was obtained in plots, which had not received the compaction treatment. These results, therefore, indicate that mechanical loosening of soil layers below normal tillage depth should only be performed if compacted layers have been identified.

The non-inverting tillage system suggested by Weichel (1984) and examined in DARCOF-I.3 enables a combination of rather deep loosening with the superficial tillage of a seedbed (Munkholm et al., 1998; Munkholm et al., accepted). Our results showed that the mechanically loosened soil had a clearly improved rooting potential (Munkholm et al., 1998; Munkholm, 2000). However, this was not reflected in significant increases in crop yields. The reason may be that the intial years of the tillage trial were rather humid with frequent rainfall events throughout the growing season (unpublished data). This would be in accordance with Barraclough & Weir (1988), who found that subsoiling a panned sandy loam soil was only related to an increase in yield if the water supply (precipitation) during the growing season was limiting. In order to test the effect of subsoil loosening in dry conditions, therefore, the DARCOF-I.3 established an extra trial with plant growth in dry conditions (Nielsen et al., accepted). From the traditionally ploughed plots as well as from the subsoiled plots, a number of soil columns with a diameter of 20 cm and a depth of 40 cm were excavated at seed germination in the spring. When growing the mixed crop of spring barley and pea under sheltered conditions until harvest (i.e. with a maximum of water stress), a significantly higher number of roots were found in the subsoiled soil than in the ploughed soil (Table 1). Moreover, a significant reduction in pea yield and a tendency to a reduction in the barley yield were found for the traditionally ploughed soil. From the yield of the two species grown together, it further appeared that peas benefited the most from the loosening of the dense layer below ploughing depth (Table 1). This may be due to the smaller flexibility and generally greater thickness of pea roots as compared to the finer, seminal roots of barley (Dexter, 1986). In general, compacted soil layers and subsoil loosening may therefore be anticipated to influence the competition between the plant species in intercropping and most so when the crops suffer from water stress. Similarly, the competition between weeds and the crop may be influenced, which may be important especially in organic farming.

Table 1. Root density and above-ground dry matter production 32 days after germination when intercropping spring barley and peas in soil cores (20 cm Ø and 40 cm length) under sheltered condition (no irrigation). The soil cores were minimally disturbed and excavated from the bulk soil in the field at germination. Figures with the same lettering are not significantly different (P=0.05). (Nielsen et al., accepted).

	Spring barley		Peas		Sum	
	Ploughed	Subsoiled	Ploughed	Subsoiled	Ploughed	Subsoiled
Root density in 0-40 cm, cm cm^{-3}	4.0^a	4.6^a	2.6^a	2.9^a	6.6^a	7.5^b
[1]Dry matter production, hkg ha^{-1}	19.9^a	19.0^a	9.8^a	12.3^b	29.7^a	31.3^a

[1] Above-ground dry matter production when harvested 32 days after germination

4.6 Ground pressure and axle load

The stresses applied to the plough layer soil and the upper part of the subsoil are determined by the ground pressure exerted on the soil during traffic (Olsen, 1994). The ground pressure is determined by the tyre equipment and the inflation pressure. Vermeulen & Perdok (1994) concluded that ground pressures on moist soil should never exceed 100 kPa when high axle load machinery is used. They further stated this to be a realistic goal for vehicles used in agriculture. Subsoil compaction, however, is predominantly determined by the wheel (or axle) load (Olsen, 1994). Håkansson & Petelkau (1994) reviewed general recommendations for maximum allowable wheel loads. They suggested further studies to quantify the strength of different soils at different water contents. As general recommendations until further knowledge has been obtained, Håkansson & Petelkau (1994) refer to those used in the former East Germany and in Sweden. For traffic on moist agricultural land, these axle load limits were set to 4 and 6 tonnes, respectively.

4.7 Recompaction of mechanically loosened subsoil

Whatever strategy chosen for improving the structural conditions and soil functions of previously compacted soil layers, a key question for continued sustainable agriculture is concerned with ways of preventing recompaction of the soil. The results reported by Hipps & Hodgson (1988) suggested that repeated subsoiling might be necessary in order to retain the positive effects of the mechanical loosening. Recompaction of initially loosened soil will occur during traffic. And due to the low strength of recently tilled soil (Hadas, 1997), the pressure exerted on the soil surface as well as the axle loads of vehicles crossing the soil should be kept at a minimum.

Re-compaction is also likely to take place during mouldboard ploughing. In traditional mouldboard ploughing, the tractor wheels are running in the furrow. It has been suggested for long, that on-land ploughing with all tractor wheels on top of the soil would decrease the compaction of the subsoil (e.g. Kuipers, 1989). This has normally been considered to create practical problems in controlling the plough. However, recent achievements in agricultural engineering have facilitated the introduction of ploughing systems with reasonable performance (e.g. Anken & Nadlinger, 1996) and systems have been suggested also for small- and medium scale ploughs (Kouwenhoven & Boer, 1997; Domsch et al., 1997; Kouwenhoven et al., 1999). Although Hoffmann & Sorge (1993) showed that on-land ploughing reduced the compaction of the subsoil, only few reports are concerned with this important aspect of soil tillage.

Research topic B:

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

The desired soil structure in relation to crop emergence and development may be characterised by a proper aeration, a good contact between root and soil, and a low resistance against root penetration. This means that the soil must be adequately loose to secure aeration and a low penetration resistance, and sufficiently dense to secure proper root-soil contact. Optimal conditions for the soil microorganisms and fauna also require a well-aerated soil and the soil biota are furthermore influenced by the ‘morphology’ of the pore system (van Veen & Kuikman, 1990; Postma & van Veen, 1990; Schjønning et al., 1998). The characteristics mentioned here are part of the term *soil tilth* as defined for quantitative use by Karlen *et al.* (1990) (see box below). The definition clearly states the multidisciplinary, 'holistic' nature of the term. Karlen *et al.* (1990) further considered the *tilth-forming processes* in order to provide a tool/framework for a better understanding of how soil management affects the soil tilth (see box below).

Soil tilth *The physical condition of a soil described by its bulk density, porosity, structure, roughness, and aggregate characteristics as related to* *- water, nutrient, heat and air transport* *- stimulation of microbial and faunal populations and processes* *- impedance to seedling emergence and root penetration*
Tilth-forming processes *The combined action of physical, chemical, and biological processes that bond primary soil particles into simple and complex aggregates and aggregate associations that create specific structural or tilth conditions*

The combined concepts of *tilth* and *tilth forming processes* as defined here constitute an extremely relevant framework for studying soil fertility and quality as related to the organic farming system. Crop rotation, animal manure and compaction by traffic are key factors in the **formation and stabilisation of soil structure** (tilth-forming processes), cf. Figure 1. The **structural strength and friability** and the **soil pores as a habitat for microorganisms** express the resulting soil tilth, cf. Figure 1. Our preceding work on the subject (DARCOF-I.3) clearly showed that valuable information for general conclusions can be obtained by this approach (Schjønning et al., 1999a; Munkholm et al., 1999; Schjønning et al., submitted). Below is given a state of the art for each of the three aspects included in the concepts of tilth-forming processes and tilth.

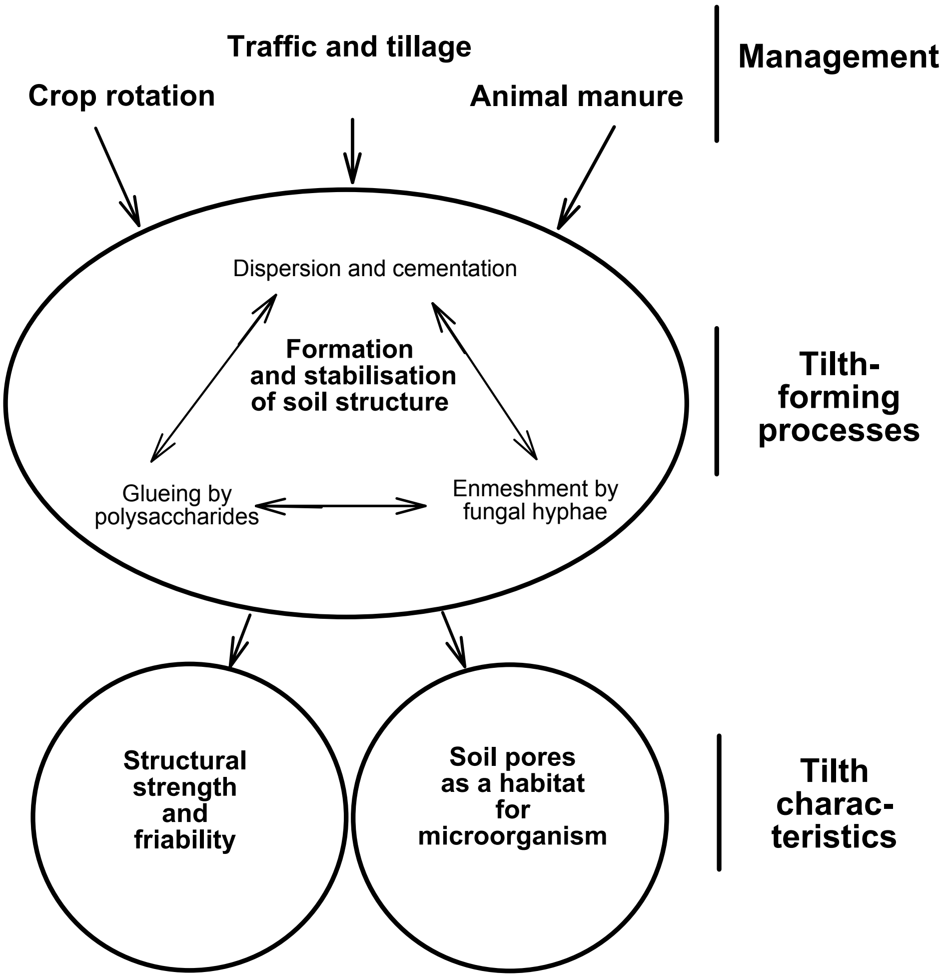

Figure 1. The conceptual framework of research topic B.

4.8 Formation and stabilisation of soil structure

The formation and stabilisation of soil primary particles into aggregates are essential to obtain a well-structured soil that can sustain growth and development of plant roots and soil organisms (Oades, 1993). Similarly, the counteracting effects keeping soil friable are essential for agricultural use of the soil. Soil in natural ecosystems is normally well aggregated and still friable. Managed soils, on the contrary, are seldom ‘self-mulching’ (Grant & Blackmore, 1991) and need mechanical disturbance to yield seedbeds optimal for plant growth.

4.8.1 Soil aggregation

Soil aggregation is a complex process, in which the ‘naked’ mineral particles interact with organic matter, polycations, soil fauna, plants and microbes. The process has been considered to include a number of steps, which in a simplified form may be outlined as follows (Cheshire, 1979; Tisdall & Oades, 1982; Burns & Davies, 1986; Goldberg, 1989; Degens, 1997; Beare et al., 1997; Ladd et al., 1996; Hadas, 1997):

- Flocculation of clay minerals and cementation of particles by hardening dispersible clay and by Fe- and Al-oxyhydroxides (dominant at the domain level, <5 μm)
- Gluing effects of bonding agents, e.g. extracellular polysaccharides (EPS) excreted from plants, fauna and microbes (micro-aggregate level, 5-250 μm)
- Cross-linking and enmeshment by fungal hyphae and plant roots (macro-aggregate level, >250 μm)

A number of papers have given some evidence of the validity of the conceptual model of aggregation (e.g. Muneer & Oades, 1989ab; Dorioz et al., 1993; Degens, 1997).

4.8.2 Extracellular polysaccharides

As described by Burns & Davies (1986), the polysaccharides in soil aggregation are predominantly of microbial origin (Cheshire, 1977; Oades, 1984). Recent evidence suggest hot-water extractable polysaccharides to correlate best to the stability of soil structural units (Ball et al., 1996; Degens, 1997). Hot water is not considered to solubilise or hydrolyse plant structural carbohydrates (Cheshire, 1979) and should therefore be relatively enriched in non-structural plant carbohydrates and extracellular microbial carbohydrates. The correlation between hot water extractable carbohydrate and aggregate stability is usually better than for total carbohydrates (Haynes et al., 1991; Haynes & Francis, 1993). Results obtained in DARCOF-I.3 showed that organic manuring and a diversified crop rotation increased the carbohydrate content in the microaggregate size fractions (Debosz et al., 1998).

4.8.3 Fungal hyphae

Eash et al. (1994) found that enhanced aggregation in soil following plant residue additions was not due to the residue *per se*; rather it was probably caused by greater fungal activity as indicated by a large increase in observed hyphal lengths. Thus the authors quantitatively demonstrated soil fungi to play a major role in soil aggregation when they nourish and proliferate on organic amendments. Other researchers have cast doubt on the potential role of fungal hyphae in enmeshment (e.g. Degens et al., 1994). However, Carter and Oades (cited in Oades, 1984) used periodate treatment to destroy polysaccharides in aggregates and found no decline in aggregate stability. This underlines an earlier observation that the stability of the aggregates was directly related to the extent of hyphal development within those aggregates (Tisdall & Oades, 1980). A number of saprophytic fungi have also been found to be able to stabilise sand grains by enmeshment, e.g. a *Penicillium* species (Forster, 1990).

One purpose of DARCOF I.3 was to elucidate the role of EPS and fungal hyphae in soil aggregation. Using calcoflour staining to obtain the total lengths of fungal hyphae (West, 1988; Eash et al., 1994) we found significantly more hyphae in the organically cultivated soils than in their conventionally cultivated counterparts. The biggest difference was found between the organic soil with a diversified crop rotation and manuring and the conventional soil continuously grown to small grain cereals and receiving synthetic fertilisers. These results do not, however, reveal the relative importance of the different management factors.

4.8.4 Interaction between physical and biological mechanisms

Results obtained in DARCOF-I.3 suggest that the interactions between abiotic and biotic bonding and binding forces are complex and highly influenced by soil management (Schjønning et al., 1999; Schjønning et al., submitted; Munkholm & Schjønning, in prep.; Debosz et al., in prep.; Elmholt, unpubl. data). An organically managed soil with a diversified crop rotation and frequent amendments of animal manure showed significantly higher levels of EPS and lengths of fungal hyphae than a conventionally managed counterpart that had been grown for decades with annual crops and no input of organic matter. However, a poorer ease of fragmentation was detected for the latter soil. I.e., the biotic ‘bonding’ and ‘binding’ forces suggested erroneously a stronger soil structure for the organically managed soil. The conventional soil also displayed a significantly higher dispersibility of clay and a high tensile strength of dry aggregates. A correlation between these two characteristics has been observed also by other researchers (Kay & Dexter, 1992; Barzegar et al., 1995; Watts & Dexter, 1997). Therefore, our recent results may be interpreted in terms of a high influence of the physicochemical process characterised by cementation of dispersed clay particles (Figure 1). As a consequence of low levels of biotic aggregating agents, the conventionally managed soil may have been more susceptible to slaking of aggregates. Re-orientation and hardening of the dispersed clay minerals succeedingly may have resulted in a dense and mechanically strong but non-friable soil.

Also traffic from agricultural machinery has proven effective in increasing clay dispersibility and tensile strength of large aggregates (Watts et al., 1996ab; Schjønning et al., submitted). Future research in binding and bonding mechanisms in soil should therefore give due reference to abiotic as well as biotic stabilisation mechanisms (Figure 1). Further, it should include the interaction between long-term effects of crop rotations and organic amendments on the one side and short-term effect of traffic and tillage on the other.

4.9 Structural strength and friability

The long- and short-term management history for a given soil is determining for the formation and stabilisation of soil structural units (tilth-forming processes, Figure 1). The result of these processes is reflected in the soil tilth. Important aspects of tilth are the structural strength and friability as these soil properties determine soil compactability, potential root penetration, and ease of tillage. The main objective of secondary tillage is to form an appropriate seedbed by crushing large clods and levelling the soil surface. Soil behaviour in this process is dependent on the friability, which can be defined as *the tendency of a mass of unconfined soil to breakdown and crumble under applied stress into a particular size range of smaller fragments* (Utomo & Dexter, 1981). Keeping the soil friable is a major concern in agricultural management. For some heavy clay soils (mainly vertisols), the soil forms an ideal seedbed by natural cycles of drying and wetting often referred to as a 'self-mulching' behaviour (Grant and Blackmore, 1991). However, the vast majority of soils need an input of external mechanical energy to fragment. A friable soil exhibits a high ‘ease of fragmentation’, i.e. a high tendency of larger clods to fragment into a desirable aggregate size distribution (Utomo & Dexter, 1981).

4.9.1 Effects derived from crops

Monoculture maize and continuous growing of small grain cereals have been shown to result in stronger soil aggregates and lower ease of fragmentation in comparison with soil grown with a diversified crop rotation. Watts et al. (1996b) found monoculture maize soil to have stronger 13-19 mm aggregates than soil with a two or four-year crop rotation. Schjønning et al. (submitted) and Munkholm & Schjønning (in prep.) similarly measured a considerable increase in aggregate strength for a soil continuously grown with small grain cereals as compared with an organically managed soil with a diversified crop rotation. The increase in aggregate strength was associated with a reduction in ease of fragmentation and friability. On the other hand, results by Schjønning et al. (submitted) indicated that binding forces from residual roots of previous grass leys might be the reason that a lower ease of fragmentation was obtained for a crop rotation including leys as compared with a rotation including only annual crops. Watts & Dexter (1998) suggested that the effects of crop rotation on soil fragmentation may relate to the higher amount of organic matter often found in such soils as soil friability has been shown to increase with an increased content of soil organic matter. However, an improved interpretation would require a better understanding of the processes involved (Figure 1).

4.9.2 Effects derived from animal manure

During DARCOF-I.3, measurements were carried out in two replicate fields of the classical field trials on animal manure and mineral fertilisers at Askov Experimental Station (Christensen & Trentemøller, 1995). The results indicated that a period of more than 100 years of contrasting fertilisation had resulted in larger strength of the aggregates in unfertilised soil in comparison with those in synthetically or organically fertilised soil (Munkholm & Schjønning, unpublished results). I.e., 'starving out' the soil with no fertiliser input at all clearly increases its strength and reduces its friability. In one of the fields, the soil applied with animal manure displayed a significantly higher friability index than the soil dressed with mineral fertilisers. Watts et al. (1996b) reported no effects from differentiated applications of farmyard manure on the strength of soil aggregates. There is a need for further studies on the effects of animal manure on soil mechanical behaviour.

4.9.3 Effects derived from traffic and tillage

Intensive tillage and traffic have been reported to give stronger aggregates and lower friability. Watts et al. (1996b) and Watts and Dexter (1998) reported significant negative effects of wheel traffic on aggregate tensile strength and soil friability estimates. Furthermore they found that the traffic intensity had a higher impact on aggregate tensile strength than other management practices. The case studies in organically managed soils reported by Schjønning et al. (submitted) similarly displayed substantial reductions in soil ease of fragmentation and soil friability estimates due to intensive traffic. Also Voorhees & Lindstrom (1984) found compaction to eliminate the positive effects of a change in soil management (conservation tillage as opposed to mouldboard ploughing). Munkholm et al. (1999) documented a significant effect of compaction as well as energy input by a rotary tiller upon aggregate tensile strength of a sandy loam.

The present knowledge, as reviewed above, points out a pressing need for a better understanding of the relative importance of animal manure, crop rotation and traffic/tillage effects on soil mechanical behaviour. The ultimate objective of further research concerning tillage and traffic effects would be identification of threshold values for energy input in order to sustain the positive effects of manure and crops.

4.10 Soil pores as a habitat for microorganisms

The soil pore system serves as pathway for transport of water and air, and as a habitat for soil biota. The physical distribution of the pore network in the bulk soil determines whether the overall aeration potential facilitates aerobic conditions in soil microhabitats. As the tilth-forming processes (Figure 1) modify soil structure, the management tools may significantly influence the conditions for microbiological processes.

Micro-organisms play a crucial role in decomposition of organic matter, plant nutrient cycling, and as symbionts or pathogens of crop plants in all agricultural systems. They are, however, of special relevance to the organic farming systems where the natural processes they are involved in cannot be short-circuited by the use of agrochemical inputs (Lopez-Real & Hodges, 1986). Crop rotations affect soil microbial biomass by regulating the quantity and quality of plant biomass input, especially root biomass. Collins et al. (1992) showed that the greater the input of plant biomass from cereal-pasture rotation, the larger the increase in soil microbial biomass. These effects on microbial biomass are mainly due to the amount of C inputs through plant growth and return of plant residues to the soil. Application of farmyard manure to soil also increases microbial biomass. Debosz et al. (1999) measured an increase in microbial biomass C eight years after the introduction of cover crops, animal manure and straw mulching. In the study performed in DARCOF- I.3, microbial biomass C contents in organic managed soils were ~35% higher than in the soils managed according to conventional farming methods receiving comparable inputs of organic matter.

4.10.1 Soil pore space and microorganisms

Soil microorganisms have only access to locations in the soil where the physical dimensions of the pore space allow them to function. Van Veen & Kuikman (1990) suggested that for some soils up to 90% of the catalytic surface of organomineral complexes can be considered as sterile. The term *habitable pore space* for microorganisms (Postma & van Veen) may be considered to equal the volume of 0.2-30 µm pores. Pores smaller than 0.2 µm are regarded inaccessible to microorganisms (Bakken & Olsen, 1987) and pores larger than 30 µm are only water-filled when the soil is very wet (water content above field capacity). Similarly, the *protective pore space* accessible to microorganisms but not to nematodes and other predators may be taken as the volume of 0.2-3.0 µm soil pores (Postma & van Veen, 1990).

Hassink et al. (1993) showed that the bacterial biomass of some grassland soils was positively related to the volume of 0.2-1.2 µm pores. Recent results by Schjønning et al. (1999b) and Thomsen et al. (1999) similarly suggested a positive effect of a high protective pore space upon the microbial biomass. Also our studies in DARCOF- I.3 revealed that a significant correlation existed between the volume of protective pore space and microbial biomass (Schjønning et al., submitted), Figure 2. Notice that two of the soils in Figure 2 (Conv-P) displayed a lower microbial biomass than would be expected from the general relation between the volume of protective pore space and the microbial biomass. These soils had received no animal manure for decades and were furthermore grown with annual cash crops as compared to the other soils grown with diversified crop rotations. The data in Figure 2 do not allow general conclusions due to the few soils examined and due to possible interactions between management effects. However, the results point out the need for further studies in order to elucidate the potential effects of management tools.

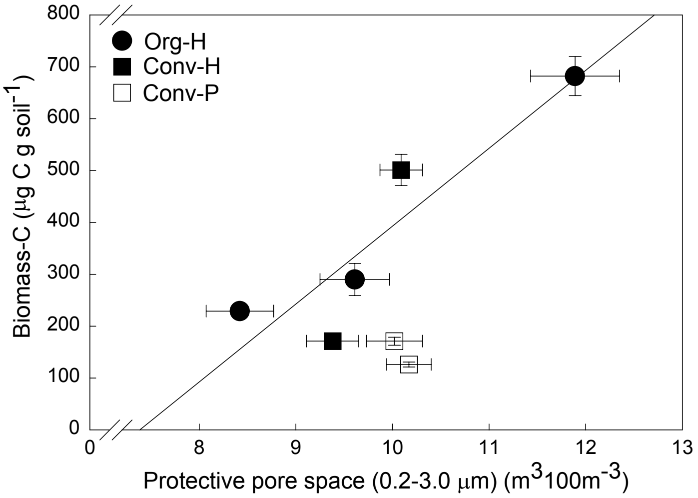

Figure 2. Relation between the volume of protective pore space and the microbial biomass for seven loamy soils grown either organically with animal husbandry (Org-H), conventionally with animal husbandry (Conv-H) or conventionally with a non-diversified crop rotation and with no application of animal manure for decades (Conv-P). The line indicate linear regression, including all Org-H and Conv-H soils. Data from DARCOF-I.3 (Schjønning et al., submitted).

4.10.2 Pore tortuosity

Also the size distribution and tortuosity of soil pores are of importance in characterising the soil as a habitat for microorganisms. Investigations in soil pore characteristics most often have been concerned with tillage and traffic effects (e.g. Ball, 1981b; Schjønning, 1989). There is a need also of studying the effects of long-term differences in crop rotation and soil manuring.

A number of authors have suggested the use of air and water transport measurements for refining our understanding of soil pore characteristics (Gradwell, 1961; Ball; 1981a; Groenevelt & Lemoine, 1984). Schjønning & Munkholm (in prep.) quantified a tremendous difference in soil structure between an organically managed soil and a nearby conventional soil. The former soil (labelled DFG) had a diversified crop rotation and was frequently amended with animal manure. The conventional counterpart soil (labelled CCC), on the contrary, had been grown for at least two decades with small grain cereals and receiving no organic manures. It appeared that the DFG soil had a larger volume of macropores >10 µm. Also the pore 'morphology' was different. The DFG soil exhibited a tortuous pore system ramified in the matrix of the bulk soil, while the CCC soil displayed a continuos system of macro-pores or 'downpipes' with a poor three-dimensional distribution in the bulk soil. The detected differences will obviously influence the general aeration of bulk soil volumes between the macropores and thereby the living conditions for microorganisms.

5. Objectives and expected achievements

5.1 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].

5.2 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.

6. Description of workpackages including methods

6.1 Overview of project structure and methodology

The ROMAPAC project will make use of three existing field trials as research ‘objects’:

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

The DTS and the CRE trials were initiated in 1996 as part of the initial set-up of field experiments by DARCOF. The soils used for the trials were converted to organic farming at the initiation of the trials, and the soils at all sites have now fully adapted to the crop rotations and management strategies imposed. The LAM trial was initiated in 1987 and is run with four different levels of organic inputs to the soil. Within the CRE trial, three crop rotations will be addressed and labelled CRE$_{1-3}$. The characteristics of the trials are explained in detail below. Figure 3 shows how ROMAPAC uses the trials in relation to its research topics.

The work concerning research topic A will be addressed in three workpackages (WP A1, WP A2 and WP A3), while all work related to research topic B is described in one workpackage (WP B). Finally, project co-ordination constitutes one workpackage (WP C).

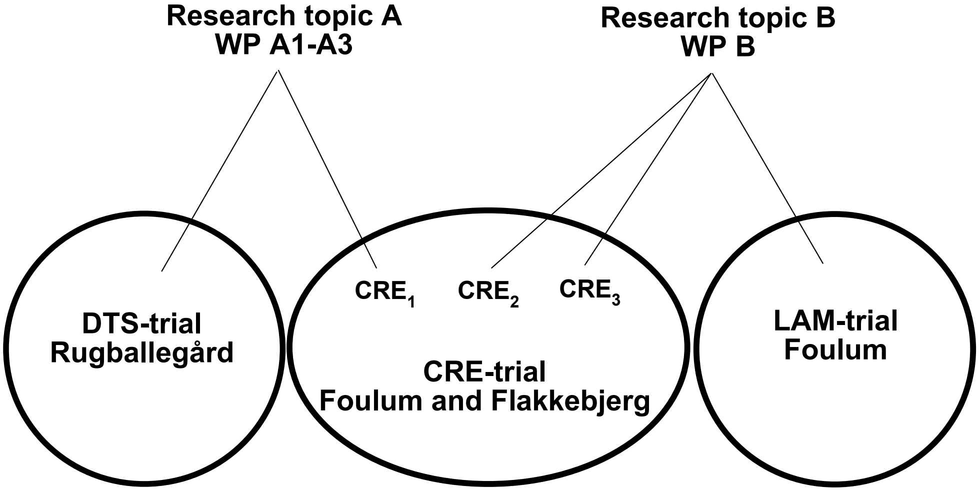

Figure 3. Project structure in terms of field trials addressed within the research topics A and B. DTS = Development of tillage strategies, CRE = Crop rotation experiments, LAM = Levels of input of animal manure

6.2 Basic characteristics of field trials

Development of tillage strategies (DTS)

This trial was initiated by DARCOF-I.3 and will be used in the ROMAPAC workpackages WP A1 and WP A3. It is located on a loamy soil at the organically managed 'Rugballegård' Research Station. During the initial period of trial (1996-1999), four different tillage strategies were compared in a randomised block design with four replicates. The treatments included traditional mouldboard ploughing to 20 cm depth, mouldboard ploughing to only 10-12 cm depth, and two treatments with non-inverting tillage to ~35 cm depth. For one of the latter treatments, preparation of seedbed and sowing were performed together with the subsoiling by use of a combined implement constructed as part of the project.

Due to two years of grass/clover ley in the rotation, all fields do not experience the differentiated treatments every year. However, at the end of 1999, all five fields had been treated according to the plan at least once and two of the fields received the treatments twice.

The trial is run in a five-year crop rotation for ’mixed’ farming and includes five fields with the following crops, all being grown every year:

Spring barley undersown with a pea/grass/clover mixture
1st year grass/clover mixture
2nd year grass/clover mixture
Spring oat
Winter wheat

Crop rotation experiment (CRE)

The trial is run at four sites with different soil types (Olesen et al., submitted). The current study will only use the experimental sites at Foulum (loamy sand) and Flakkebjerg (sandy loam). The experiment follows a factorial design with three factors and two replicates where all fields in the rotations are represented every year. The experimental factors are 1) Fraction of grass-clover and pulses in the rotation (crop rotation), 2) With/without catch crop and 3) With/without animal manure. Plots receiving manure are supplied with slurry at rates of ammonium nitrogen in the slurry corresponding to 40% of the nitrogen demand of the specific rotation. Straw residues are chopped and incorporated into the soil. The crop rotations are all four-course rotations, but they differ in their proportion of nitrogen fixing crops. Three crop rotations will be used for WP A1, WP A2, WP A3 and WP B in the ROMAPAC project:

Rotation CRE_1 (in the original CRE context: rotation 2 without catch crops) [WP A2, WP A3]:
Spring barley undersown with a grass/clover mixture
Grass/clover mixture for green manure
Winter wheat
Lupine

Rotation CRE_2 (in the original CRE context: rotation 2 with catch crops) [WP B]:
Spring barley undersown with a grass/clover mixture
Grass/clover mixture for green manure
Winter wheat with undersown catch crop of ryegrass
Lupine with undersown catch crop of ryegrass

Rotation CRE_3 (in the original CRE context: rotation 4 without catch crops) [WP B]:
Spring barley
Spring oats
Winter wheat*
Lupine

*The standard crop is spring wheat at this point in the rotation, but winter wheat will be grown in the relevant years with the purpose of enabling comparisons in identical crops between the two rotations.

Levels of input of animal manure (LAM)

This trial is used for WP B. The trial is located on a loamy sand at Foulum and run in two fields. Four levels of organic inputs to the soil are compared in a factorial design with three replicates. The ROMAPAC project will address a treatment with application of animal manure (slurry) and a reference receiving no organic amendments except the stuble from the crops. In order to level the input of nutrients to the soil, the reference treatment is supplied with synthetic fertilisers. Since 1987, both fields have been grown with the crop rotation:
Winter wheat
Spring barley
Spring barley
Spring rape*

*Every second rotation grown to peas, i.e. 1996-1999: peas; 2000-2003: spring rape

6.3 WP A1. Development of tillage strategies including recompaction evaluation

The primary task in WP A1 is to run the field trial with development of tillage strategies initiated in 1996. The trial plots will then be utilised by WP A3 for evaluation of tillage effects on soil characteristics and root growth. Included in WP A1 is, however, also registration of weeds and crop yields. Finally, it should be mentioned that WP A1 as an extra task shall provide an on-going DARCOF-project with ‘research objects’ for studies of tillage effects on soil biota. This DARCOF-project is labelled ‘IV.3. Qualitative and quantitative relationships between soil preparation procedures, microflora, fauna and the timing of nitrogen release in organic farming’ (Kristensen, 1999) and is concluded ultimo 2000.

The ROMAPAC project will continue the original plan for year 2000 for all fields. From 2001, modifications will be made in order to evaluate the risk of re-compaction of loosened soil by traffic and during mouldboard ploughing. These treatments will be investigated in a crossed split-plot design for the basic treatments with non-inverting deep tillage.

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

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

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

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

- Yields and content of N, P and K in the harvested material
- Total above-ground plant production, including content of N
- Above-ground weed biomass
- Weekly measurements of crop spectral reflectance for assessment of light interception (Olesen et al., 2000).

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

In WP A3, the task is to evaluate the subsoiling effects on soil physical characteristics and root growth. The treatments in the DTS trial at Rugballegård as well as those in the CRE_1 rotation at Foulum and (to a minor extent) Flakkebjerg will be included in these investigations. For the DTS trial, the subsoiled treatments will be evaluated with traditionally ploughed soil as a reference. Further, the measurements will include the new treatments regarding traffic and ploughing strategy (see the trial plan in WP A1).

For all combinations of locations and treatments, the mechanical strength of the soil in the 0-60 cm layer will be evaluated by cone penetration measurements (Olsen, 1988). These measurements will take place in the spring at water contents of field capacity. Soil sampling for bulk density and micro-penetrometer studies (Lipiec & Usowicz, 1997), and measurements of root growth will be performed according to the plan below. These studies will take place in a winter wheat crop.

	2001	2002	2003
DTS, field B3	R_s+R_r		
DTS, field B4		R_s+R_r+S+W	
CRE_1, Foulum			R_s+R_r+S+W
CRE_1, Flakkebjerg			R_s

R_s: Root studies by soil core sampling, washing and quantification of root length and diameter with the technique of Bouma et al. (2000).
R_r: Root studies by rhizotron-studies in the field during the growing season
S: Soil physical studies on core samples at controlled water potential
W: Water content measurements by Time Domain Reflectometry technique during the growing season

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

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

Research objects

As already described, ROMAPAC will benefit from the accumulated effects of crop rotation and animal manure amendments found in the existing CRE and LAM field trials (see section 6.2). Samplings and measurements for this purpose will take place in year 2002 in a winter wheat crop.

At Foulum, the effects of differentiated crop rotations will be studied in the CRE trial by sampling in the CRE_2 and CRE_3 rotations. The manure effects at Foulum will be studied in the LAM trial.

At Flakkebjerg, the crop rotation effects as well as the manure effects will be studied in the CRE trial. The crop rotation effects will be elucidated by addressing the CRE_2 and CRE_3 rotations, - both without application of animal manure. The organic manure effects will be elucidated by addressing plots of the CRE_3 rotation with and without amendments with animal manure (CRE_{3+} and CRE_{3-}). I.e., at Flakkebjerg the CRE_{3-} plots will serve as a common reference for both main effects.

Treatments prior to sampling and measurements

In order to enable the study of the interaction between the basic crop and manure effects and the mechanical disturbance by field traffic, half of the plots selected for studies of crop and manure effects will be treated as follows. In the years 2000 and 2001, the soil will be trafficked 'wheel by wheel' immediately following mouldboard ploughing prior to establishing the specific crops. For the CRE_2 rotation the crop preceding the winter wheat is grass/clover mixture. In this case, the traffic will take place in the crop in the spring at water contents of field capacity.

Field measurements

Field measurements and sampling for laboratory studies will take place in the winter wheat crop in the spring at water contents of field capacity. The *in situ* measurements include a quantification of 'ease of fragmentation' by the soil drop method (Munkholm & Schjønning, in prep.; Schjønning et al., submitted). The method is based on the drop shatter method by Hadas & Wolf (1984) and involves drop from a specified height of minimally disturbed soil cubes sampled immediately before the test. Further, the shear strength will be measured by the shear vane method (Serota & Jangle, 1972) and by the torsional shear box method (Payne & Fountaine, 1952). All characteristics are measured for the 6-13 cm soil layer.

Laboratory studies

Soil will be sampled in minimally disturbed cubes, in minimally disturbed 100 cm^3 cores and also in remoulded form. The remoulded soil will be air-dried at arrival at the laboratory while the minimally disturbed samples will be stored at 2^oC until analyses.

Soil textural composition and content of C, N, P and K will be analysed by standard methods. Air-dried soil will be fractionated to yield aggregates in the four size-classes 8-16, 4-8, 2-4 and 1-2 mm. Aggregate tensile strength will be measured on these aggregates according to the method described by Dexter and Kroesbergen (1985). An index of soil friability will then be estimated from the slope of an aggregate tensile strength / aggregate volume relation in a log-log presentation (Utomo & Dexter, 1981). Stability of wet aggregates that are sub-sampled from the minimally disturbed cubes will be measured in principle as described by Pojasok & Kay (1990) and as detailed by Schjønning et al. (submitted). Dispersibility of clay from bulk soil derived from the same soil cubes will be quantified with a turbidimetric measurement of dispersed clay following a mechanical shaking procedure (Pojasok & Kay, 1990; Schjønning et al., submitted).

Water retention will be measured with standard technique at a number of predefined matric potentials (including –10 kPa), using the 100 cm^3 minimally disturbed cores. Further, when equilibrated at each of the matric potentials, bulk soil air diffusivity and permeability will be measured with the methods of Schjønning (1985) and Grover (1955), respectively. Finally, water retention at –100 kPa and -1.5 MPa matric potentials will be measured in order to quantify the habitable and protective pore space (Postma & van Veen, 1990).

Extracellular polysaccharides (EPS) will be measured with the technique of Ball et al. (1996) as modified by Debosz et al. (in prep.). The extraction procedure includes an initial washing of the soil with cold water followed by hot-water extraction. Fungal hyphal lengths will be measured by epifluorescent microscopy using calcofluor staining, in principle as suggested by West (1988) and Eash et al. (1994). Finally, microbial biomass C will be determined by the fumigation-extraction method (Vance et al., 1987). Soil for the methods mentioned here will be sub-sampled from the minimally disturbed soil cubes. I.e., measurements will take place in field-moist soil.

6.7 WP C. Project co-ordination and dissemination of results

Co-ordination of the whole project including dissemination of results has been designed a separate workpackages. This is partly due to the fact that the two topics included in ROMAPAC – although generally correlated – constitute two separate task forces. The co-ordination will include frequent meetings with two sub-groups of research participants. A project manual will be written with detailed descriptions of tasks and timetables. The co-ordination further involves keeping contact to the persons in charge of the trials at the three locations. Project co-ordination further involves preparing annual reports of progress and the final report from the project.

Another important task included in this workpackages is dissemination of results to consultants and farmers. It is the opinion of the research group, that the problems addressed in the ROMAPAC project should have a high priority in further development of organic farming. Especially the subsoil compaction problem is regarded a severe threat to soil fertility. The organic farmers should as quickly as possible initiate a change from the use of machines with axle loads above 6 tonnes and also shift to low-pressure tires. Therefore, as in the former DARCOF-I.3, much effort will be put into the preparation of papers in farmers' magazines etc. Also oral presentations at seminars and meetings will be included.

6.8 Workpackages list

Table 2: Workpackages list

Work-package No	**Work package title**	**Responsible participant**	**Budget 1000DKK**	**Start**	**End**	**Deliv. No**
A1	Development of tillage strategies including recompaction evaluation	PS	468	04/00	12/02	D1, D2, D3
A2	Above-ground crop response to compaction and subsoiling	JEO	777	08/00	12/04	D4, D5, D6
A3	Soil effects and root response to compaction and subsoiling	LJM	1435	01/01	12/04	D7, D8
B	Topsoil tilth as affected by crop rotations, animal manure and traffic	PS	2679	04/00	12/04	D9, D10
C	Project co-ordination and dissemination of results	PS	272	04/00	12/04	D11, D12, D13, D14, D15

6.9 Summary of workpackages

Table 3. Description of workpackages. Person-months include only scientific personel.

WP A1: Development of tillage strategies including re-compaction evaluation

Workpackages number: A1
Responsible person: PS
Contributing persons: KJR, LJM
Person-months: 3.75

Objectives WP A1

- Run an existing field trial in year 2000 in order to provide 'research objects' for the running DARCOF-IV.3 project
- Modify and run the existing trial for evaluation of traffic effects on subsoil compaction and thereby providing 'research objects' for WP A3
- Evaluate tillage effects on weeds and crop yields

Description of work (summary, see section 6.3 for details)

The main task of WP A1 is to carry out an existing field trial on different tillage strategies for the years 2000 through 2002. In year 2000, the existing plan will be followed in order to support another DARCOF-project by providing 'research objects'. In 2001 and 2002, only two fields will be managed according to the trial plan, which further will be modified by testing the effects of different traffic strategies and different systems for mouldboard ploughing (traditional in-furrow and on-land systems).

Deliverables

D1. Research objects for DARCOF project IV.3
D2. Research objects for WP A3
D3. DARCOF-report on 1997-2000 years trial results

Milestones

M_A1.1. The trial has been performed in year 2000 according to the old plan (Sept. 2000)
M_A1.2. An on-land plough has been procured and used for the first time (April 2000)
M_A1.3. The controlled traffic strategy has been implemented for use (May 2000)
M_A1.4. The DARCOF-report has been published (March 2002)

Table 3. Description of workpackages - continued

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

Workpackages number: A2
Responsible person: JEO
Contributing persons: LJM, PS
Person-months: 7.5

Objectives WP A2

- Evaluate the effects of compacted soil and subsoil loosening on above-ground crop response in terms of dry matter production, nutrient uptake, weed competition, and growth rhythm

Description of work (summary, see section 6.4 for details)

For each of the years 2000 through 2003, a number of plots in the CRE experiment at Foulum and Flakkebjerg will be mechanically loosened by means of a Howard Paraplow working to a depth of ~40 cm. Only one half of each plot will be treated in this way in order to use the other half as a reference for the treatment effects. Yields and contents of N, P and K in the harvested materials will be registered in treated soil as well as in the reference sub-plots. Further, total above-ground plant production and the biomass of weeds will be measured. Finally, crop light interception will be followed weekly by measurements of canopy spectral reflectance.

Deliverables

D4. Demonstration of effects for farmers (field-days)
D5. Research objects for WP A3
D6. International scientific paper

Milestones

M_A2.1. The subsoiling treatment has been performed at both locations and all plots (August 2003)
M_A2.2. The measurements have been carried through for all plots [plots treated year 2003 will not be investigated] (September 2003)
M_A2.3. An international scientific paper has been submitted for publication (December 2004)

Table 3. Description of workpackages - continued

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

Workpackages number: A3
Responsible person: LJM
Contributing persons: PS, JEO, KJR
Person-months: 16

Objectives WP A3

- Evaluate the effects of compacted soil and subsoil loosening on soil physical properties of importance to root growth
- Quantify the effects of compacted soil and subsoil loosening on root growth of winter wheat at three soil types
- Evaluate the root growth rhythm of winter wheat for two soil types and as affected by subsoil loosening

Description of work (summary, see section 6.5 for details)
WP A3 will use subsoiled and traditionally ploughed reference plots provided by WP A1 and WP A2 for detailed studies of tillage effects on soil strength and root growth. Three locations will be included: Foulum (loamy sand), Flakkebjerg (sandy loam) and Rugballegård (sandy loam). The soil physical measurements will quantify *in situ* soil strength in subsoiled and in reference plots. They will further include measurements of micro-penetrometer resistance at controlled water regimes in the laboratory. Root growth will be studied in the field by core sampling and (for two locations only) by rhizotron-studies. The soil cores will be sampled at several depths at the flowering stage of winter wheat. Following washing of soil from the roots, quantification of length, diameter, weight etc. of these will be done by an automated system.

Deliverables
D7. Presentation of results at the 16th International Conference of the International Soil Tillage Research Organization (ISTRO)
D8. International scientific paper

Milestones
M_A3.1. Rhizotron studies of roots have been implemented for use at Rugballegård, field B3 (April 2001)
M_A3.2. Core sampling has been completed at Rugballegård, field B3 (June 2001)
M_A3.3. Measurements and samplings completed at Rugballegård, field B4 (June 2002)
M_A3.4. Measurements and samplings completed at Foulum and Flakkebjerg (June 2003)
M_A3.5. Presentation of results at the 16th ISTRO Conference (June 2003)
M_A3.6. International scientific paper submitted (May 2004)

Table 3. Description of workpackages - continued

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

Workpackages number: B
Responsible person: PS
Contributing persons: SE, KD, LJM
Person-months: 29.5

Objectives WP B

- Quantify the effects of crops and animal manure on abiotic as well as biotic mechanisms involved in the tilth-forming processes
- Identify the relative importance of mechanical disturbance in terms of soil surface traffic on the crop and animal manure effects mentioned above
- Investigate soil behaviour in terms of strength and friability as affected by the tilth-forming processes and in turn the management tools involved
- Investigate soil porosity as related to its function as a habitat for micro-organisms
- Evaluate and confirm recent findings on the correlation between descriptive and integrating field methods and differentiating laboratory methods for evaluation of soil tilth

Description of work (summary, see section 6.6 for details)
WP B comprises all the aspects involved in research topic B. The LAM trial at Foulum and two rotations in the CRE trial at Foulum and Flakkebjerg will be used for the studies. Sub-plots will be trafficked 'wheel by wheel' two years ahead of samplings and measurements in order to investigate the interaction between the two main management tools (crop rotation and manure amendments) and the mechanical disturbance. Field measurements and sampling for laboratory studies will take place in a winter wheat crop in the spring at water content of field capacity. The field measurements will address soil strength and friability. The laboratory studies will include binding and bonding mechanisms of soil structural units. Further a number of stability and friability measurements and soil pore descriptions will be included. Finally, the measurement programme includes determination of the microbial biomass.

Deliverables
D9. Presentation of results at the 16th International Conference of the International Soil Tillage Research Organization (ISTRO)
D10. International scientific paper(s)

Milestones
M_B.1. The mechanical treatments of sub-plots have been performed (October 2001/2002)
M_B.2. Field measurements and samplings completed at the LAM and CRE trials, Foulum and the CRE trial, Flakkebjerg (May 2002)
M_B.3. Laboratory measurements completed for spring 2002 samplings (January 2003)
M_B.4. Field measurements and samplings completed at the CRE trials, Foulum and Flakkebjerg (May 2003)
M_B.5. Presentation of results at the 16th ISTRO Conference (June 2003)
M-B.6. International scientific paper(s) submitted (October 2004)

Table 3.Description of workpackages - continued

WP C: Project co-ordination and dissemination of results

Workpackages number: C
Responsible person: PS
Contributing persons: (JEO, LJM, KJR, SE, KD)
Person-months: 5

Objectives WP C

- Co-ordination of project
- Dissemination of results

Description of work (summary, see section 6.7 for details)

A project manual will be written with detailed descriptions of tasks and timetables. The co-ordination further involves keeping contact to the persons in charge of the trials at the three locations. Project co-ordination also involves preparing annual reports of progress and the final report from the project.

Another important task included in this workpackages is the dissemination of results to consultants and farmers. Much effort will be put into the preparation of papers for farmers' magazines etc. Also oral presentations at seminars and meetings will be included.

Deliverables

D11. Project manual
D12. 1., 2., 3., 4. annual status report
D13. Papers in farmers' magazines
D14. Oral presentations at seminars and meetings
D15. Final status report

Milestones

M_C.1. Project manual completed (June 2000)
M_C.2. Annual status reports completed (November 2000, 2001, 2002, 2003)
M_C.3. Final status report completed (November 2004)

7. Implementation and time schedule

7.1 Deliverables list

Table 4. Deliverables list

Deliv.No	**Deliverable title**	**Deliv. date**	**Meeting**[1]	**Nature**[2]
D1	Research objects for DARCOF project IV.3	04/00		O
D2	Research objects for WP A3	04/01		O
D3	DARCOF-report on 1997-2000 years trial results on development of tillage strategies	03/02		Re
D4	Demonstration of subsoiling effects for farmers	06/02-04		O
D5	Research objects for WP A3	04/02		O
D6	International scientific paper, above-ground crop effects from subsoiling	10/04		Pu
D7	Presentation of results at the 15th ISTRO Conference, root growth in loosened soil	06/03		Pu
D8	International scientific paper, root growth dynamics as related to compaction and subsoiling	11/04		Pu
D9	Presentation of results at the 15th ISTRO Conference, tilth and tilth-forming processes as affected by crops, manure and compaction	06/03		Pu
D10	International scientific paper(s), tilth and tilth-forming processes as affected by crops, manure and compaction	12/04		Pu
D11	Project manual	09/00		Re
D12	1., 2., 3., 4. annual status report	10/xx	X	Re
D13	Papers in farmers' magazines	xxxx		Fm
D14	Oral presentations at seminars and meetings	xxxx		O
D15	Final status report	10/04	X	Pu

[1] Plenum project group meetings will be held in connection with the preparation of each annual report

[2] Pu= International publications in books and journals; Fm= papers in farmers' magazines; Re= Reports; O= Other (see WP description)

7.2 Timetable

Table 5. Timetable

		2000						2001						2002						2003						2004					
TASKS		**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
	WP A.1 :Development of tillage strategies including recompaction evaluation																														
	Field trial, old plan, all fields		x	x	x	x																									
	Field trial, new plan, two fields		x					x	x	x	x	x	x	x	x	x	x	x	x												
M_A1.1	Trial performed by old plan					x																									
M_A1.2	On-land plough has been procured and used first time		x																												
M_A1.3	The controlled traffic strategy has been implemented			x																											
M_A1.4	A DARCOF-report on tillage strategies has been publ.														x																
	WP A.2: Above-ground crop response to compaction and subsoiling																														
	Subsoiling events				x						x						x						x								
	Measurements of above-ground crop response								x	x	x	x			x	x	x	x			x	x	x	x			x	x	x	x	
M_A2.1	All subsoiling performed																						x								
M_A2.2	All measurements performed																													x	
M_A2.3	International paper submitted																														x
	WP A3. Soil effects and root response to compaction and subsoiling																														
	Root studies at DTS trial, Rugballegård								x	x	x				x	x	x														
	Root studies at CRE trial, Foulum and Flakkebjerg																				x	x	x								
M_A3.1	Rhizotron studies of roots have been implemented								x																						
M_A3.2	Core sampling completed at Rugballegård, field B3									x																					
M_A3.3	Measurements and samplings completed at Rugb., B4															x															
M_A3.4	Measurements and samplings compl., Foulum and Fl.																					x									
M_A3.5	Presentation of results at ISTRO conference																					x									
M_A3.6	International paper submitted																											x			
	WP B. Topsoil tilth as affected by crop rotations, animal manure and traffic																														
	Compaction treatments in subplots, LAM and CRE trial		x						x			x			x			x													
	Field and laboratory measurements, 2002 sampling														x	x	x	x	x	x											
	Field and laboratory measurements, 2003 sampling																				x	x	x	x	x	x	x				
M_B.1	Compaction treatments in subplots completed											x						x													
M_B.2	Field measurements and samplings 2002 completed														x																
M_B.3	Laboratory measurements for 2002 samplings compl.																				x										
M_B.4	Field measurements and samplings 2003 completed																				x										
M_B.5	Presentation of results at ISTRO conference																					x									
M_B.6	International paper(s) submitted																													x	
	WP C: Project coordination and dissemination of results																														
	Production of project manual		x	x																											
	Project coordination		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Preparation of papers for farmers' magazines[1]										*x*						*x*						*x*						*x*		
M_C.1	Project manual completed					x																									
M_C.2	Annual status reports completed					x						x						x						x							
M_C.3	Final status report completed																													x	

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[1] Dissemination of results will take place frequently during the project, - not at the exact dates indicated

8. Collaborative partners

There will be collaboration with several research groups and projects on a national basis. The ROMAPAC project has been obliged to provide a running DARCOF-project (labelled ‘IV.3’ and headed by Jørgen A. Axelsen) with ‘research objects’ for their studies. This implies that the ROMAPAC project in year 2000 will have a close co-operation with the above-mentioned project. Further, a link exists to the suggested DARCOF-I.4 project ‘Nitrogen management and cropping methods for enhanced bread wheat production’ in terms of an agreement that the expertise concerning physical characterisation of the topsoil properties in the ROMAPAC project will be available for the other project. Another co-operation is concerned with root studies. It has been agreed that the ROMAPAC project may have its root samples analysed by an automated technique at the Department of Fruit, Vegetable and Food Science within the Danish Institute of Agricultural Sciences (Kristian Thorup-Kristensen and Kai Lønne Nielsen). The agreement further includes assistance in installing transparent tubes for rhizotron studies in the field. These services will be paid for by the ROMAPAC funding.

At the international level, a close link exists to professor Bev Kay at the Department of Land Resource Science, University of Guelph, Ontario, Canada. The project participant Lars J. Munkholm is currently (January-June 2000) studying at this Department as a part of his Ph.D. study. Bev Kay is an expert in soil friability research, and our studies will be based on the most recent advances in this field of science. The studies in subsoil compaction will benefit from an existing co-operation with Johan Arvidsson at the Swedish University of Agricultural Sciences, with Rainer Horn at Chr. Albrecths University at Kiel, Germany and with Jan van den Akker at theWinand Staring Centre for Integrated Land, Soil and Water Research, Wageningen, The Netherlands. Our research will be in line with the suggestions created by a running EU-project on subsoil compaction with these persons as co-ordinators.

9. Budget

Budget, 1000 DKK. DAE: Dept. Agric. Engineering; DCPSS: Dept. Crop Phys. Soil Science

	2000	2001	2002	2003	2004	Σ
DAE (WPA1)						
Salary (scientific)	19	0	0	0	0	19
Salary (technical)	55	70	72	0	0	197
Operation	15	7	5	0	0	27
Overhead	18	15	15	0	0	48
Σ DAE (WPA1)	***107***	***92***	***92***	***0***	***0***	***291***
DCPSS (WPA1)						
Salary (scientific)	19	85	21	0	0	125
Salary (technical)	1	4	1	0	0	6
Operation	13	3	1	0	0	17
Overhead	7	18	4	0	0	29
Σ DCPSS (WPA1)	***40***	***110***	***27***	***0***	***0***	***177***
DCPSS (WPA2)						
Salary (scientific)	22	45	47	50	209	373
Salary (technical)	1	2	2	2	8	15
Operation	28	60	63	99	10	260
Overhead	10	22	23	29	45	129
Σ DCPSS (WPA2)	***61***	***129***	***135***	***180***	***272***	***777***
DCPSS (WPA3)						
Salary (scientific)	0	142	149	157	165	613
Salary (technical)	0	100	129	123	8	360
Operation	0	44	59	78	4	185
Overhead	0	57	67	72	36	232
Sub-contractor*	0	15	15	15	0	45
Σ DCPSS (WPA3)	***0***	***358***	***419***	***445***	***213***	***1435***
DCPSS (WPB)						
Salary (scientific)	0	81	291	328	602	1302
Salary (technical)	0	3	256	244	27	530
Operation	0	39	173	162	26	400
Overhead	0	25	144	147	131	447
Σ DCPSS (WPB)	***0***	***148***	***864***	***881***	***786***	***2679***
DCPSS (WPC)						
Salary (scientific)	38	40	42	45	47	212
Salary (technical)	2	2	2	2	2	10
Operation	1	1	1	1	1	5
Overhead	8	9	9	9	10	45
Σ DCPSS (WPC)	***49***	***52***	***54***	***57***	***60***	***272***

*Department of Fruit, Vegetable and Food Science within the Danish Institute of Agricultural Sciences; payment for assistance in root studies

Budget - summary:

Budget, 1000 DKK

	2000	2001	2002	2003	2004	Σ
Σ DAE	**107**	**92**	**92**	**0**	**0**	**291**
Σ DCPSS	**150**	**797**	**1499**	**1563**	**1331**	**5340**
Σ Project	**257**	**889**	**1591**	**1563**	**1331**	**5631**

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