Paul Kristiansen , Acram Taji et al. (eds.) Organic agriculture: a global perspective, Chapter 15. CSIRO, Australia, 2006.

Chapter 15

Research to support the development of organic food and farming

Christine Watson, Scottish Agricultural College, UK, Hugo Alrøe, Danish Research Centre for Organic Farming, Denmark, and Erik Steen Kristensen, Danish Research Centre for Organic Farming, Denmark

Introduction

Agriculture and organic agriculture in particular are developing rapidly, not only as a result of technological change but also to changes in agricultural policy and public expectation. Research allows new knowledge to be developed and is thus vital for the future of organic agriculture. The question, 'What is the purpose of research on organic farming? Is it to increase yield and productivity, to compare it with other forms of agriculture, or to quantify its environmental and social impact, minimise the adverse effects and maximise the benefits and so on? The answer is of course, that research has a role in all of these and many other aspects of developing the organic food chain. The precise purpose of the research is usually defined by the funding body, and may differ with whether the funding body is from the public or private sector. In this Chapter, development of organic research is examined briefly through both the public and private sectors and then some of the issues that surround research on organic agriculture in terms of approaches and appropriate methodologies is explored. The extent to which organic and conventional agriculture require different research and different approaches to research is explored.

History and status of organic research

Niggli and Willer (2001) define four stages in the development of organic farming research:

1 pioneer farmers and scientists;
2 pioneer private research institutes;
3 organic farming chairs at universities; and
4 organic farming projects and institutes at state research institutions.

Stage 1 is characterised by the comparisons of organic and conventional farming systems at Haughley, Suffolk, England initiated by Eve Balfour (Balfour 1943). Although many scientists today would not recognise this as a scientific experiment, there is still some useful information to be gleaned from those early pioneers (Blakemore 2000). The private institutes that emerged through the 20th century (Table 15.1) generally have been driven by outstanding individuals or

Table 15.1 Private institutes

Country	Organisation	Year established
Germany	Institute for Biodynamic Agriculture	1950
Switzerland	Forschungsinstitut für biologischen Landbau	1974
Netherlands	Louis Bolk Institute	1976
United States of America	Rodale Institute	1976 (founded in 1947)
Austria	Ludwig Boltzmann Institute	1980
United Kingdom	Elm Farm Research Station Henry Doubleday Research Association	1982 1984
Sweden	Biodynamic Research Institute	1986

groups of individuals with a strong personal commitment to organic or biodynamic agriculture. Many of those same individuals were responsible for the 1st International Scientific Conference of the International Federation of Organic Agricultural Movements (IFOAM) held in 1977, and described by Niggli (2002) as the debut of organic farming research. Some of the private organisations, such as the Louis Bolk Institute, were founded to allow researchers to pursue research that was not accepted by conventional scientific organisations, such as homeopathic studies (Van Mansfeld and Amons 1975). However, it was really during the 1980s that public funding for organic agricultural research started to become available. During the same period, positions and departments of ecological and organic agriculture began to appear in universities in Europe. The first chairs of organic or alternative agriculture in Europe were established at the University of Kassel at Witzenhausen, Germany, and Wageningen University in the Netherlands in 1981; the first Chair in Biodynamic Agriculture was established at Kassel in 2005.

During the 1980s in the United States of America (USA) there was one United States Department of Agriculture (USDA) post assigned to work with the Rodale Institute, Pennsylvania (Parr 2003), although there were other linkages between farmers, university staff and USDA staff during this period (Jawson and Bull 2002). Support for USDA involvement in organic research was only realised in 1998 when the Organic Farming Bill was finally passed by the US Congress. The first faculty position dedicated to organic farming in a Land Grant University was established at Iowa State in 1997 (Delate and DeWitt 2004). The situation has changed rapidly, however, and in September 2003, the USDA announced US$4.5 million in grants for organic agriculture projects (USDA 2004). In Australia, research is funded from levies paid by producers and matched by Commonwealth funding, as well as by state departments of agriculture and universities. Wynen (2003) estimated that in 2001 only around two-thirds of the A$656,200 funding was actually spent on research that directly benefited organic farming.

The USDA funding for organic research is aimed at helping farmers and ranchers to increase the production of high quality products while decreasing costs (USDA 2004). The focus of the research appears to be very much within the farm, and orientated towards production rather than the environment. The five-year R&D Plan for Organic Produce (2001–2006) formulated in Australia by the Rural Industries Research and Development Corporation (RIRDC) covers many aspects of the supply chain both on and off farm, with market development and communication featuring heavily (RIRDC 2005). The *European Action Plan for Organic Food and Farming* was launched in June 2004 (Commission of the European Communities 2004). Action 7 relates specifically to strengthening research on organic agriculture and production methods. One area that is highlighted in the plan is the need for research in the processing sector of the organic food chain. Within the Sixth Framework Programme (2002–2006) of the Commission of the European Communities there is no specific 'agriculture' priority but relevant topics are contained within the programs on 'Food quality and safety', 'Sustainable development, global

Table 15.2 Estimated national financial input into organic farming research in 11 European Union countries (ERANET)

The estimate is a minimum based on targeted organic research programs that does not include, for example, professorial appointments in organic agriculture.

	Current[A]	Future[B]
Austria	0.7	1.5
Denmark	8	7
Finland	2	2
France	5.7	5.7
Germany	10	7
Italy	1.5	2
Netherlands	8	8
Norway	3	2
Sweden	5.7	5.9
Switzerland	10	15
United Kingdom	3.2	3.9
Total	57.8	60

[A] Average 2000–04, [B] 2005–10.

change and ecosystems' and 'Strategies for sustainable land management' (Commission of the European Communities 2004). Amounts of funding available in several EU member states are given in Table 15.2. Each member state of the EU also has its own Action Plan, containing guidance on research to be funded at national level. Within the UK, funds have been set aside to encourage industry funding of organic research through the LINK scheme, where government matches industry funding (S 2002). There is some concern among the UK research community that this may not be an appropriate funding route, given the incompatibility between the need for a systems focus in research on organic farming and the limited availability of industrial funding bodies with an interest in farming systems (Elm Farm Research Centre 2003). The LINK scheme works well where agriculture is driven by inputs rather than ecological systems. There is a similar scheme operating in Canada where companies can become research partners and their funding will be matched by government. Five categories of partner are recognised on the basis of the level of contribution made OACC (2005).

Cropping aspects of organic production have received more attention than livestock aspects until recently; this is reflected in the number of refereed publications (Watson and Atkinson 2002). Lund and Algers (2003) relate the later development of research on animal husbandry to the situation in Europe where the regulations for organic animal husbandry were established only in 1999, eight years after the regulations on crop husbandry (Council Regulations 2092/91 and 1804/99). Biodynamic agriculture has received little funding from public sources, although considerable work has been carried out in some private research institutes. A short description of the development of biodynamic research and institutions in Europe and the USA is given in Koepf (1993). Reports of biodynamic systems in mainstream journals are relatively rare, although there are some notable exceptions such as Reganold *et al*. (1993) and Carpenter-Boggs *et al*. (2000).

Researching organic systems

According to Lockeretz and Anderson (1993), there is a need for rethinking the approaches, processes and institutional structures of agricultural research, because of the range and scale of consequences that agricultural research is expected to address today. There are high political demands on the relevance and proactive perspective of research relative to the changing goals, intentions and values of society and agriculture. These demands are not restricted to agricultural research. They are part of a more general change in the conception of science and its role in society, from that of science as an independent source of objective knowledge to that of science as special learning process within society.

Agriculture is an area undergoing rapid development, both in terms of technological development and the development of alternative production systems, and agricultural research is influential in these developments. In this sense, agricultural science is a 'systemic' science, a science that influences its own subject area (Alrøe and Kristensen 2002). Furthermore, agricultural practice involves both social and ecological systems, and research into these socioecological systems faces the dual challenge of understanding complex agroecosystem interactions and the practices of people in social systems. Agricultural systems research is, therefore, inherently framed in a social context, and necessarily involves questions concerning different interests and values in society as well as different structures of rationality and meaning (Kristensen and Halberg 1997).

There is, therefore, a need to explicitly address how values in the form of intentions and social interests feature in agricultural research. This is in terms of where and how values enter into the research process, and also in terms of what the systemic nature of agricultural research means in relation to the conventional scientific criteria of quality. This need applies generally to agricultural research. Moreover, the role of values is particularly evident with regard to organic farming, because special values and goals are obvious and decisive and because these values are clearly different from the values of mainstream agriculture.

The special values of organic agriculture are summarised and what this obvious and manifest value basis means for organic research, how is to be performed, and how it is to be evaluated is briefly considered. Sound research approaches and appropriate methodologies for organic research are described and the relationship between organic and conventional research is discussed.

Ethics, principles and standards

Organic farming has differentiated itself from conventional agriculture by way of alternative agricultural practices, world views and values. Most notably, the organic movement has explicitly formulated basic principles and standards for organic production and processing. The principles are based on a perception of humans and human society as an integrated part of nature and a holistic conception of health. Understanding the ecological processes that drive productivity and environmental impact through soil biology, vegetation dynamics, pest population dynamics, disease epidemiology and so on, is a key to improved organic systems. This does not imply that they are unimportant in conventional farming. Organic farming does, however, not have access to all the technological means for overcoming natural and ecological insufficiencies and problems (notably artificial pesticides, fertilisers, preventive medicine) that conventional farming has, and it therefore relies on cooperation with natural ecological systems to a greater extent. Values of animal welfare, biodiversity and livelihood are also an integral feature of organic farming. This comprehensive, integrated view of nature and ethics is evident in one of the original key ideas of organic agriculture that 'the health of soil, plant, animal and man is one and indivisible' (Lady Eve Balfour in Woodward *et al*. 1996).

In the existing IFOAM Basic Standards (IFOAM 2002), there are 15 principal aims plus general principles for each area in the standards, and the principles are thus quite complex to overview. There is, however, a process going on within IFOAM to rewrite the principles of organic agriculture. The process is expected to result in a set of basic ethical principles to be decided upon in the General Assembly 2005 in Adelaide. In the draft of May 2005, there are

Box 15.1 IFOAM draft principles of organic agriculture, May 2005

Principle of health
Organic agriculture should sustain and enhance the health of soil, plant, animal and human as one and indivisible.

Principle of ecology
Organic agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them.

Principle of fairness
Organic agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities.

Principle of care
Organic agriculture should be managed in a precautionary and responsible manner to protect the health and well-being of current and future generations and the environment.

four principles on health, ecology, fairness and care (POA Task Force 2005) (Box 15.1). From the perspective of research, the formulation of basic ethical principles of organic agriculture have been advocated as a necessary tool for researchers to initiate far-seeing, proactive research that can assist the development of organic agriculture, and the sustainable development of agriculture in general, in a constructive and critical way (Alrøe and Kristensen 2004). The present IFOAM process will hopefully provide a simpler and more consistent source of organic principles for researchers to use as a starting point when planning and performing research on organic agriculture.

Quality criteria for organic research

In the same way that proponents of conventional agriculture have criticised organic farming so too have 'conventional' researchers criticised organic research. In the foreword to Tinker (2000), it is suggested that 'the majority of literature on the subject [of organic farming] was written from a strongly committed point of view'.

This kind of critique can lead the organic research community to reflect on the quality of past organic research, and whether organic research can be of high quality. The answers to these questions depend entirely criteria of quality that are used. Some of the critiques of organic research are based on the presumption that science should be free of values and ideologies, an idea that Thompson (1995) has termed 'ethical reductionism'. The argument is that organic agriculture is inherently ideological, science should operate without reference to ideologies and, therefore, research that operates from the viewpoint of organic ideology and values is not scientific.

But science is neither value free nor independent. Values do and should enter into important phases of the research process such as problem identification, design of methods and experiments, model assumptions and the use of normative concepts (Alrøe and Kristensen 2002). Some concepts that are widely used in agricultural research are clearly value laden. Obvious examples include sustainability, food quality, soil quality, nature quality, animal welfare, rural development and human wellbeing. Such concepts often have different meanings in different groups, discourses and research disciplines. These conceptual differences influence the kinds of technologies and production systems that are investigated and developed, and how the systemic connections of food systems are handled in research. The exposure of the different meanings of such concepts, and the values and ethics embedded in these different meanings, has already been the subject of some attention.

Values have a more direct role in the choice of problem to investigate. There is always a choice of subject matter or research issue in science, though this choice is not always explicitly discussed. This choice depends on the perspective that is used and on what is taken as problematic from this point of view. The choice determines the potential relevance of the research to different groups or to society in general, and it is connected to underlying goals, interests and values. Moreover, 'technical' choices on research objects (as determined in the setup of experiments and surveys), research methods and model assumptions are not independent of values either. Take the example of setting up of farm systems experiments. When such experiments are established, choices include which systems, the specific structure of them, where to make them either similar or different. In a study of dairy systems, are those systems to be 'organic', 'integrated' or 'conventional' and (since none of these are clear cut) what kind of organic, integrated or conventional? Are the stable systems to be based on solid manure or slurry? Are the breeds to be Jersey, Holstein or something else? Are the bull calves to be sold or fattened, as steers or bullocks? These choices on system structure are in many ways related to the intentions and goals behind the research. Once an experiment has been established, these intentions and goals no longer influence the conduct of the experiment. However, when the results are ready, if an organic system with deep bedding and solid manure is compared with a conventional system with slurry, then the choice of systems structure influences the results (e.g. with regard to welfare, nutrient losses, crop yields) (see Lantinga 2001).

Values are important in agricultural science, be it conventional or organic. From this, it follows that the handling of different perspectives and the values and understandings that they harbour is important in relation to the communication and cooperation between researchers engaged in organic and conventional systems, and in cross-disciplinary communication in general. It also follows that objectivity in the sense of value freedom is not an appropriate criterion of scientific quality. There is a need to revise the ideal of objectivity so that it can span the range of criteria that are developed in individual research disciplines across the sciences, and support cross-disciplinary cooperation and communication. The criterion of reflexive objectivity has, therefore, been suggested as a second general quality criterion of agricultural research that complements the criterion of relevance (Alrøe and Kristensen 2002, Schjønning *et al*. 2004) (Box 15.2).

The criterion of reflexive objectivity suggests that research should investigate and describe its own societal, intentional and observational context and work explicitly with the goals and values involved, to facilitate peer criticism and the use and critique by different users and stakeholders. Reflexive objectivity and relevance seem to be important criteria for all agricultural research but not least in organic agriculture because of the important role of values in this form of agriculture. Making the role of values explicit is a way to avoid the two pitfalls of organic research:

1 it lacks real relevance for organic agriculture; and
2 the organic values directly influence the research results.

If one conceives of agricultural science as systemic, recognises the interaction of agricultural research, agriculture and society, and accepts that agricultural research therefore cannot and should not be value free, then such general changes in the perception of agricultural science cannot be implemented by single researchers or research groups alone. The successful implementation of such changes in perceptions will involve all the different institutional struc-

Box 15.2 Key quality criteria for organic research

Relevance	Reflexive objectivity
Establishing the societal and intentional context of the research by way of: 1 participation 2 value inquiry 3 transparency	Communicating the cognitive context of the research results by way of: 1 clarifying values and revealing funding 2 documenting methods 3 ensuring the falsifiability of theories, models and hypotheses 4 establishing the generalisability of the results 5 showing relevant areas of ignorance and uncertainty.

tures of science (e.g. organisational structuring of research, research policy and funding, scientific journals and other media of publication, educational institutions).

Sound research approaches in organic agriculture

From the early days of organic research, holistic approaches were held up to be more appropriate for organic systems than reductionist ones, embracing the integrative philosophy of organic farming (Howard 1943, Woodward 2002b). This has in part led to the idea that the holistic approach to research is the 'holy grail' of organic research. The extent to which this type of research occurs is, however, questionable. Lockeretz (2000) carried out an analysis of organic and conventional research published over ten years in the *American Journal of Alternative Agriculture* and concluded that there was no systematic distinction in the kinds of questions posed or how they were answered between organic and conventional research. However fitting that may be for the history of organic research publication, the aspirations towards more holistic research methods in organic agriculture are worthy of a more comprehensive analysis. A range of barriers against the realisation of holistic aspirations can be found, and a two-pronged approach, which will look at the soundness of research methodologies in the organic context as well as at methodological and institutional barriers, is outlined.

There has been a long-standing and unfruitful opposition between reductionist and holistic science in connection with agricultural and ecological research (see e.g. Lockeretz and Anderson 1993, Thompson 1995, Rowe 1997), which has hampered cross-disciplinary cooperation. From the holistic view, analytic, reductive methods are necessarily reductionist and are therefore bad science because they do not capture the connectedness of complex reality. Furthermore they are (at least in part) to blame for the present agricultural and environmental problems. From the reductionist view, analytic, reductive methods ensure the objectivity of science, and other methods are, therefore, not scientific.

Two comments are pertinent. First, any scientific method will give a 'reduced' view – the world as we see it is not 'the real world'. Hence the term 'holistic' seems to promise more of science than can be fulfilled. Second, since reduction is a powerful approach in science that can contribute significantly to learning, the term 'reductionist', which often has a negative ring, should be used only where a science is unaware of the consequences of reduction or denies that there are any such consequences.

A more comprehensive systemic or wholeness-orientated approach does not imply a dismissal of traditional disciplinary science. But it does imply that the consequences of reduction must be included in the answers that science provides. As argued above, good science exposes and communicates the societal, intentional, and observational context of research, in order to achieve good and valid communication and critique of the results. This communication is also an important precondition for better cooperation between different kinds of science. In this view, the different kinds of research have the same potential for doing good science, and this view of science can, therefore, serve as a better platform for promoting cross-disciplinary research cooperation.

The efforts toward more holistic approaches to research in organic agriculture can be divided into four groups:

1 holistic methods such as picture creation by way of crystallisation;
2 systems research, including long-term crop rotation trials and farm system experiments;
3 participatory approaches that involve stakeholders in research, including on-farm research and action research; and
4 cross-disciplinary research approaches that include ‘non-agricultural’ disciplines, social sciences and the humanities in a comprehensive systemic research methodology.

Holistic methods

One exception to the rejection of Lockeretz (2000) of there being any difference between organic and conventional research is in the controversial area of food quality from organic production. Debate centres on whether there are qualities of foods, important to health and wellbeing, that are not sufficiently well understood to permit appropriate quantitative measurements to be made (Atkinson *et al*. 2002). Recent discoveries such as the ability of antioxidants to remove or protect against the impact of free radicals (Ramirez-Tortosa *et al*. 2001) suggest that there is still much to learn about the links between food and health. Scientists working on organic production have focused on developing holistic methods that link food quality and production systems, such as crystallisation methods based on the work of Pfeiffer (1975) and others. Such concepts, however, continue to be ridiculed by the conventional science community (e.g. Williams 2002).

These methods are only holistic in a certain, narrow sense that concerns the way food quality is measured in the laboratory. The samples that are measured may come from traditional agricultural trials. Another example of a method that combines rigorous experimental methods with a holistic measure is the experimental study of the influence of organic diets on the health of rats (Lauridsen *et al*. 2005). Many consumers expect organic food to be healthier than conventional, but it is very difficult to test this hypothesis in a scientific way. Other factors also influence human health so that they may hide the effect of organic diets, and it is difficult to generalise from measurements of single components of organic diets to the holistic state of health. However, Lauridsen *et al*. (2005) did show that comprehensive measures of the effects on health can be obtained from a study on rats under standardised experimental conditions, and that in some respects, the rats benefited from eating organically grown food.

Systems research

The sustainability of organic farming in the long term is of major interest to policy makers. Several long-term cropping system trials have been established to investigate this (e.g. Table 15.3, Table 15.4). There is a clear split in research approaches between studies that compare organic and conventional systems (e.g. Mäder *et al*. 2002, and further examples in Table 15.3) and studies that compare different management systems within organic farming, in order to improve the systems (e.g. Olesen *et al*. 1999 and further examples in Table 15.4).

Considerable research effort and funding has been spent comparing and contrasting organic and other types of farming systems. The trials listed in Table 15.3 mostly address rotations for horticulture or agriculture. Few studies compare systems of perennial cropping, one exception is the Washington State apple production systems trial (Reganold *et al.* 2001). Within Table 15.3, treatments have been classified into organic, biodynamic, low input or integrated and conventional on the basis of the author's descriptions. One difficulty in interpreting these experiments, and indeed making comparisons between them, is the lack of definition of the terms of low input and integrated farming. Furthermore, there is huge variation in farming systems across relatively small geographical regions (Trewavas 2004). There is also a lack of information available in the public domain on actual practices on organic farms, although this information may be available within certification organisations. Such comparisons can provide useful information when the purpose of the study is clearly defined (Spedding 1975) and the basis of the comparison is fair. Defining starting points, boundaries and time scale are important in this respect. Lampkin (1994) points out that the fundamental issue is the comparison of systems rather than modification to individual management practices. This perhaps means it is more difficult to make valid and useful comparisons of biophysical properties than economic ones. It is important to separate out those aspects of the system that need to be assessed at the whole systems level (i.e. those which are dominated by interactions or large-scale ecological processes, and those which can be compared at the small plot scale) (Watson and Atkinson 2000).

In the trials listed in Table 15.3 and Table 15.4 the study areas vary from relatively small plots, such as the DOK (bioDynamic–Organic–Konventional) trial (Mäder *et al.* 2002), to several hectares (e.g. Leake 1996). One complicating factor in interpreting results of these trials is whether they truly compare farming systems or simply rotations. Factorial crop rotation experiments (e.g. Mäder *et al.* 2002, Watson *et al.* 1999) and field-scale testing of crop rotations (e.g. Cormack 1999) that allow factorial experiments within them, contribute to different aspects of the understanding of how crop rotations function. As soon as the crops or even varieties within a rotation are changed the effect of that rotation both in terms of yield and productivity as well as soil structure and environmental impact will change, regardless of the production system. However, under given soil and climatic constraints the most productive choice of crops and varieties in a rotation will differ depending on whether the system is managed conventionally or organically. Thus, are any differences between the biophysical aspects of the rotation due to the system or the rotation? The DOK trial in Switzerland has compared the same crop rotation under different systems of manuring and pest management since 1978 (Mäder *et al.* 2002). Although this trial has provided a wealth of interesting information on soil properties and crop protection and production but the question remains as to how applicable this information is in the context of practical farming. Despite the reliance on forage legumes for fertility building in many organic systems, surprisingly few trials include grazing livestock. Many trials utilise livestock manure to mimic whole systems, but these can never truly represent realistic grazing situations where there is constant interaction between soils and plant and animal production.

Lack of replication is a drawback of many of the trials in Table 15.3 and Table 15.4 (e.g. two replicates in the SAC crop rotations trials) (Watson *et al.* 1999). Lack of replication and the non-use of livestock perhaps both reflect the costs and funding commitment needed to run trials of this type. Some of the difficulties of running rotation trials are discussed in Taylor *et al.* (2002). Olesen (1999) recommends the involvement of experts from outside individual research groups in the design of long-term experiments. This would increase the rigour of the experimental design by drawing on wide experience from past experimentation. It can also help to add value to experiments by ensuring that design factors such as plot size are appropriate for all the parameters likely to be studied in the experiment.

Where studies are carried out within organic systems (e.g. Table 15.4), it is particularly important that background information on aspects like time since conversion and the particular

Table 15.3 Examples of long-term experiments that compare organic cropping systems with conventional and other systems

Name	Site	Start date	Systems compared (O, B, L, C[A])	Rotation	Reference
K-Trial	Järna, Sweden	1958–1990	B, C	Ley/arable + manure	Granstedt and Kjellenberg (1997)
DOK trial	Frick, Switzerland	1978	O, B, C	Ley/arable + manure	Mäder *et al.* (2002)
Long-term fertilisation trial	Darmstadt, Germany	1980	O, B, C	Arable + manure	Raupp (2001)
Farming Systems Trial	Pennsylvania, USA	1981	O, C	Arable + manure	Drinkwater *et al.* (1998)
Cropping systems trial	Foulum, Denmark	1987	O, L, C	Ley/arable + manure/ grazing	Mikkelsen and Rasmussen (1994)
Focus on Farming Practice	Leicester, UK	1989	O, L, C	Ley/arable and stockless	Leake (1996)
Apelsvoll cropping systems experiment	Norway	1990	O, L, C	Ley/arable and stockless	Eltun (1994)
Glenlea Study	Manitoba, Canada	1992	O,L,C	Stockless arable	Gleanlea Study (2005)
Long-Term Research on Agricultural Systems	California, USA	1993	O, L, C	Stockless arable/ horticulture	Denison *et al.* (2004)
Apple production systems	Washington, USA	1994	O, L, C	Apple orchard	Reganold *et al.* 2001
Farming Systems Project	Maryland, USA	1996	O, C	Stockless arable	USDA 2006
Mediterranean Arable Systems Comparison Trial	Pisa, Italy	2001	O, C	Stockless arable	CIRAA 2006

[A] O, Organic; B, biodynamic; L, low input or integrated; C, conventional.

Table 15.4 Examples of long-term experiments that compare different organic cropping systems

Name	Site	Start date	No. of organic systems compared	Rotation	Reference
Stockless Trial, Elm Farm Research Station	Berkshire, UK	1987	4	Stockless arable	Philipps *et al.* (1999)
Rotations Trial, Scottish Agricultural College	Aberdeen, UK	1991	2	Ley/arable, grazed by sheep	Watson *et al.* (1999)
Ty Gwyn	Aberystwyth, UK	1992	2	Dairy	IGER (1996)
DARCOF Rotations Trial (EXUNIT)	4 sites, Denmark	1997	4	Arable + manure	Olesen *et al.* (1999)

standards applied are included (Lund and Algers 2003). The location of the experiment in terms of soil and climate is also an important context for the results. The Danish crop rotation experiments are carried out at four different locations in Denmark (Olesen *et al*. 1999), and even within this fairly small geographical area the results so far show clear differences between the different locations (Askegaard *et al*. 2004). The differences are not only in yields, but also in the interactions between location (soil, climate) and rotations. A further issue is that the organic standards have changed over time (Woodward and Vogtmann 2004), meaning that past research carried out within organic systems may not be applicable today. One example of this is Watson *et al*. (1993) who describe a farm that imports large quantities of conventional poultry manure. Trewavas (2001) quotes this work to show that organic farming is unsustainable although the system in question would now not be certifiable. Regional differences in standards also need to be accounted for in comparing published literature. Lund and Algers (2003) give examples of how the organic animal husbandry standards differ between three neighbouring European countries.

There are also many organic experimental farms used in organic research, but these farms are less well documented in the literature than the long-term experiments. In Zanoli and Krell (1999) a preliminary overview is given of some of these farms. Case studies (e.g. Cobb *et al*. 1999) are a good example of how the socioeconomic and biophysical aspects of organic farming can be brought together.

Participatory research

Participatory research methods, which have been commonly used in developing countries (e. g. Bellon 2001), are now being widely accepted in industrialised countries in both conventional (e.g. Cerf *et al* 2000) and organic farming (e.g. Krell and Zanoli 2000, Andrews *et al*. 2002). A range of participatory research methods are used from action research to on-farm research. In action research, the research goals are determined by the participants in the system in question. On-farm research, however, may be more or less ‘participatory’ depending on how much the farmer, farm workers, advisers and others are involved in the research. There is, thus, no sharp dividing line between on-farm research and the experimental research farms mentioned above.

Cross-disciplinary research

The desire to make research in organic agriculture more holistic or systemic is based on ideas and aims within the organic movement: a holistic perception of health, aspirations towards more fair food systems, and aims to farm in systems that are more self-sufficient, based on natural structures and processes within the system, and with limited options for utilising outside inputs as a means to improve growth and protect against pests and diseases. The same desire can also be found partly within research in conventional agriculture based primarily on the recognition of farms as systems in their own right. But due to the comprehensive ideas and aims of organic agriculture, there is a particular emphasis on the problems related to science being fragmented by disciplinary specialisation. Some in the science community have traditionally undervalued the need for interdisciplinary and transdisciplinary work and for methodological and organisational structures that can facilitate such work (Dalgaard *et al*. 2003) although recent advances in whole-farm research methods are creating the methods and structures needed to carry out robust holistic research (e.g. Firbank *et al*. 2003, Perry *et al*. 2003).

The notions of systemic science and wholeness-oriented research seem to capture essential features of an important shift in the conception of what science is as well as in the general methodology and structure of science. The shift is related to the involvement of science in new complex areas, such as the socioecological problems of society and environment. Here, different disciplines such as ethics, sociology, ecology and chemistry ought to be in close cooperation. This is not often the case and there is thus a need for systemic research methodologies that enable transdisciplinary research efforts (Alrøe and Kristensen 2002).

Cross-disciplinary research approaches need to build on an understanding of how different methods relate to their 'research world', and what this means. For example, if laboratory research, field trials, crop rotation experiments and on-farm research are compared, they differ in complexity, and subsequently in the conditions for experimentation and control, and thereby for replications or reproductions of phenomena. They also differ with respect to the need for ethical considerations. Furthermore, systemic approaches that include, for example, the human and social parts of the agricultural systems into their research world are often perceived as less scientific than conventional, analytical approaches, which have delimited their research worlds to exclude those aspects of reality. However, these obviously different approaches are not different in their potential for doing good science. This recognition can serve as a basis for a reflexive discussion of the focus and meaning conveyed by different research perspectives and the strengths and weaknesses of different research methods in cross-disciplinary research approaches.

In Figure 15.1, some examples of different disciplines and methods relevant to organic research are placed in relation to two methodological dimensions. One is the complexity of the research world described above. The other is the degree of involvement of the researcher or the 'research unit' in its research world. The triangular form illustrates that in simple and well-controlled research worlds, the detached and involved phases of research can be employed in close cooperation, whereas detached, descriptive, historical methods are widely different from involved, interactive, developmental action research methods though they both work with complex research worlds.

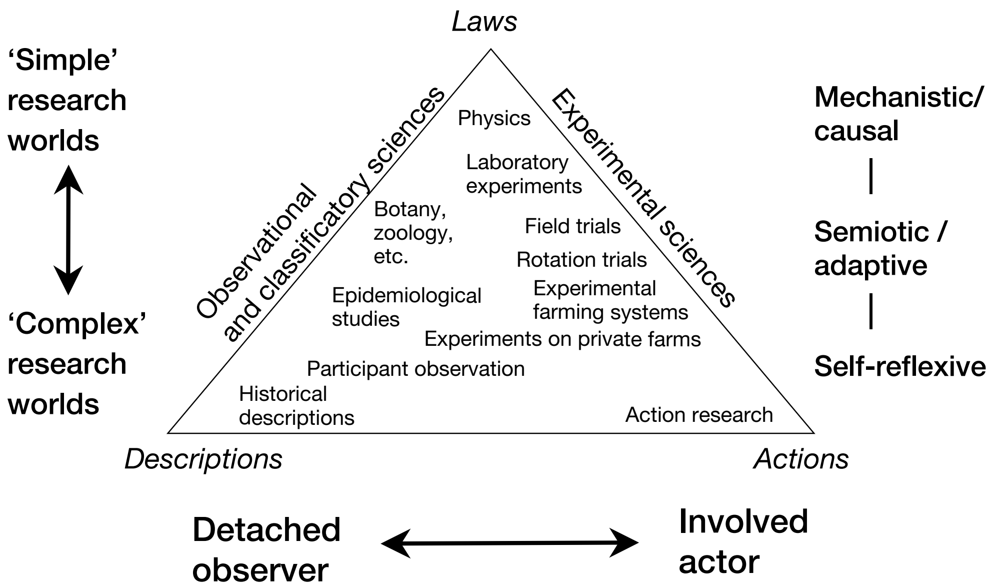

Figure 15.1 Some research disciplines and methods of relevance for organic research ordered according to two methodological dimensions: the complexity of the research world (spanning from causal over adaptive to self-reflexive entities) and the degree of involvement of the researcher (adapted from Alrøe and Kristensen 2002). The triangular form shows that simple research worlds allow the researcher to intervene and withdraw from the research world in closely connected processes, whereas the involved and detached stances are widely different in relation to complex research worlds.

The epistemological limitation with regard to using causal knowledge from simple research worlds is that some aspects are neglected because of the reduction. Some examples of neglected aspects are crop rotation effects when doing research on single fields, the effects on farm economics when doing research on cropping systems, the role of motivation (intention) in behavioural studies, and the management factor when studying farm dynamics in experimental farming systems or in the assessment of animal welfare.

Agriculture is, by definition, about management. Lockeretz (2000) describes organic farming as interfering with nature just enough to get the job done, in comparison to conventional agriculture which at times creates completely artificial environments. Regardless of the system, the role of the human being is central to the success of that system. The human role is most often highlighted in relation to animal health and welfare but is just as likely to apply to crop and soil husbandry. Martini *et al.* (2004) question the assertion that yield improvements following conversion to organic production are related to improvements in soil quality and suggest that they may relate to improved management skills and experience. Accounting for the role of the manager thus becomes critical in comparative studies of systems. Trewavas (2004) asserts that the only way to make a fair comparison between organic and conventional farming is to use matched fields, on the same farm, managed by the same person. Although this may overcome some of the difficulties in edaphic and climatic factors, it may negate the comparison because it has been shown many times that organic and conventional farmers have different attitudes to crop and animal husbandry (e.g. Lund and Algers 2002). There is also evidence that as the organic farming sector grows in size, there are accompanying changes in the type, and philosophy, of farmers going organic (Lund *et al.* 2002).

In general, there are methodological and technical limits to doing more holistic research because of the complexity and diversity of the research worlds. For example, it is difficult to make a general predictive model of a complex research world. This is particularly true if this world involves people, companies and organisations, which are self-reflexive and therefore adapt and change their perceptions of themselves in accordance with the knowledge they gain from the model presented by the researchers. There are also ethical limits to research in complex worlds, connected to the presence of humans, animals and ecosystems, which the researchers have a moral responsibility to take into consideration and, in the case of people, to involve them in these ethical considerations (see also Latour and Woolgar 1979). In this perspective, reduction entails (apart from methodological benefits) that the ethical questions are externalised – they become part of the external communications of science and the actual research can be done without ethical considerations. In a wider systemic perspective, however, where science is seen as a part of society and nature, and with reference to the criterion of relevance or (more generally) given the idea that science is morally responsible for its actions (Jonas 1984, Alrøe and Kristensen 2003), there can be decisive ethical concerns connected with the potential consequences of reductive research methods. The development and implementation of a comprehensive systemic research methodology that enables transdisciplinary research must, therefore, also involve normative sciences that are concerned with ethics and how to do good science.

Future perspectives on research approaches

The role of institutions and individuals in organic research

Across the world research on organic farming is carried out within a range of universities, colleges, research institutes and private consultancies as well as by dedicated organic organisations. The nature of 'conventional' or 'mainstream' organisations versus dedicated organic organisations brings with it different approaches to research and to the promulgation of research results. The attitudes and cultures of both individual researchers and organisations are important in determining research approaches, interpretation of research findings and efficiency of transfer of research results to the end-user community. Linkages between non-governmental and governmental organisations have been particularly recognised as valuable within the organic farming sector in developing countries (Shrum 2000). As with all agricultural research, the nature and direction of research is perhaps most strongly influenced by the source of funding.

Scientists working within state-funded organisations, where research is carried out on several types of farming systems, may find themselves faced with different challenges to those working in 'organic-only' institutes (Watson and Atkinson 2002). Wynen (1997) notes that few 'career scientists' have chosen to get involved in organic farming as there is a lack of recognition of the validity of the subject among the conventional science community. The existence of organisations like the Danish Research Centre for Organic Farming (DARCOF), and the growing involvement of universities and conventional institutes in organic research, is changing this attitude slowly. For organisations with multiple interests there are physical and human resource implications to organic farming research. Alongside the investment in research facilities for systems research and long-term experiments, there is likely to be a need to duplicate equipment and personnel where systems are fundamentally incompatible. For example, where the same organisation is researching both genetically modified organisms and organic farming, there are both ethical and practical reasons for running two entirely separate research teams.

Multifunctional organisations that traditionally have had a responsibility for technology transfer in addition to research may have taken a different approach to organisations with a sole focus on research. For example, for those working directly with farmers, research aimed at understanding and improving organic farming is likely to be more important than comparisons between different systems. However, the paradigm shift towards end-user relevance and stakeholder involvement in research is resulting in changes in approach among the more traditional research organisations.

Research training and education

Despite the rigours of scientific training, the culture of the organisation and the nature of the individual scientists involved will influence both research design and data interpretation. In aiming to understand something as complex as the functioning of systems, the scope for different interpretations of experimental data is likely to be greater than in reductionist experimentation. Scientific training at tertiary level tends to include a high degree of specialisation and encourages monodisciplinary rather than interdisciplinary thinking. Scientists need to be able to contribute not only from their own disciplines but also to recognise the disciplinary part of the bigger jigsaw, as well as being able to 'step outside their own discipline when it becomes a hindrance rather than a help' (Lockeretz 2000). There is a need to address training needs of researchers involved in organic farming to ensure that they do understand the systems within which they are working. Teams where systems thinkers and disciplinary thinkers can work effectively as one are needed.

On the use of conventional research in an organic context

Research on organic farming is often, correctly, focused on the development of systems that prevent problems such as pests, diseases or nutrient shortages. Contrastingly much conventional research has focused on finding short-term interventionist solutions to such problems. The commodity based thinking prevalent in agriculture has also contributed to this paradigm.

Ongoing changes in mainstream agriculture, particularly those driven by the environmental and human health agendas of reducing pesticide use and environmental contamination are likely to narrow the gap between organic and conventional research needs. The focus of much conventional research on finding new, acceptable input products to solve technical problems will have to be replaced by research of the ecological and social aspects that will allow inputs to be reduced. This change should allow wider application of research on organic farming to conventional systems and *vice versa*. In the past, the conventional sector has sometimes claimed that zero N or zero agrochemical treatments in variety trials are relevant information for organic agriculture. This shows a misunderstanding of the systems concept of organic farming which means that crop production in organic systems is more a function of past cropping and environment than of current management, a concept described by Olesen (1999) as the 'memory' of the system.

Research in organic farming – peer reviews and publication

It is relatively easy to quantify research effort in terms of amounts of government money spent on organic farming. It is harder to quantify the outcomes of this research and more difficult still to estimate its value to the industry. Conventionally, research output in UK universities and research institutions is on the basis of refereed publication output. The number of refereed journal articles produced annually with the words organic, biological, ecological or biodynamic farm, farms, agriculture or farming in the title, keywords or abstract has increased dramatically since 1980. The number of refereed publications cited in the Science Citation Index on organic farming increased from 21 in 1981–1985 to 286 between 1996 and 2000 (Watson and Atkinson 2002). This clearly reflects an increase in research funding but may also reflect a greater acceptance of the importance of understanding the underlying biology and socioeconomics of organic systems. Although publication in high impact factor refereed publications may be a suitable indicator of scientific quality in fundamental science, it is less useful in applied science (as defined by OECD 2003). Several researchers have highlighted difficulties in publishing work on organic farming systems in refereed journals (e.g. MacRae *et al*. 1989). Two journals were started explicitly to allow publication of such work: the *American Journal of Alternative Agriculture* (1986) (now titled *Renewable Agriculture and Food Systems*) and *Biological Agriculture and Horticulture* (1982). Neither of these journals is highly rated through the conventionally used impact factor system that depends on citations in other refereed journals. Publication of studies of organic farming has become much more common in mainstream agricultural systems journals, although there is still concern among scientists over publication of truly interdisciplinary work, especially research that aims to integrate the social and natural sciences.

To this end, the *International Journal of Agricultural Sustainability* was started in 2003.

A 'fit for purpose' criterion may be much more useful in trying to assess the value of applied organic farming research to end-users. With respect to organic farming, much of the research has been reported in conference proceedings and other forms of grey literature as illustrated by the inclusion of over 100,000 abstracts on organic research on the CABI publishing website (CABI 2006). Grey literature has been one of the most prevalent routes of knowledge transfer in organic farming (Woodward 2002a). There are often long lags between expenditure and final output from research, estimated by Barnes (1999) of 16 years and upwards. Participative approaches to research may cut this time lag significantly with regard to stakeholders. Preprint archives with full-text papers can speed up the communication to other researchers considerably (e.g. Taubes 1996). The recently established web-based archive Organic Eprints (Organic Eprints 2006) is an open, international archive for research in organic agriculture that accepts, for example, preprints, published papers, reports, project descriptions and popular articles. The main objectives of the archive are to facilitate the communication of research papers and proposals, to improve the dissemination and impact of research findings, and to document the research effort. In 2005 it included 2700 papers and received more than 50,000 visits per month. Nevertheless refereed journal output will probably continue for some while to be a dominant marker in agricultural science to gain both respect and reward for individuals and organisations.

Coordination of organic research

Many countries have either a formal or informal network of organic researchers. The following are examples of how these networks operate in different countries. Scientific Congress on Organic Agriculture Research (SCOAR) launched by the Organic Farming Research Foundation in the USA brings together producers and scientists to build a long-term organic research agenda (Sooby 2001). The Organic Agriculture Centre for Canada (OACC 2005) founded in 2001, and funded through Agriculture and Agri-Food Canada and the Natural Sciences and Engineering Research Council with additional funding from seven provinces, coordinates and collaboratively develops research with agricultural schools in several Canadian universities. In the UK, the Colloquium of Organic Researchers was formed in 2000 to provide a discussion forum for issues unique to organic research. In the Netherlands researchers from the private Louis Bolk Institute are involved as external experts in projects on organic farming carried out in conventional organisations, to ensure their appropriateness and relevance to organic agriculture (Niggli 2002). In Denmark, the Danish Research Centre for Organic Farming, described as a research institute 'without walls' coordinates state funded projects on organic farming carried out at a range of institutions. There are other initiatives such as conferences and workshops for organic farming research in the Nordic countries and in the German-speaking countries.

In June 2003, the International Society of Organic Agriculture Research (ISOFAR) was launched in Germany. ISOFAR has 12 sections, mainly based on disciplines, and five cross-disciplinary working groups. The latter address issues such as the relationship between organic agriculture and biotechnology, methodological approaches to organic research and coordination of long-term experiments (ISOFAR 2006).

Across Europe there are many different institutes and traditions for organic farming research that until now have not been coordinated. Many of the research groups involved are geographically isolated and lack 'critical mass'.

As part of the EU ERANET scheme, the EU hopes to exploit the potential for improved research quality and value-for-money through transnational cooperation. The overall objective of CORE Organic (Coordination of European Transnational Research in Organic Food and Farming) is to enhance quality, relevance and utilisation of resources in research in organic food and farming in the EU. This will be achieved by research cooperation and coordination of research facilities, and to establish a joint pool of at least three million Euro per year for transnational research in organic food and farming by the end of the project in 2007 (CORE 2006). The aims are set out in Box 15.3.

Box 15.3 Aims of CORE Organic

1. Increase exchange of information and establishment of a common open web based archive.
2. Coordination of existing research and integration of knowledge.
3. Sharing and developing best practice for evaluating organic research.
4. Identification and coordination of future research.

One of the activities that will be carried out in CORE Organic is a research priorities exercise aimed at involving a wide variety of stakeholders in the organic sector, from producers to consumers. A UK exercise is being carried out as a pilot for this wider study during 2005. Previous exercises in establishing organic research priorities in the UK have tended to consult a fairly narrow range of stakeholders and have focused on technical rather than social issues. Reed (2004) argues strongly for social science to move up on the organic research agenda. At least in European terms, the basis for this is that following the reform of the Common Agricultural Policy, organic farming may be more important as a means of bringing a diverse range of added benefits to rural communities than as a system of food production.

Conclusions

Research is important in the development of organic food and farming. To fulfil this role a broad range of methods and approaches is needed. There is no single kind of scientific method that is adequate and there is also a need to develop new methods and approaches. It is a great challenge to include very different methods, applied within a wide range of perspectives, in an interdisciplinary or transdisciplinary research effort. There are no essential barriers to establishing such cross-disciplinary research collaborations but there are many practical and structural barriers. The recent initiatives on increased international research cooperation within organic research will, however, help to realise more comprehensive research efforts by forming organic research communities that, for example, share experiences, provide for expensive facilities for large-scale and long-term systems research and coordinate research initiatives. There are also many ways in which research in organic agriculture can benefit from cooperation with mainstream agricultural research. These options increase in step with the establishment of ways of organising organic research that promote such interaction and with the changing research agendas for conventional research. Despite these benefits, and because of the positive integration of organic research into mainstream institutes, there is still a clear need to sustain dedicated organic research institutes and to foster new international research networks and organisations that focus entirely on organic research.

References

Alrøe, H.F. and Kristensen, E.S. 2002. Towards a systemic research methodology in agriculture: Rethinking the role of values in science. *Agriculture and Human Values* 19: 3–23.

Alrøe H.F. and Kristensen, E.S. 2003. Toward a systemic ethic: in search of an ethical basis for sustainability and precaution. *Environmental Ethics* 25: 59–78.

Alrøe, H.F. and Kristensen, E.S. 2004. Why have basic principles for organic agriculture? And what kind of principles should they be? *Ecology and Farming* 36: 27–30.

Andrews, S.S., Mitchell, J.P., Mancinelli, R., Karlen, D.L., Hartz, T.K., Horwath, W.R., Pettygrove, G.S., Scow, K.M. and Munk, D.S. 2002. On-farm assessment of soil quality in California's Central Valley. *Agronomy Journal* 94: 12–23.

Askegaard, M., Olesen, J.E., Rasmussen, I.A., Driessen, E., Nielsen, E., Thomsen, H.C., Bak, H. and Lindberg, J.F. 2004. Økologiske sædskifter til produktion af korn. *Grøn Viden*, Markbrug nr. 298.

Atkinson, D., Watson, C.A., Pearce, B., Woodward, L., Wolfe, M., Welsh, J. and Nowack, K. 2002. Organic agriculture and GM crops. In: *BCPC Conference, 2002 – Pests and Diseases*. British Crop Protection Council, Surrey. pp. 523–530.

Balfour, E.B. 1943. *The Living Soil*. Faber and Faber, London.

Barnes, A.P. 2002. Publicly-funded UK agricultural R&D and 'social' total factor productivity. *Agricultural Economics* 27: 65–74.

Bellon, M.R. 2001. *Participatory, Research Methods for Technology Evaluation: A Manual for Scientists Working with Farmers*. CIMMYT, Mexico, DF.

Blakemore, R.J. 2000. Ecology of earthworms under the 'Haughley Experiment' of organic and conventional management regimes. *Biological Agriculture and Horticulture* 18: 141–159.

CABI 2006. *Organic Research Database*. CAB International, Wallingford. <http://www.organic-research.com>. Accessed 17/1/06.

Carpenter-Boggs L, Kennedy, A.C. and Reganold, J.P. (2000) Organic and biodynamic management: effects on soil biology *Soil Science Society of America Journal* 64: 1651–1659.

Cerf, M., Gibbon, D., Hubert, B., Ison, R., Jiggins, J., Paine, M., Proost, J. and Röling, N. (2000) (Eds) *Cow Up a Tree. Knowing and Learning for Change in Agriculture and Rural Development. Case Studies from Industrialised Countries*. INRA Éditions, Paris.

CIRAA 2006. *Organic Farming – Long-term Systems Comparison Experiment (MASCOT)*. Centro Interdipartimentale di Ricerche Agro-Ambientali 'Enrico Avanzi', University of Pisa, Pisa. <http://www.avanzi.unipi.it/researchactiviti_file/Organic_farming_ENG.htm>. Accessed 17/1/06.

Cobb, D., Feber, R., Hopkins, A., Stockdale, L., O'Riordan, T., Clements, B., Firbank, L., Goulding, K., Jarvis, S. and Macdonald, D. 1999. Integrating the environmental and economic consequences of converting to organic agriculture: evidence from a case study. *Land Use Policy* 16: 207–221.

Commission of the European Communities 2004. *European Action Plan on Organic Farming. Commission Working Document. SEC (2004) 739*. European Commission, Brussels.

CORE Organic 2006. *CORE Organic - Joining Resources to Improve Research in Organic Food and Farming*. Coordination of European Transnational Research in Organic Food and Farming, Tjele. <http://www.core-organic.org>. Accessed 17/1/06.

Cormack, W.F. 1999. Testing a stockless arable organic rotation on a fertile soil. In: Olesen, J. E., Eltun, R., Gooding, M.J., Jensen, E.S. and Köpke, U. (eds) *Designing and Testing Crop Rotations for Organic Farming*. DARCOF, Tjele. pp. 115–124.

Dalgaard, T., Hutchings, N.J. and Porter, J.R. 2003. Agroecology, scaling and interdisciplinarity. *Agriculture, Ecosystems and Environment* 100: 39–51.

Defra 2002. *Action Plan to Develop Organic Food and Farming in England*. Defra, London.

Delate, K. and DeWitt, J. 2004. Building a farmer-centred land grant university organic agriculture program: a Midwestern partnership. *Renewable Agriculture and Food Systems* 19: 80–91.

Denison, R.F., Bryant, D.C. and Kearney, T.E. 2004. Crop yields over the first nine years of LTRAS, a long-term comparison of field crop systems in a Mediterranean climate. *Field Crops Research* 86: 267–277.

Drinkwater, L.E., Wagoner, P. and Sarrantonio, M. 1998. Legume-based cropping systems have reduced carbon and nitrogen losses. *Nature* 396: 262–265.

Duthie, G.C. 2001. Anthocyanin-rich extract decreases indices of lipid peroxidation and DNA damage in Vitamin E depleted rats. *Free Radical Biology and Medicine* 31: 1033–1037.

Elm Farm Research Centre 2003. *A Review of UK Research and Development for Organic Food and Farming*. Report OF0338 for Department of Environment, Food and Rural Affairs, London. Elm Farm Research Centre, Newbury.

Eltun, R. 1994. The Apelsvoll cropping system experiment. I. Background, objectives and methods. *Norwegian Journal of Agricultural Sciences* 8: 301–315.

Firbank, L.G., Heard, M.S., Woiwod, I.P., Hawes, C., Haughton, A.J., Champion, G.T., Scott, R.J., Hill, M.O., Dewar, A.M., Squire, G.R., May, M.J., Brooks, D.R., Bohan, D.A., Daniels, R.E., Osborne, J.L., Roy, D.B., Black, H.I.J., Rothery, P. and Perry, J.N. 2003. An introduction to the farm-scale evaluations of genetically modified herbicide-tolerant crops. *Journal of Applied Ecology* 40: 2–16.

Glenlea Study 2005. *Welcome to the Glenlea Study – Canada's Oldest Organic-Conventional Cropping Comparison Study. History of the Glenlea Study*. Department of Plant Science, University of Manitoba, Winnipeg. <http://www.umanitoba.ca/faculties/afs/plant_science/glenlea/glenleahistory.html >. Accessed 17/1/06.

Granstedt, A. and Kjellenberg, L. 1997. Long-term field experiment in Sweden: effects of organic and inorganic fertilizers on soil fertility and crop quality. In: Lockeretz, W. (ed.) *Agricultural Production and Nutrition*. Tufts University, Boston. pp. 79–90.

Howard, A. 1943. *An Agricultural Testament*. Oxford University Press, Oxford.

IFOAM 2002. *IFOAM Basic Standards for Organic Production and Processing*. IFOAM, Tholey-Theley, Germany.

IGER 1996. Conversion to organic milk production. In: Hagger, R. and Padel, S. (eds) *IGER Technical Review Number 4*. Institute of Grassland and Environmental Research, Aberystwyth.

ISOFAR 2006. *International Society of Organic Agriculture Research*. ISOFAR, Bonn. <http://www.isofar.org>. Accessed 17/1/06.

Jawson, M.D. and Bull, C.T. 2002. USDA research into organic farming. *American Journal of Alternative Agriculture* 17: 201–202.

Jonas, H. 1984. *The Imperative of Responsibility. In Search of an Ethics for the Technological Age*. University of Chicago Press: Chicago.

Koepf, H.H. 1993. *Research in Biodynamic Agriculture: Methods and Results*. Bio-Dynamic Farming and Gardening Association, Kimberton.

Krell, R. and Zanoli, R. 2000. (eds) *Research Methodologies in Organic farming: On-Farm Participatory Research*. *REU Technical Series 63*. FAO, Rome.

Kristensen, E.S. and Halberg, N. 1997. A systems approach for assessing sustainability in livestock farms. In: Sørensen, J.T. (ed.) *Livestock Farming Systems. More Than Food Production. Proceedings of the 4th International Symposium on Livestock Farming Systems*. European Association for Animal Production, Wageningen. pp. 16–30.

Lampkin, N.H. 1994. Researching organic farming systems. In: Lampkin, N.H. and Padel, S. (eds) *The Economics of Organic Farming: An International Perspective*. CAB International, Wallingford. pp. 27–44.

Lantinga, E. 2001. Presentation on nutrient balances. In: *Workshop on Organic farming, System Thinking and the Future*. 21–23 February 2001. International Agricultural Centre, Wageningen, the Netherlands.

Latour, B. and Woolgar, S. 1979. *Laboratory Life: The Social Construction of Scientific Facts*. Sage, Beverly Hills.

Lauridsen, C., Jørgensen, H., Halekoh, U., Christensen, L.P. and Brandt, K. 2005. Organic diet enhanced the health of rats. *DARCOFenews*. March.

Leake, A.R. 1996. The effect of cropping sequences and rotational management: an economic comparison of conventional, integrated and organic systems. *Aspects of Applied Biology* 47: 185–195.

Lockeretz, W. 2000. Organic farming research today and tomorrow. In: Alföldi, T., Lockeretz, W. and Niggli, U. (eds) *IFOAM 2000 – The World Grows Organic. Proceedings of the 13th IFOAM Conference*. vdf Hochschulverlag AG an der ETH Zurich, Basel. pp. 718–720.

Lockeretz, W. and Anderson, M.D. 1993. *Agricultural Research Alternatives*. University of Nebraska Press: Lincoln.

Lockeretz, W. and Boehncke, E. 2000. Agricultural systems research. In: Hovi, M. and Garcia Trujillo, R. (eds) *Diversity of Livestock Systems and Definition of Animal Welfare. Proceedings of the 2nd NAHWOA Workshop*. Veterinary Epidemiology and Economics Research Unit, Reading, pp. 5–12.

Lund, V. and Algers, B. 2003. Research on animal health and welfare in organic farming – A literature review. *Livestock Production Science* 80: 55–68.

Lund, V., Hemlin, S. and Lockeretz, W. 2002. Organic livestock production as viewed by Swedish farmers and organic initiators. *Agriculture and Human Values* 19: 255–268.

MacRae, R.J., Hill, S.B., Henning J, Mehuys, G.R. (1989) Agricultural science and sustainable agriculture: a review of the existing scientific barriers to sustainable food production and potential solutions. *Biological Agriculture and Horticulture* 6, 173–219.

Mäder, P., Fliessbach, A., Dubois, D., Gunst, L., Fried, P., Niggli, U. 2002. Soil fertility and biodiversity in organic farming. *Science* 296: 1694–1697.

Martini, E.A., Buyer, J.S., Bryant, D.C., Hartz, T.K. and Denison, R.F. 2004. Yield increases during the organic transition: improving soil quality or increasing experience? *Field Crops Research* 86: 255–266.

Mikkelsen, G. and Rasmussen, K.J. 1994. Research in cropping systems in Denmark. The design and evolution of the integrated strategy for cropping systems with special attention on soil tillage and utilization of organic matter. In: *Proceedings of the 13th International Conference of the Soil Tillage Research Organization*. International Soil Tillage Research Organization, Aalborg. pp. 729–736.

Niggli, U. 2002. The contribution of research to the development of organic farming in Europe. In: Powell, J. (ed.) *Proceedings of the UK Organic Research 2002 Conference: Research in Context*. 26–28 March 2002, Aberystwyth. Organic Centre Wales, Institute of Rural Studies, University of Wales Aberystwyth, Aberystwyth. pp. 19–24.

Niggli, U. and Willer, H. 2001. Stimulating the potential for innovation in organic farming by research. In: Danish Ministry of Agriculture and Fisheries (ed.) *Proceedings – Organic Food and Farming – Towards Partnership and Action in Europe*. Copenhagen, Denmark, 10–11 May 2001. Danish Ministry of Agriculture and Fisheries, Copenhagen. pp. 194–203.

OACC 2005. *Information about OACC Partnerships*. Organic Agriculture Centre of Canada, Truro. <http://www.organicagcentre.ca/FriendsAndPartners/oacc_partners_info.html>. Accessed 17/1/06.

OECD 2003. *Frascati Manual 2002 Proposed Standard Practice for Surveys on Research and Experimental Development*. Organisation of Economic Cooperation and Development, Paris.

Olesen, J.E. 1999. Perspectives for research on cropping systems In: Olesen, J.E., Eltun, R., Gooding, M.J., Jensen, E.S. and Köpke, U. (eds) *Designing and Testing Crop Rotations for Organic Farming*. DARCOF, Tjele. pp. 11–20.

Olesen, J.E., Rasmussen, I.A., Askegaard, M. and Kristensen, K. 1999. Design of the Danish crop rotation experiment. In: Olesen, J.E., Eltun, R., Gooding, M.J., Jensen, E.S. and Köpke, U. (eds) *Designing and Testing Crop Rotations for Organic Farming*. DARCOF, Tjele. pp. 49–62.

Organic Eprints 2006. *Organic Eprints*. Danish Research Centre for Organic Farming, Forschungsinstitut für biologischen Landbau and Bundesprogramm Ökologischer Landbau, Tjele, Frick and Bonn. <http://orgprints.org>. Accessed 17/1/06.

Parr, J.F. 2003. USDA research on organic farming. *American Journal of Alternative Agriculture* 18: 171–172.

Perry, J.N., Rothery, P., Clark, S.J., Heard, M.S. and Hawes, C. 2003. Design, analysis and statistical power of the Farm-Scale Evaluations of genetically modified herbicide-tolerant crops. *Journal of Applied Ecology* 40: 17–31.

Pfeiffer, E. 1975. *Sensitive Crystallisation Processes: A Demonstration of Formative Forces in the Blood*. Anthroposophic Press, New York.

Philipps, L., Welsh, J.P. and Wolfe, M.S. 1999. Ten years experience of all-arable rotations. In: Olesen, J.E., Eltun, R., Gooding, M.J., Jensen, E.S. and Köpke, U. (eds) *Designing and Testing Crop Rotations for Organic Farming*. DARCOF, Tjele. pp. 71–78.

POA Task Force. 2005. *Elaborated Draft of Principles of Organic Agriculture, January 17th 2005*. <http://ecowiki.org/IfoamPrinciples/WorkPlan>. Accessed 31/8/05.

Ramirez-Tortosa, C., Anderson, Ø., Gardner, P.T., Wood, S.G. Morrice, P.C., Duthie, S.J., Collins, A.R. and Duthie, G.C. 2001. Anthocyanin-rich extract decreases indices of lipid peroxidation and DNA damage in Vitamin E depleted rats. *Free Radical Biology and Medicine* 31: 1033–1037.

Raupp, J. 2001. Manure fertilization for soil organic matter maintenance and its effects upon crops and the environment, evaluated in a long-term trial. In: Rees, R.M., Ball, B.C., Campbell, C.D. and Watson, C.A. (eds) *Sustainable Management of Soil Organic Matter*. CAB International, Wallingford. pp. 301–308.

Reed, M. 2004. *More Than Just Fashionable Foods – the Importance of the Social Sciences in Organic Research*. <http://www.organic-research.com/Reviews.asp?action=display&openMenu=relatedItems&ReviewID=1135&Year=2004>. Accessed 31/8/05.

Reganold, J.P., Glover, J.D., Andrews, P.K. and Hinman, H.R. (2001) Sustainability of three apple production systems. *Nature* 410: 926–929.

Reganold, J.P., Palmer, A.S., Lockhart, J.C. and Macgregor, A.N. 1993. Soil quality and financial performance of biodynamic and conventional farms in New Zealand. *Science* 344–349.

RIRDC 2005. *Organic Produce Research Program*. Rural Industries Research and Development Corporation, Barton. <http://www.rirdc.gov.au/programs/org.html>. Accessed 31/8/05.

Rowe, J.S. 1997. From reductionism to holism in ecology and deep ecology. *The Ecologist* 27: 147–151.

Schjønning, P., Elmholt, S. and Christensen, B.T. 2004. Soil quality management – concepts and terms. In: Schjønning, P., Elmholt, S. and Christensen. B.T. (eds) *Managing Soil Quality: Challenges in Modern Agriculture*. CABI Publishing, Wallingford. pp. 1–16.

Shrum, W. 2000. Science and story in development: the emergence of non-governmental organizations in agricultural research. *Social Studies of Science* 30: 95–124.

Sooby, J. 2001. *State of the States. Organic Farming Research at Land Grant Institutions 2000–2001*. Organic Farming Research Foundation, Santa Cruz.

Spedding, C.R.W. 1975. *An Introduction to Agricultural Systems*. Elsevier Applied Science: London.

Taubes, G. 1996. *Speed of Publication – Stuck in First Gear. Science* 271: 5250: 765.

Taylor, D., Younie, D., Coutts, M., Matheson, S. and Mayer, C. 2002. Experiences designing and managing organic rotations trials. In *Proceedings of the UK Organic Research 2002 Conference*. pp. 37–42. Organic Centre Wales: Aberystwyth.

Thompson, P.B. 1995. *The Spirit of the Soil. Agriculture and Environmental Ethics*. New York: Routledge.

Tinker, P.B. 2000. *Shades of Green*. RASE: Warwickshire.

Trewavas, A. 2004. A critical assessment of organic farming-and-food assertions with particular respect to the UK and the potential environmental benefits of no-till agriculture. *Crop Protection* 23: 751–781.

Trewavas, A.J. 2001. Urban myths of organic farming. *Nature* 410: 409–410.

USDA 2004. *USDA Awards $4.5 Million in Grants for Organic Agriculture Projects (News Release No. 0423.04)*. United States Department of Agriculture, Washington DC. <http://www.usda.gov/wps/portal/!ut/p/_s.7_0_A/7_0_1OB?contentidonly=true&contentid=2004/09/0423.xml>. Accessed 17/1/06.

USDA 2006. *Long-Term Field Experiment to Evaluate Sustainability of Organic and Conventional Cropping Systems*. United States Department of Agriculture, Washington DC. <http://www.ars.usda.gov/research/projects/projects.htm ?ACCN_NO=407791>. Accessed 17/1/06.

Van Mansfeld. J.D. and Amons, F. 1975. Inquiry into the limits of biological effects of chemical compounds in tissue culture 1 Low dose effects of mercuric oxide. *Zeitschrift für Naturforschung* 30: 643–649.

Watson, C.A. and Atkinson, D. 2002. Organic farming – the appliance of science. In *Proceedings of the UK Organic Research 2002 Conference*. pp. 13–17. Organic Centre Wales, Aberystwyth.

Watson, C.A., Fowler, S.M. and Wilman, D. 1993. Soil inorganic-N and nitrate leaching on organic farms. *Journal of Agricultural Science* 120: 361–369.

Watson, C.A., Younie, D. and Armstrong, G. 1999. Designing crop rotations for organic farming: Importance of the ley-arable balance. In: Olesen, J.E., Eltun, R., Gooding, M.J., Jensen, E.S. and Köpke, U. (eds) *Designing and Testing Crop Rotations for Organic Farming*. DARCOF, Tjele. pp. 91–98.

Williams, C.M. 2002. Nutritional quality of organic food: shades of grey or shades of green? *Proceedings of the Nutrition Society* 61: 19–24.

Woodward, L. 2002a. Organic research – driven and directed by funders? In: Powell, J. (ed.) *Proceedings of the UK Organic Research 2002 Conference: Research in Context. 26–28th March 2002 Aberystwyth*. Organic Centre Wales, Institute of Rural Studies, University of Wales Aberystwyth, Aberystwyth. pp. 7–12.

Woodward, L. 2002b. *Science and Research in Organic Farming*. Elm Farm Research Centre, Newbury.

Woodward, L. and Vogtmann, H. 2004. IFOAM's organic principles. *Ecology and Farming* 36: 24–26.

Woodward, L., Flemming, D. and Vogtmann, H. 1996. Reflections on the past, outlook for the future. In: Østergaard, T.V. (ed.) *Fundamentals of Organic Agriculture. Proceedings Volume I of the 11th IFOAM International Scientific Conference*. IFOAM, Copenhagen. pp. 259–270.

Wynen, E. 1997. *Research on Biological Farming Methods in Europe, Perspectives, Status and Requirements. Biological Farming research in Europe REU Technical Series 54*. FAO, Rome.

Wynen, E. 2003. *Organic Agriculture in Australia – Levies and Expenditure*. Rural Industries Research and Development Corporation, Barton.

Zanoli, R. and Krell, R. (eds) 1999. *Research Methodologies in Organic Farming. REU Technical Series No. 58*. FAO, Rome.