2007 NATIONAL ORGANIC RESEARCH AGENDA

SOILS • PESTS • LIVESTOCK • GENETICS

Outcomes from the Scientific Congress
on Organic Agricultural Research (SCOAR)

By Jane Sooby, Jonathon Landeck, and Mark Lipson

ORGANIC FARMING RESEARCH FOUNDATION

Organic Farming Research Foundation • Santa Cruz, CA

Primary funding provided by USDA's Initiative for Future Agriculture and Food Systems
USDA-CSREES-IFAFS, Project #000-5192,
"Revitalizing Small and Mid-Sized Farms: Organic Research, Education and Extension"

ORGANIC FARMING RESEARCH FOUNDATION

The Organic Farming Research Foundation (OFRF) is a national public interest organization founded in 1990 by certified organic farmers.

OFRF's integrated strategy of grantmaking, policy, research and education initiatives and networking activities support organic farmers' immediate information needs while moving the public and policymakers toward greater investment in organic farming systems.

Grantmaking

Since 1992, OFRF's grantmaking program has awarded more than $1.5 million for over 200 projects. Our grantmaking objective is to generate practical, science-based knowledge to support modern organic farming systems. OFRF-funded projects emphasize grower-researcher collaboration, studies conducted on-farm and in certified organic settings, and outreach of project results.

Policy

OFRF's policy program objectives are to ensure that the public and policymakers are well-informed about organic farming issues, and to increase public institutional support for organic farming research and education.

Organic Farmers Action Network

OFRF encourages organic farmers to participate in the policy process by joining our Organic Farmers Action Network (OFAN). OFAN subscribers will receive free policy updates and tools for communicating with representatives in Congress to advocate for increased funding for organic research, technical assistance and marketing support, organic conservation programs and maintenance and improvement of national organic standards. Email action@ofrf.org to join.

Education

OFRF seeks to share new insights into organic farming systems with all farmers who use or want to adopt organic practices. The results of research projects funded by OFRF generate information useful to farmers who are working to develop and improve integrated, systems-level organic management practices. Every OFRF-funded project is required to have an outreach component that disseminates the results to the grower and research communities.

Research

OFRF conducts original research about organic farming in the U.S. OFRF research reports include:

- *National Organic Farmers' Surveys*
- *State of the States: Organic Farming Systems Research at Land Grant Institutions*
- *Searching for the 'O-Word': Analyzing the USDA Current Research Information System for Pertinence to Organic Farming*

The results of OFRF-funded projects are published in our newsletter, the *Information Bulletin*, available free online at www.ofrf.org.

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Despite the authors' best efforts, there may be errors of statement or emphasis in a project such as this. Any such errors are solely the responsibility of the authors.


Paul Bousquet

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Organic Farming Research Foundation

EXECUTIVE SUMMARY

This *National Organic Research Agenda 2007* presents a catalogue of research needs for organic agriculture. It is intended to inspire research that will help organic farmers and ranchers improve the agricultural, environmental, and economic performance of their production systems.

Organic producers identified their research needs and goals in a series of meetings held in 2000-2002 under the auspices of the Scientific Congress on Organic Agricultural Research (SCOAR). These meetings brought producers and scientists together as peers to discuss the questions that form the core of this research agenda.

The current volume is focused on four production-related topics discussed at these meetings.

- Soil: microbial life, fertility management, and soil quality;
- Systemic management of plant pests: weeds, insects, and diseases;
- Organic livestock and poultry management systems; and
- Breeding and genetics.

Chapter One of this agenda discusses soil microbial life, fertility management, and soil quality. It emphasizes that basic and applied research on soil microbial life and other aspects of the soil system should contribute to organic growers' ability to evaluate the soil health of their fields and pastures, estimate levels of nutrient inputs and exports, and choose fertility management strategies that match crop needs while reducing nutrient losses from the farming system. Along with strategies to manage nutrients and microbial communities effectively, growers also need to know how recommended practices will affect the profitability of their farming system.

Chapter One presents the following broad research outcomes:

- Identification and understanding of soil microbial community patterns in relation to productivity and soil quality in mature organic systems across all soil types and climatic regions.
- Soil management protocols for optimizing organic crop and pasture production based on biochemical and biophysical conditions found in various soil types and climatic regions.

Chapter Two discusses systemic management of plant pests (weeds, insects, diseases). It emphasizes that pest control research has traditionally focused on the pest itself, looking for ways to eliminate a weed, insect, or disease by disrupting its breeding cycle, eliminating its habitat, or killing it outright with pesticides. Developing methods for systemic biocontrol of pests requires that the researcher take a broader view of the farm, shifting the frame of reference to the farm as an ecosystem and looking for ways to enhance soil health, microbial soil communities, and other conditions that will improve overall crop resistance to pests. The research outcomes presented here reflect an approach to pest control research that will help growers create the healthiest possible environment for crop production, and develop specific pest control techniques to use when necessary to prevent major economic losses.

Chapter Two presents the following broad research outcomes:

- In general, research is needed to understand and develop management systems that shift the focus of pest management from use of external inputs to internal biological controls arising from the system itself, leading to whole farm systemic resistance to weeds, insects, and diseases.
- Continued study and documentation of pest life cycles and their spatial and temporal relationships to natural hosts, prey, and predators. This is particularly important for developing "organic IPM" protocols and, taking a wider view, bioregion-specific organic crop and pest management strategies.
- Refinement of methods to study the role of above- and below-ground biodiversity to nurture and sustain landscape level habitat conditions that accommodate beneficial organisms and suppress economically significant pest infestations
- Crop breeding programs that select for disease and insect resistance in biologically diverse systems.

Chapter Three discusses organic livestock and poultry management systems. It emphasizes that rapid growth in the organic livestock and poultry sectors reflects heightened demand for organic meat, dairy, and egg products, but production challenges persist due to a lack of well-funded research efforts targeted at specific animal health care, pasture management, and nutrition issues. Producers rank animal health care as their highest priority for organic livestock research. Effective disease controls will require systems-based research on intensive grazing management, good nutrition, and strategic use of supplements and preventative treatments. Standard, economically viable rations to complement pasture and provide complete nutrition for all species of livestock and poultry within the constraints of the National Organic Standards also need to be developed. Breeding programs that emphasize adaptability to organic management systems are needed to enhance animal health and productivity.

Chapter Three presents the following broad research outcomes:

- Technical information sufficient to support increased U.S. production capacity to meet the existing and future demand for organic meat, eggs, and dairy.
- Health care protocols that are compatible with the National Organic Standards for each species of livestock and poultry.
- Standard organic livestock and poultry rations that fully meet animals' nutritional needs.
- Models of economically viable, integrated crop-livestock production systems.
- Identification of economic factors and management practices that reduce the risks of transitioning to organic production.

Chapter Four discusses breeding and genetics. It emphasizes that organic growers and livestock producers require breeding programs that produce crops and animals which meet the unique needs and conditions of organic farming systems. Breeding crops and livestock under conventional management for use in organic systems fails to meet these needs. Organic crop breeding programs should focus on optimizing yields by considering such factors as insect and disease resistance, weed competition, good response to organic fertility sources, and good yield in biologically diverse systems. Organic livestock breeding should focus on selecting healthy, adaptable animals that perform well on pasture and that have disease and parasite resistance.

Chapter Four presents the following broad research outcomes:

- Organic breeding goals developed cooperatively between farmers and breeders.
- Breeding under certified organic conditions, both on-farm and on-station, to develop high quality crop varieties and healthy livestock breeds that are well-adapted to local organic production systems.
- Crop varieties and animal breeds that are compatible with each other in mixed crop-livestock systems.
- Access by breeders and organic farmers to a large diversity of plant and animal genetic resources maintained and protected in the public domain by public institutions.

PREFACE

The Roots of NORA 2007

The idea for this National Organic Research Agenda germinated in 1998, following the publication of OFRF's analysis of the total USDA research portfolio for projects pertaining to organic farming. That study, titled *Searching for the 'O-Word'*, found very few federally-funded projects with explicit organic farming objectives: less than 0.1% of USDA research funding in 1995 was directly pertinent to organic agriculture (Lipson 1997).

Having quantified a baseline, the next challenge was how to cultivate more organic research activity in the public sector. OFRF responded by developing initiatives to obtain federal recognition of and funding for organic research, and these efforts continue today. To show how increased resources might be utilized, concrete research objectives were needed. Thus we set the goal to develop a research agenda for organic agriculture.

The only resource available that resembled such an agenda was a document produced in 1980 under the auspices of the USDA itself. At the direction of Agriculture Secretary Bob Berglund, in the late 1970s the USDA established a Study Team on Organic Farming to undertake a "comprehensive study of organic farming in the United States." The team of scientists was led by Dr. Richard Harwood from Michigan State University and was staffed at the USDA by Dr. Garth Youngberg. The *Report and Recommendations on Organic Farming* subsequently issued by the Organic Study Team acknowledged that the USDA knew very little scientifically about organic agricultural productivity, much less the economic benefits and costs of organic farming (USDA Study Team on Organic Farming 1980).

The Study Team posed an intriguing question that remains relevant today: "*Under what specific circumstances and conditions can organic farming systems produce a significant portion of our food and fiber needs?*" With an eye on that over-arching question, the Organic Study Team put forward 18 general recommendations for research, extension and education "to address the needs and problems of organic farmers and to enhance the success of conventional farmers who may want to shift toward organic farming, adopt organic methods, or reduce their dependence upon agricultural chemicals." They added a final recommendation for a permanent "Organic Resources Coordinator" within USDA.

Shortly after the 1980 report was issued, incoming Secretary John Block refused to distribute the report and did not permit any official follow-up within the department. Organic agriculture became a taboo subject within USDA. When OFRF examined the state of USDA organic research in the mid-90s, it was clear that the taboo was still largely in place throughout the agricultural research community (Lipson 1997). Almost no progress had been made by scientists in response to the Study Team's questions and recommendations.

On the positive side, the *Searching for the 'O-Word'* study also showed that a few scientists were ready to pursue the recommendations articulated by the Study Team. These observations led OFRF to form the Scientific Congress on Organic Agricultural Research, or SCOAR.

Many of the Study Team's recommendations remain immediately relevant today. While it has taken a generation of organic farming to formalize a follow-up organic research agenda, NORA 2007 represents a serious response by SCOAR participants to the vision of Harwood and Youngberg's USDA Organic Study Team.

The SCOAR Process

As the *Searching for the 'O-Word'* investigation concluded, an obvious follow-up was to assemble a network of the scientists doing *bona fide* organic research along with advanced organic farming practitioners. SCOAR institutionalized such an organic research dialogue between organic producers and agricultural scientists. SCOAR strives to establish a peer relationship between farmers and scientists, and attempts to transcend the traditional "customer-provider" model of research and extension promulgated by the land grant system.

OFRF convened a national Steering Committee to guide SCOAR's activities. It was composed of organic crop and livestock producers and scientists from land grant and other colleges, the USDA's Agricultural Research Service (ARS), and various Cooperative State Research, Education and Extension Service (CSREES) agencies, who collectively represented broad geographical, commodity, and disciplinary diversity. (Members of the SCOAR Steering Committee are listed in the acknowledgments of this publication.) The Steering Committee defined SCOAR's mission to be "to plan and promote research and information-exchange for understanding and improving organic agricultural systems." One of the goals under this mission is to identify research goals and priorities (see Appendix 1, *Mission and objectives of SCOAR*).

The SCOAR network held a series of regional and topical meetings with producers and scientists to discuss and design plans for basic, applied, and developmental organic farming research. Between April 2000 and June 2002, SCOAR research agenda discussion meetings took place in Phoenix, Arizona; Pacific Grove, California; La Crosse, Wisconsin; Grand Junction, Colorado; Rock Hill, South Carolina; Santa Fe, New Mexico; and Chicago, Illinois (see Appendix 2). At the January 2001 Inaugural Assembly of SCOAR in Pacific Grove, California, an outline of a National Organic Research Agenda began to evolve.

The SCOAR network received an institutional boost in 2001 with its inclusion in a $1.8 million grant awarded by USDA's Initiative for Future Agriculture and Food Systems (IFAFS) to a consortium of investigators from North Carolina State University, Ohio State University, Iowa State University, Tufts University, and OFRF. This Organic Agriculture Consortium (OAC) pursued a number of experiments and outreach efforts directed towards revitalizing small and mid-sized family farms by integrating research, education and extension efforts on organic agriculture. The IFAFS grant made it possible for the SCOAR network to develop NORA 2007 and other tangible products in support of organic farming research and education (see next page).

During its sequence of meetings and conference presentations, and through the OFRF website, the SCOAR network has recruited more than 900 producers, scientists, and organic advocates as participants. SCOAR currently provides a bi-monthly electronic bulletin of organic research and education news.

Following the publication of NORA 2007, the SCOAR network will be applied to further extend, revise, and pursue these recommendations.

Citations

Lipson, M. 1997. Searching for the 'O-Word': Analyzing the USDA Current Research Information System for Pertinence to Organic Farming. Santa Cruz, CA: Organic Farming Research Foundation.

USDA Study Team on Organic Farming. 1980. Report and recommendations on organic farming. Washington, D.C.: USDA.

A copy of this report is available for free from the Alternative Farming Systems Information Center. Send an email to afsic@nal.usda.gov with the subject line "Publication request-free organic report CD."

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Products created by the Scientific Congress on Organic Agricultural Research (SCOAR)

- OFRF developed the first SCOAR product in response to the Farm Security and Rural Investment Act of 2002 (Section 7218): ***Administrative Recommendations for the Organic Agriculture Research and Extension Initiative.*** These recommendations emphasized funding on-farm research; producer involvement in identifying and assessing research; a systems approach that acknowledges the relationships between multiple elements of an organic farm; and sensitivity to the scale and economic viability of different sized organic farm enterprises.

- A joint SCOAR/OAC product that contributes to the application of NORA 2007 is the **Organic Agriculture Information** website (www.OrganicAgInfo.org). This interactive website contains current, accurate, scientifically-based or practically validated information about organic agriculture, plus information on production, economic data, research results, farmer anecdotes, certification information, transition strategies, and other subjects related to organic agriculture.

- Every other month, OFRF disseminates an electronic ***SCOAR Bulletin*** to the entire network that contains information about organic agricultural activities in higher education, organic research and education funding opportunities, job opportunities in organic agricultural research, current literature on organic agriculture, conference and workshop announcements, and related resources. A compendium of SCOAR's activities and information is available on the OFRF website (www.ofrf.org).

- **Subscribe to the SCOAR bulletin at http://ofrf.org/subscribe/scoar.html**
- **For past issues and archives of the SCOAR process, visit http://ofrf.org/networks/networks.html**
- **For reports on research and educational activities conducted by the Organic Agriculture Consortium visit http://ofrf.org/networks/oac.html**


Paul Bousquet

Organic Farming Research Foundation

INTRODUCTION

This *National Organic Research Agenda 2007* presents a catalogue of research needs for organic agriculture. It is intended to inspire research that will help organic farmers and ranchers improve the agricultural, environmental, and economic performance of their production systems.

Organic producers identified their research needs and goals in a series of meetings held in 2000-2002 under the auspices of the Scientific Congress on Organic Agricultural Research (SCOAR). These meetings brought producers and scientists together as peers to discuss the questions that form the core of this research agenda.

This agenda covers four topical areas:

- Soil: microbial life, fertility management, and soil quality;
- Systemic management of plant pests: weeds, insects, and diseases;
- Organic livestock and poultry management systems; and
- Breeding and genetics.

During the SCOAR meetings, we also gathered research priorities in the areas of organic food quality, economics and marketing, and socioeconomic issues. These key issues in organic farming require additional development into a separate research agenda using a collaborative process similar to that which we used to produce the current material. However, the current volume is focused on production-related topics.

Organic agriculture in the U.S. is conducted in widely diverse regional agro-ecosystems and includes many different production types and management systems. Thus the research topics presented here are intentionally broad and not specific to particular crops or livestock types. We encourage groups of farmers, ranchers, and scientists to further refine and adapt this agenda to their specific needs.

Other source materials for this research agenda include OFRF's *Third National Organic Farmers' Survey* (Walz 1997), the USDA's *Report and Recommendations on Organic Farming* (USDA Study Team on Organic Farming 1980), and *Searching for the 'O-Word,'* also published by OFRF (Lipson 1997). Significant organic research needs described in these historic documents have yet to be met and still deserve to be considered today.

The organic systems research ideal is most pertinent to organic producers' needs when it features the following characteristics:

- **Organic research should be conducted under certified organic conditions.**

  Since the final implementation of the Federal Organic Rule in Oct. 2002, producers who market any product as "organic" must be certified unless their annual sales are under $5,000. Among other requirements, organic producers now must abide by strict rules on compost production and application, and are required to use organic seed and transplants when "commercially available." They are also required to use cultural practices to address insect, weed, and disease problems before resorting to the application of a "substance" to control these pests. Meeting the same challenges by transitioning research acres to certified organic status and maintaining certification is more than an exercise in empathy on the part of researchers, it is necessary to guarantee relevance of organic research findings.

  Further rationale for conducting research under organic conditions comes from numerous studies measuring the changes that occur in soil as it is taken through the transition from chemical to organic management (these are detailed in Chapter 1). Differences between organically- and conventionally-managed soil chemical and physical properties are so distinctive and characteristic, and have the potential to impact so many aspects of the system, that we feel it essential that organic research be conducted under long-term, certified organic management.

- **Organic research should involve organic producers as active team members.**

  Advantages to such an approach include ensuring the relevance of research topics; having access to grower wisdom in managing organic plots; creating better potential for the extension of findings to the larger community; and potentially providing access to organic on-farm research sites. Also, we strongly encourage researchers to seek funding for their farmer cooperators in the form of stipends or other remuneration for their contributions.

- **Organic research should emphasize multidisciplinary systems approaches, rather than input-substitution approaches, to managing pest problems and fertility needs.**

  Organic agriculture involves more than substituting organically-compliant materials for chemical inputs; it requires refining management practices in order to strengthen the system's innate resistance to pest attacks and ability to cycle nutrients in an efficient way. Discovering the principles underlying whole-system functioning and how to optimize this through management practices is the kind of scientific guidance that organic producers need most.

There remains a need to develop and refine methodologies for whole systems organic farming research. Recognizing and measuring system components and how they interact to influence whole system functioning differs significantly from the more traditional approach of analyzing the effect of one or two management practices on system outputs. The scientific literature contains some guidance on using systems methods in organic agricultural research (Drinkwater 2002, Delate 2002, Mueller et al. 2002); still, methodological and statistical approaches for studying whole farming systems are not yet widely applied.

- **Research trials should be set up for long-term studies of organic systems.**

  Long-term studies of organic farms are needed in order to document changes that occur in maturing organic systems. Whole-system functioning that may emerge over time includes enhanced nutrient cycling, improved soil quality, and systemic resistance to pests. Showing how long-term organic management contributes to these traits can lead to a better understanding of organic systems and how to manage them for optimal production.

Structure of the *National Organic Research Agenda 2007*

Each chapter begins with a summary of research goals on that particular topic, followed by a set of broad research outcomes. We hope that these broad outcomes will be suitable as planning statements for long-term guidance of research programs.

We then present a list of basic research needs that describe the underlying science needed to describe the structure and functions of integrated systems. These are followed by a list of applied research needs, which involve practical applications of the basic research findings. We have attempted to fit research topics identified through the SCOAR process into these two categories as best we can, but are aware that some topics may not clearly fit into either category. The breeding and genetics chapter does not divide research topics into basic and applied as all of this work falls into the applied category.

The text following the research topics is divided into two parts. The first part, the growers' perspective, attempts to frame the broader topic in terms of practical agricultural management concerns. The second part, the scientific context, provides an overview of the literature and work done to date on the research needs presented. The scientific context discussion for each chapter was shaped by the research topics identified through the SCOAR process. We do not claim that these discussions are comprehensive literature reviews on the topic. However we do try to cite the most recent literature whenever possible, and to provide representative scientific citations related to the research priorities.

The *National Organic Research Agenda 2007* (NORA 2007) represents a conceptual framework for ongoing planning, implementation, and inventory of organic research. We hope that NORA 2007 will be of practical use to all organic farming research practitioners – producers and scientists alike – as well as to administrators and policy makers. We also invite continued feedback and revision from organic producers and scientists via their participation in SCOAR and other efforts to develop a practical organic research program in the U.S.

Citations

Delate, K. 2002. Using an agroecological approach to farming systems research. HortTechnology 12:345-354.

Drinkwater, L.E. 2002. Cropping systems research: reconsidering agricultural experimental approaches. HortTechnology 12:355-361.

Koenig, R.L., and B. Baker. 2002. U.S. National Program standards: implications for researchers. American Pathological Society, APSnet feature Nov. 2002. Online at http://apsnet.org/online/feature/organic/

Lipson, M. 1997. Searching for the 'O-Word': Analyzing the USDA Current Research Information System for Pertinence to Organic Farming. Santa Cruz, CA: Organic Farming Research Foundation.

Mueller, J.P., M.E. Barbercheck, M. Bell, C. Brownie, N.G. Creamer, A. Hitt, S. Hu, L. King, H.M. Linker, F.J. Louws, S. Marlow, M. Marra, C.W. Raczkowski, D.J. Susko, and M.G. Wagger. 2002. Development and implementation of a long-term agricultural systems study: challenges and opportunities. HortTechnology 12:362-368.

USDA Study Team on Organic Farming. 1980. Report and recommendations on organic farming. Washington, D.C.: USDA.

Walz, E. 1997. Final results of the third biennial national organic farmers' survey. Santa Cruz, CA: Organic Farming Research Foundation. Online at http://ofrf.org/publications/pubs/3rdsurvey_results.pdf

Organic Farming Research Foundation

Chapter 1

Soil: Microbial Life, Fertility Management, and Soil Quality

Paul Bousquet

Summary of Research Goals

Basic and applied research on soil microbial life and other aspects of the soil system should contribute to organic growers' ability to evaluate the soil health of their fields and pastures, estimate levels of nutrient inputs and exports, and choose fertility management strategies that match crop needs while reducing nutrient losses from the farming system. Along with strategies to manage nutrients and microbial communities effectively, growers also need to know how recommended practices will affect the profitability of their farming system.

Broad Research Outcomes

- Identification and understanding of soil microbial community patterns in relation to productivity and soil quality in mature organic systems across all soil types and climatic regions.
- Soil management protocols for optimizing organic crop and pasture production based on biochemical and biophysical conditions found in various soil types and climatic regions.

Basic Research Needs

- Determine the degree to which soil organic matter (SOM) quality and the rate of SOM formation may be functions of microbial community response to cover crops, cover crop sequences, and crop residue management.
- Explore how specific cover crop sequences or mixtures interact with soil biota to stimulate plant resistance mechanisms and/or influence nutrient uptake.
- More precisely characterize the various fractions of soil organic matter and determine how these interact with soil biota to affect soil physical and chemical properties for different soil types.
- Determine how soil nutrient ratios influence plant performance.
- Analyze nutrient inputs and harvested outputs over time (mass balancing) to determine net losses or accumulations of nutrients for specific organic cropping systems.
- Identify ways to increase resident soil nutrient reservoirs and decrease nutrient losses by analyzing nutrient cycling mechanisms for carbon, nitrogen, and other nutrients within various soil types, climate zones, and organic management regimes.
- Analyze short- and long-term effects of organic soil fertility inputs and pest management strategies on soil microbial communities by crop, soil type, and climate zone.
- Develop refined counting methods for identifying and quantifying soil microorganisms.

Applied Research Needs

- Determine relationships between crop nutrient content and soil quality.
- Develop nutrient budgeting tools such as look-up tables of the nutrients contributed to soils by specific crops and inputs.
- Develop refined soil test recommendations for nitrogen, phosphorus, potassium, and micronutrients for all crops, soil types, and climate zones.
- Develop low-cost, farmer-friendly soil testing methods and kits to assess soil quality and fertility status.
- Investigate plant and soil microbial community response to crop rotations that feature green manures, cover crops, and ley fallow techniques.
- Determine how organic farming can conserve soil organic matter, build soil quality, reduce erosion, and contribute to carbon sequestration under management that includes routine tillage.
- Determine the timing of nutrient release by various organic fertility amendments. For example, determine the availability of phosphorus from rock phosphate and potassium from low solubility sources when applied to soils that are farmed organically.
- Conduct efficacy testing on products marketed to organic farmers as microbial stimulants, such as humic acids, humates, fulvates, and mycorrhizal stimulants.

Growers' Perspectives on Soil Health and Fertility

All agricultural producers manage soil in many different ways for a number of distinct purposes. Managing soil fertility is distinct from but related to managing for soil health, which is not an end in itself but is thought to stimulate crop response to pest assault and also to improve crop quality by raising levels of nutrients and polyphenols. Soil is also directly manipulated with a variety of tillage strategies to manage weeds.

Organic growers generally regard soil health as the most important component of their farming system. Organic farmers understand that soil is more than an inert medium in which plants are rooted; they are aware that soil itself comprises a complex ecosystem that interacts with crop and weed populations and applied inputs to directly influence crop yields, crop quality, a crop's resistance to disease and insects, its competitive ability against weeds, and nutrient cycling.

Therefore, in organic farming a guiding premise is *feed the soil to feed the plant*. Building a healthy and thriving soil community through careful soil management produces vigorous, nutrient-rich crops that have an enhanced ability to fend off insect and disease attacks; similarly, high quality pasture is crucial to producing healthy livestock. Scientific evidence to substantiate this premise would provide a basis for moving away from the input-substitution model that has framed conventional agricultural research for decades.

In OFRF's *Third National Survey of Organic Farmers*, growers ranked soil and crop management as their highest research priority (Walz 1997), and identified fertility management, soil health, and crop rotations as the three most important research areas within this topic (Walz 1997). This chapter addresses each of these research areas.

Fertility Management

Organic farmers rely on cover crops and other organic nutrient sources that must be broken down and transformed by soil microorganisms into inorganic nutrient forms before plants can absorb them through their roots. Soluble inorganic fertilizers used by conventional growers are available immediately to plant roots, so nutrient application is timed to coincide with crop uptake need. Because of the very different nature of organic fertility practices, characterized by a gap in time between application of fertility amendments and availability of nutrients, an ongoing challenge that organic growers face is managing soil-building residues and other inputs in a way that avoids tie-up of nitrogen (N) during periods of crop demand on the one hand, yet prevents build-up of large, highly leachable nitrate (NO_3^-) pools on the other (Burger and Jackson 2003). There is a great need for research into the timing of nutrient release by organic fertility sources.

Planting cover crops is organic farmers' most common fertility management practice (see next section), and compost application is second (Walz 1997). Compost is a unique type of soil amendment because it is applied for multiple functions—not simply as a fertility input, but to improve soil structure and drainage, increase organic matter levels, enhance plant resistance to insects and diseases, control weeds, and as a source of macro- and micronutrients. While much work has been conducted in conventional container systems documenting the effectiveness of compost in suppressing root-borne diseases, comparatively little work has been done to document the role of compost in building soil and plant health.

Other external sources of fertility are used in certified organic production, including gypsum and lime; animal by-products such as fish products, bone and blood meal; kelp or seaweed; minerals; uncomposted manure; and compost tea (Walz 1997). Though soil environments are comprised of so many variables that it may be difficult to determine standard nutrient release rates of various organic inputs, organic farmers would benefit from data on breakdown and nutrient release rates of these inputs under different soil structure, moisture, and temperature conditions.

As the mediator between living plants and non-living nutrients, soil organic matter has numerous functions in cropping systems, including nutrient capture and sequestration, nutrient transfer via cation exchange, and building soil structure. Soil organic matter may also mediate microbial biocontrol of pathogens in yet unknown ways. Scientists are still determining the precise nature of soil organic matter, its many fractions, and how these fractions might interact with plant roots and soil microbes. Identifying the various fractions of soil organic matter and how these interact with soil biota and affect soil physical and chemical properties is important to understanding organic farming systems.

While nitrogen, phosphorus, and potassium (N-P-K) levels are of primary interest to conventional growers, organic growers place importance on secondary nutrient ratios that may affect microbial functioning or soil physical properties. Many farmers believe that the calcium:magnesium ratio is a crucial indicator of soil quality. There is very little research on this topic, though the existing literature indicates that "cation balancing" effects may be site-specific. For example, Schonbeck found that calcium amendments seemed to "loosen" up a pre-existing hardpan and improve water infiltration in one soil type, while the same treatment decreased water infiltration and tightened hardpan in another soil type (Schonbeck 2000). More work needs to be done to clarify these relationships under various conditions.

Scientists have documented a noticeably higher ratio of ammonium:nitrate (NH_4^+:NO_3^-) in organic soils than in conventional soils. Implications of this are discussed in the next section.

An important question related to soil fertility is how soil test results can be of most use to organic farmers. Standard soil tests are used in conventional agriculture to make recommendations for soluble inorganic fertilizer applications. Because organic farmers apply biological forms of nutrients that are released slowly over time, they are not able to use the results of standard soil tests without significant reinterpretation into organically relevant recommendations. What tests are most meaningful to organic growers? Growers need simple tests for soil quality indicators, such as field apparatus and methods for measuring soil active carbon, or using a simple aggregate stability test as an indicator of soil health (Schonbeck pers. comm.). A test that can relate soil microbial levels to nitrogen release rates would be useful. Also, there may be a role for plant tissue tests to guide organic fertilization recommendations.

Crop rotations and cover crops

Crop rotation is a fundamental management practice used by organic producers. Crop rotations are such an integral component of organic cropping systems that a minimum two-year rotation is required in certified organic systems, and many organic farms use considerably longer rotations. Crop rotation design is influenced by a variety of market and farm management objectives. Field benefits of rotation include soil nutrient and soil quality enhancement, weed suppression, and disruption of insect and disease life cycles.

An ideal crop rotation includes cash crops and cover crops—crops grown to provide soil cover. Organic producers use cover crops as their primary fertility input (Walz 1997). The most common way to manage a cover crop for fertility is to incorporate it as a nutrient-releasing green manure crop. Legume cover crops such as clover, vetch, alfalfa, and peas perform nitrogen fixation and contribute to soil organic matter formation. Additional benefits of cover crops in a rotation include improved water infiltration, decreased soil compaction, conservation of soil moisture, and water quality protection through decreased wind and water erosion. Improved soil quality under long-term rotation can result in increased yields.

Agricultural scientists have extensively studied the many roles that cover crops play in farming systems, but more work is needed that focuses on optimal ways to select cover crop species, manage them for multiple objectives, and integrate cover cropping into organic crop rotations.

Soil quality and soil health

Most agricultural practitioners believe that conscientious organic soil management practices have a positive impact on soil quality by stimulating microbial activity, thereby modifying soil nutrient cycling, changing soil structure, and affecting the subterranean habitat. How soil "quality" is defined and how it relates to soil "health" is a continuing discussion within soil science. What farmers mean by soil "health" includes optimal organic matter levels, lush crop appearance, reduced erosion, and the presence of earthworms (Romig et al. 1996).

Although organic farmers use management practices intended to improve the soil, critics of organic farming point to the widespread use of tillage for weed control as a practice that damages soil structure, destroys soil organic matter, and contributes to erosion. At the same time, long-term studies of organic soils to which tillage was applied have shown higher biological activity, increased soil organic matter, higher water infiltration rates, and increased soil water storage compared with conventional tilled soils (see, e.g., Temple 2003). Important questions to study include determining how much tillage is enough to effectively manage weeds and at the same time enhance rather than degrade soil organic matter, soil quality, soil structure, nutrient cycling, and microbial activity. Other cultural practices that can replace tillage in managing weeds need to be developed.

Another soil quality issue pertinent to organic farmers and ranchers is how to manage crops during the transition from conventional to organic management. It is accepted wisdom that crop yields decrease during the initial transition to organic production, until a rebound occurs and yields return to levels comparable to (and sometimes surpassing) those prior to the transition. While many organic practitioners assume that this "transition effect" is due to increasing levels of organic matter over time, some researchers postulate that the change is related more to increased farmer experience with organic management practices (Martini et al. 2003). Is the transition effect attributable to changes in soil nutrient dynamics, to increased grower experience, or to other factors? Thoroughly documenting the soil changes that occur over time can help to answer this question, and generate management recommendations for growers making the transition.

Scientific Context

It is well established scientifically that specific and measurable changes take place in farm ground (both cropped fields and pasture) that undergoes a transition from chemical to organic management. Such changes have been documented in long-term studies comparing organic and conventional farming systems, which show distinct changes over time in the biological, chemical, and physical properties of the organically managed soils (Drinkwater et al. 1998; Clark et al. 1998; Mäder et al. 2002; Reganold et al. 2001; Swezey et al. 1998; Kramer et al. 2006).

To cite one example, organically managed soils were found to have:

- greater capacity for labile carbon (C) pools
- greater potential for organic carbon sequestration
- gradual rather than instantaneous rate of ammonium (NH_4^+) release
- higher ratio of ammonium to nitrate (NH_4^+:NO_3^-)
- higher potential mineralizable nitrogen (N)
- greater storage of surplus N
- greater efficiency of N-P-K and organic C utilization
- greater buffering capacity
- change toward neutral pH

(Fließbach and Mäder 1997)

The differences found between soils in organic and conventional production systems are so distinctive that this is the primary reason to conduct meaningful organic research under certified organic management.

A small though strong body of scientific work has examined the functions of soil microbial communities in agroecological systems. This is a complex and challenging area of scientific study because of the multiple interactions underlying soil microbial ecology and their management implications for crop production. Only recently have techniques been developed to assay soils for differences in microbial functional groups and community structure. Particularly problematic has been the in-situ measurement of such important processes as mineralization, nitrification, and denitrification (Burger et al. 2005). Regression analysis, multivariate analysis, and ecological modeling can be useful in determining the interactions that occur between plants, management practices, and microbial community functioning. Growers need the results of this kind of research translated into practical management recommendations.

Fertility management

Because soil microbes and crops use and cycle the same nutrients, a knowledge of soil microbial communities and their ecological structure and functioning is fundamentally important to understanding soil fertility dynamics and crop nutrient availability. Factors such as soil type and texture, soil spatial variability, crop type, crop rotation, tillage, water management (irrigation versus rain-fed), N-P-K nutrient inputs, and timing of field operations all influence soil microbial dynamics and nutrient cycling in organically managed soils.

Drinkwater and Snapp (2007) advocate for an agroecological approach to fertility management that strives to build resident nutrient reservoirs that persist in soils rather than ephemeral pools. These investigators also emphasize the importance of including environmental and economic goals in developing fertility management strategies. Their premise is that the naturally interrelated carbon (C), nitrogen (N), and phosphorus (P) cycles in soils have been disrupted by agricultural management that reduces microbial activity through over-application of soluble fertilizers. They theorize that C, N, and P cycles can be recoupled by managing ecosystem processes at many temporal and spatial scales to reduce the need for external fertility inputs (Drinkwater and Snapp 2007).

Goldstein (2003) emphasizes the active role of corn roots in seeking out N and suggests that corn roots have the ability to stimulate mineralization in order to meet the plant's nitrogen needs. He found that the vast majority of N taken up by corn comes from soil organic matter, even when fertilizers are applied (Goldstein 2003). More work is needed to determine the respective roles of plants and soil microbial communities in nutrient cycling, and to develop practical management recommendations to optimize these roles.

There is evidence that soils in organic cropping systems are sensitive to the sources of carbon and nitrogen that they receive. For example, nutrient partitioning and retention by the soil microbial community was found to differ depending on whether the soil had received inputs of manure, legumes, corn residues, or synthetic fertilizers (Drinkwater et al. 1998). More work is needed to determine the changes that occur in microbial communities under long-term application of organic amendments, and to develop management recommendations for organic agroecosystems.

Also, there is evidence that indicates fertilization practices (Phelan et al. 1995) and organic matter levels (Davis et al. 2001) can also influence crop pest susceptibility. The potential for whole-farm resistance to weeds and other pests is discussed more thoroughly in the next chapter.

Soil organic matter — One line of scientific inquiry suggests that microbial life in organically managed soils has significant qualitative impacts on soil organic matter and, consequently, on soil fertility. Wander et al. (1994) found that organically managed systems, in comparison with conventional systems, accumulated more stable yet labile biologically active soil organic matter. These authors concluded that the biologically-active light fraction organic matter is a functionally important pool of soil organic matter, and that assays of particulate residues comprising this fraction may be the best way to characterize the quality and quantity of soil organic matter.

Phelan (1997, 2004) has developed the concept of biological buffering, which states that sustained influx of soil organic matter in organically managed soils provides the resource base for the soil community, whose interactions then attenuate or "buffer" the impact of changes in the soil environment. Phelan predicts that soil organic matter can impart greater stability in microbial population levels and resistance to disturbances by dampening fluctuations in nutrient flow, moisture, and energy (Phelan 2004). Phelan also puts forth the mineral balance hypothesis, which maintains that plants with an optimal mineral balance show lower susceptibility to pests (Phelan 1997). Among many implications of these ideas is that the relationship of soil microbial life to soil fertility in organically managed systems is not merely governed by a formulaic input of quantifiable nutrients, but rather by maintenance of a subterranean soil habitat conducive to microbial functioning and associated plant health.

While that conclusion would not surprise organic growers, it reveals a surmountable organic farming research challenge: how to define and measure the quality of soil organic matter in organically managed systems, and how to relate organic matter quality to management practices used to grow specific crops in defined rotations. To be of practical use to organic growers, this research goal will require that testing methods be developed to detect biologically significant soil parameters such as N mineralization potential and active soil carbon levels. Attainment of this goal will also require a paradigm shift from the crop-focused agronomic approach that has dominated modern U.S. agriculture to soil-focused whole farm husbandry.

Root-microbe associations — Plant roots form symbioses with a variety of microorganisms that strongly impact crop production. The relationship that legume roots have with *Rhizobium* species, which fix atmospheric nitrogen in return for carbohydrates supplied by the plant, is highly significant in the global N cycle as well as to agroecosystems. Other microbial groups that form associations with plants—such as mycorrhizae—are also important in organic nutrient cycling. These relationships require further study to elucidate their roles in crop nutrient acquisition and maintenance of crop health, and to determine management practices that support these functions.

Ammonium: nitrate ratio — Organic soils have been characterized in many studies as having a larger NH_4^+: NO_3^- ratio than conventionally managed soils (e.g., Drinkwater et al. 1995, Burger and Jackson 2003). The environmental implications of this are unclear. On the one hand, NH_4^+ is in great demand by both soil nitrifiers and N immobilizers, so higher levels of NH_4^+ can support greater microbial activity (Burger and Jackson 2003). On the other hand, autotrophic ammonia-oxidizing bacteria oxidize ammonium to nitrite; nitrite is then immediately transformed to nitrate, which can be readily leached or denitrified (Okano et al. 2004). Burger and Jackson (2004), studying vegetable systems in organically managed versus conventionally managed soils, concluded that the conversion of NO_3^- to NH_4^+ in the rhizosphere may actually contribute to greater N retention in organically managed soil by supporting larger microbial populations.

A study of three management systems in an experimental apple orchard showed that, after nine years of organic management, a higher proportion of the microbial biomass was able to perform denitrification (microbial transformation of nitrate to nitrite and then to gaseous N forms) than in conventional soils, and that denitrifiers in the organic system were more active and more efficient than those in conventional soils (Kramer et al. 2006). Increased denitrification enhanced gaseous N_2 losses and significantly reduced the size of leachable nitrate pools in the organic soil. The authors also noted that enhanced gas emissions in the organic treatments occurred without a problematic increase in N_2O emissions (Kramer et al. 2006).

Clarifying the actual extent of the NH_4^+: NO_3^- ratio in organically managed soils, determining how it is influenced by organic fertility inputs, and delineating its significance holds promise in developing management practices that will optimize soil N and C cycling in organic agroecosystems.

Nutrient budgeting — More work is needed to develop nutrient budgets for a wide variety of cropping sequences under differing climatic and soil conditions. Researchers have begun to develop nutrient budgeting tools that estimate nutrient inputs and losses from biologically managed systems. Goldstein (2003) developed a nutrient budgeting tool for corn production systems in the upper Midwest, but had to make assumptions about certain soil nutrient parameters, specifically mineralizable N levels, for it to work. (He also reports that it was not easy to measure the active organic C pool in soils.) Goldstein derived coefficients to estimate how much N and C from different amendments, including manures and plant residues, would be retained and mineralized. Using these and actual field measurements, he developed a budgeter that can estimate nitrate in the soil at harvest and the amount of surplus N lost or immobilized during the growing season.

Along similar lines, researcher Laurie Drinkwater at Cornell University has been working with organic growers in the Northeast to develop nutrient budgets for organic cropping systems based on "mass balancing." This system analyzes nutrient inputs and harvested outputs over a period of years to determine net losses or accumulations of nutrients. Drinkwater has found an excess of nutrients in about half of Northeastern organic vegetable farms. In response, she is developing a nutrient budgeting tool to make it easy for farmers to estimate the nutrient content of their fertility inputs and crop outputs in order to refine their fertility applications. This tool will rely on three databases, two containing data on the nutrient content of various green manures and soil amendments, and one that includes nutrient content levels of common crops grown in the region so that farmers can calculate nutrient exports for yields that leave the farm (Drinkwater et al. 2005).

Crop rotations and cover crops

While there is a huge scientific literature on crop rotations and cover crops, more work is needed to better understand their effects on soil microbial life, soil fertility, and disease resistance in organic cropping systems.

Karlen et al. (2006) conducted a study to determine if extended crop rotations that include forages improve soil quality, and whether they are they profitable. This work provides a good model of research that includes economic analyses of the rotations, thus offering tangible information on profitability to growers. The researchers found that extended rotations in conventional cropping systems had a positive effect on soil quality indicators, with total organic C being the most sensitive indicator of soil quality (Karlen et al. 2006). They created a soil quality index and found that continuous corn had the lowest soil quality index, while extended rotations that included at least three years of forage crops scored highest in soil quality.

A study of conventional potato cropping systems by Larkin (2003) compared the effects of two-year and three-year rotations that included barley with continuous potato production and found that different crop rotations have distinctive measurable effects on soil microbial communities. Including barley in the rotation resulted in increased bacterial biomass, specifically of plant-beneficial groups of microorganisms such as actinomycetes, fluorescent pseudomonads, and *Trichoderma* spp.

Soil quality and soil health

During the past 15 years, the concepts of soil quality and soil health have increasingly marked scientific discussions about sustainable soil management. The characterization of soil quality provides a framework for defining soil health. Commonly identified soil quality indicator properties include the soil's physical traits of soil texture, topsoil and rooting depth, bulk density, water infiltration rate, water-holding capacity, and aggregate stability; and the soil's chemical properties of pH, electrical conductivity, cation-exchange capacity, organic matter levels, exchangeable potassium, and exchangeable calcium (Doran and Parkin 1996). The soil's biological properties that indicate soil quality are to date less well characterized. These properties include mineralizable nitrogen, microbial biomass carbon and nitrogen, microbial activity measurements, earthworm populations, enzymes, and disease suppressiveness (Mitchell et al. 2000; Doran and Parkin 1996).

Work has been ongoing to develop soil quality indices that integrate various combinations of a soil's physical, chemical, and biological traits into a single value (see, e.g., Halvorson et al. 1997, Jaenicke and Legnick 1999, Karlen et al. 2006). Ferris et al. (2001) have developed nematode faunal analysis as a useful and easily derived indicator of soil quality, based on the fact that nematode populations fall into distinct indicator guilds depending on the structure and function of the soil food web. Such integrative measurements can be useful to organic farmers, particularly if straightforward field tests or inexpensive soil testing services can be offered.

Developing microbial counting methods

Despite the importance of the soil microbial dynamic, current methods in soil microbial ecology are only now starting to identify the species of microorganisms that control rates of specific N transformations (Jackson, pers. comm.). Microbial soil life has resisted characterization for so long because fewer than 10% of the microbial species are culturable using traditional lab methodologies.

Researchers have developed methods of characterizing soil microbial communities in three major categories, based on the type of information they generate. For counting microbial communities, plate counts and direct microscopy have been used; for measuring biological activity, researchers measure respiration or nitrification rates; for counting cellular constituents, researchers measure the amount of carbon in microbial biomass, or lipids, or nucleic acids (Scow 1997).

To differentiate microbial communities between farming systems, particularly organic compared to conventional, phospholipid fatty acid (PLFA) analysis has been useful (Bossio et al. 1998; Burger et al. 2005; Cavagnaro et al. 2006). As DNA sequencing technology advances, it is being applied to detecting and analyzing soil microbial communities. Soil DNA methods mainly focus on the variation within groups of specific microbial taxa, but progress is now being made in identifying the abundance of these populations (Okano et al. 2004).

None of these methods should be considered to be stand-alone techniques for characterizing soil communities. Widmer et al. (2001) compared three methods of evaluating the biological characteristics of soils: community DNA with polymerase chain reaction (PCR) and restriction fragment length polymorphism (RFLP); community PLFAs with gas chromatography and mass spectrometry; and community-level substrate utilization (CLSU) with commercially produced gram-negative plates. The authors found that all methods gave highly reproducible results, but not all of the methods correlated with the analysis of the soil communities given by cluster analysis. The authors suggest that conclusive biological soil characterization requires more than one method of analysis.

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Citations

Bossio, D.A., K.M. Scow, N. Gunapala, and K.J. Graham. 1998. Determinants of soil microbial communities: effects of agricultural management, season, and soil type on phospholipid fatty acid profiles. Microbial Ecology 36:1-12.

Burger, M. and L.E. Jackson. 2004. Plant and microbial nitrogen use and turnover: rapid conversion of nitrate to ammonium in soil with roots. Plant and Soil 266:289-301.

Burger, M., and L.E. Jackson. 2003. Microbial immobilization of ammonium and nitrate in relation to ammonification and nitrification rates in organic and conventional cropping systems. Soil Biology & Biochemistry 35:29–36.

Burger, M., L.E. Jackson, E.J. Lundquist, D.T. Louie, R.L. Miller, D.R. Rolston, and K.M. Scow. 2005. Microbial responses and nitrous oxide emissions during rewetting and drying of agricultural soil under organic and conventional management. Biology and Fertility of Soils 42:109-118.

Cavagnaro, T., L.E. Jackson, J. Six, H. Ferris, S. Goyal, D. Asami, and K.M. Scow. 2006. Arbuscular mycorrhizas, microbial communities, nutrient availability, and soil aggregates in organic tomato production. Plant and Soil 282:209-225.

Clark, M.S., K. Scow, H. Ferris, S. Ewing, J. Mitchell, and W. Horwath. 1998. Evaluating soil quality in organic, low-input, and conventional farming systems. Sustainable Agriculture Farming Systems Project Bulletin 2:1-3. Online at http://safs.ucdavis.edu/historical/newsletter/quality.pdf

Davis, J.R., O.C. Huisman, D.O. Everson, and A.T. Schneider. 2001. Verticillium wilt of potato: a model of key factors related to disease severity and tuber yield in southeastern Idaho. Amer. J. of Potato Res. 78:291-300.

Doran, J.W., and T.B. Parkin. 1996. Quantitative indicators of soil quality: a minimum data set. In Doran, J.W., and A.J. Jones, eds. Methods for assessing soil quality. pp. 25-37. Soil Sci. Soc. of America Special Publication No. 49. Madison, WI: Soil Science Society of America.

Drinkwater, L.E., and S.S. Snapp. 2007. Nutrients in agroecosystems: rethinking the management paradigm. Advances in Agronomy. 92:163-186.

Drinkwater, L.E., S. Williams, and S. Vanek. 2005. On-farm nutrient budgets in organic cropping systems. Final report submitted to the Organic Farming Research Foundation, Santa Cruz, California.

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

Drinkwater, L.E., D.K. Letourneau, F. Workneh, A.H.C. van Bruggen, and C. Shennan. 1995. Fundamental differences between conventional and organic tomato agroecosystems in California. Ecol. Apps. 5: 1098-1112.

Ferris, H., T. Bongers, and R.G.M. de Goede. 2001. A framework for soil food web diagnostics: extension of the nematode faunal analysis concept. Applied Soil Ecology 18:13-29.

Fließbach, A., and P. Mäder. 1997. Carbon source utilization by microbial communities in soils under organic and conventional farming practice. In Insam, H., and A. Rangger, eds. Microbial communities—functional versus structural approaches. pp. 109-120. Berlin: Springer-Verlag.

Franke-Snyder, M., D.D. Douds, L. Galvez, J.G. Phillips, P. Wagoner, L. Drinkwater, and J.B. Morton. 2001. Diversity of communities of arbuscular mycorrhizal (AM) fungi present in conventional versus low-input agricultural sites in eastern Pennsylvania, USA. Applied Soil Ecology 16:35-48.

Goldstein, W. 2003. Developing and testing nutrient and organic matter budgeting and practices that will reduce the leaching of nutrients into surface and groundwaters. In The Wisconsin Integrated Cropping Systems Trial—Ninth Report. pp. 82-105.

Halvorson, J.J., J.L. Smith, and R.I. Papendick. 1997. Issues of scale for evaluating soil quality. J. Soil Water Conserv. 52:26-30.

Jaenicke, E.C., and L.L. Lengnick. 1999. A soil-quality index and its relationship to efficiency and productivity growth measures: two decompositions. Am. J. of Agric. Econ. 81: 881-893.

Kramer, S.B., J.P. Reganold, J.D. Glover, B.J.M. Bohannan, and H.A. Mooney. 2006. Reduced nitrate leaching and enhanced denitrifier activity and efficiency in organically fertilized soils. Proc. Nat. Acad. Sci. 103:4522-4527.

Larkin, R.P. 2003. Characterization of soil microbial communities under different potato cropping systems by microbial population dynamics, substrate utilization, and fatty acid profiles. Soil Biol. and Biochem. 35:1451-1466.

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

ORGANIC FARMING RESEARCH FOUNDATION

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

Mitchell, J., M. Gaskell, R. Smith, C. Fouche, and S.T. Koike. 2000. Soil management and soil quality for organic crops. UC ANR Publication 7248. Online at http://anrcatalog.ucdavis.edu/pdf/7248.pdf

Okano, Y., K.R. Hristova, C.M. Leutenegger, L.E. Jackson, R.F. Denison, B. Gebreyesus, D. LeBauer, and K.M. Scow. 2004. Application of real-time PCR to study effects of ammonium on the population size of ammonia-oxidizing bacteria in soil. Applied and Environmental Microbiology 70:1008-1016.

Peel, M.D. 1998. Crop rotations for increased productivity. North Dakota State Univ. Extension Publication No. EB-48. Online at http://www.ag.ndsu.edu/pubs/plantsci/crops/eb48-1.htm

Phelan, P.L. 2004. Connecting belowground and aboveground food webs: the role of organic matter in biological buffering. In Magdoff, F., and R.R. Weil, eds. Soil organic matter in sustainable agriculture. pp. 199-225. Boca Raton: CRC Press.

Phelan, P.L. 1997. Soil-management history and the role of plant mineral balance as a determinant of maize susceptibility to the European corn borer. Biol. Agric. and Hort. 15:25-34.

Phelan, P.L., J.F. Mason, and B.R. Stinner. 1995. Soil-fertility management and host preference by European corn borer, *Ostrinia nubilialis* (Hubner), on *Zea mays* L.: A comparison of organic and conventional chemical farming. Agric. Ecosyst. and Env. 56: 1-8.

Reganold, J.P., J.D. Glover, P.K. Andrews, and H.R. Hinman. 2001. Sustainability of three apple production systems. Nature 410:926-930.

Romig, D.E., M.J. Garlynd, and R.F. Harris. 1996. Farmer-based assessment of soil quality: a soil health scorecard. In Doran, J.W., and A.J. Jones, eds. Methods for assessing soil quality. pp. 39-60. Soil Sci. Soc. of America Special Publication No. 49. Madison, WI: Soil Sci. Soc. of America.

Schonbeck, M. 2000. Soil nutrient balancing in sustainable vegetable production. Final report to the Organic Farming Research Foundation, Santa Cruz, CA. Online at http://ofrf.org/funded/reports/schonbeck_00-10.pdf

Scow, K.M. 1997. Soil microbial communities and carbon flow in agroecosystems. In Jackson, L.E., ed. Ecology in agriculture. p. 367-413. San Diego, CA: Academic Press.

Temple, S. 2003. The transition from conventional to low-input or organic farming systems: soil biology, soil chemistry, soil physics, energy utilization, economics and risk. Annual report to SARE, presenting SAFS final results. Online at http://www.sare.org/reporting/report_viewer.asp?pn=SW99-008&ry=2003&rf=1

Walz, E. 1997. Final results of the third biennial national organic farmers' survey. Santa Cruz, CA: Organic Farming Research Foundation. Online at http://ofrf.org/publications/pubs/3rdsurvey_results.pdf

Wander, M.M., S.J. Traina, B.R. Stinner, and S.E. Peters. 1994. Organic and conventional management effects on biologically active soil organic matter pools. Soil Sci. Soc. Am. J. 58:1130-1139.

Widmer, F., A. Fließbach, E. Laczko, J. Shulze-Aurich, and J. Zeyer. 2001. Assessing soil biological characteristics: a comparison of bulk soil community DNA-, PLFA-, and Biolog-analyses. Soil Biol. and Biochem 33:1029-1036.

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Chapter 2

Systemic Management of Plant Pests: Weeds, Insects, and Diseases

Paul Bousquet

Summary of Research Goals

Pest control research has traditionally focused on the pest itself, looking for ways to eliminate a weed, insect, or disease by disrupting its breeding cycle, eliminating its habitat, or killing it outright with pesticides. Developing methods for systemic biocontrol of pests requires that the researcher pull back and take a broader view of the farm, shifting the frame of reference to the farm as an ecosystem and looking for ways to enhance soil health, microbial soil communities, and other conditions that will improve overall crop resistance to pests. The research outcomes presented here reflect an approach to pest control research that will help growers create the healthiest possible environment for crop production, and develop specific pest control techniques to use when necessary to prevent major economic losses.

Broad Research Outcomes

- In general, research is needed to understand and develop management systems that shift the focus of pest management from use of external inputs to internal biological controls arising from the system itself, leading to whole farm systemic resistance to weeds, insects, and diseases.
- Continued study and documentation of pest life cycles and their spatial and temporal relationships to natural hosts, prey, and predators. This is particularly important for developing "organic IPM" protocols and, taking a wider view, bioregion-specific organic crop and pest management strategies.
- Refinement of methods to study the role of above- and below-ground biodiversity to nurture and sustain landscape level habitat conditions that accommodate beneficial organisms and suppress economically significant pest infestations
- Crop breeding programs that select for disease and insect resistance in biologically diverse systems.

Basic Research Needs

Weeds

- Conduct research on weed species biology and ecology to better understand seed bank dynamics, predict the timing of weed emergence, and establish optimal intervention periods in weed life cycles.
- Determine relationships between weed species and soil nutrient balance.
- Identify critical periods for weed control in different crops.
- Analyze the effect of interactions between biocontrol agents and other organisms on weed performance through competition, interference, predation, parasitism, and disease (Liebman et al. 2001).
- Establish techniques to manipulate microbial communities with the goals of reducing weed seed survival, seedling establishment, competitive ability, and reproduction (Liebman et al. 2001).
- Analyze allelopathic mechanisms and their impacts on weed germination, growth, and competitive ability.
- Develop models of weed population dynamics under different cover crop, tillage, and crop rotation management strategies.
- Develop optimal farm landscape plantings (farmscaping) to provide habitat for weed biocontrol agents.

Insects

- Optimize plant species mixes and planting strategies for hedgerows and buffers to provide habitat for natural enemies of crop pests.
- Develop importation strategies and habitat manipulations to maximize the effect of competitors, predators, parasites, and pathogens as biocontrol agents.
- Determine long-term soil and human health effects of applying pesticides that are compliant with the organic standards, such as sulfurs, petroleum oils, copper fungicides, and botanicals.

Diseases

- Evaluate the effect of compost and compost extracts on plant growth, yield, and disease suppression.

Applied Research Needs

Weeds

- Refine cover crop and green manure systems to suppress weeds and enhance soil fertility, including the use of multi-species cover crops and interplanting covers into standing crops.
- Evaluate the effectiveness of various crop rotation strategies in suppressing annual and perennial weeds.
- Identify effective control methods favoring systemwide approaches for specific difficult-to-control annual and perennial weeds such as bindweed, foxtail, pigweed, quackgrass, Bermuda grass, nutsedge, lambsquarters, Canada thistle, and *Galinsoga*.
- Determine how to manage nitrogen applications to optimize crop yields and minimize weed growth.
- Determine the effects of different methods and timing of cover crop take down, seedbed preparation, pre- and post-emergence crop cultivation, and post-harvest tillage on weed seed germination, seed destruction by predators, and resurgent growth of perennials.
- Identify the impacts of native pathogens on weed seeds and weed growth through classical and bioherbicide (augmentation) biocontrol methods
- Develop reduced- and no-tillage organic systems, and design new machinery to implement these systems.
- Compare the efficacy of specific tillage implements in controlling weeds with respect to such factors as timing of operations, ability to handle surface organic matter residues, soil moisture conditions, driving speed, and number of passes.
- Develop weed flaming protocols and safety standards.
- Determine the role of single and multi-species grazing of pastures, fallow fields, and crop residues for weed suppression.

Insects

- Develop cultural practices to activate induced systemic resistance in crops.
- Develop composts and compost teas to stimulate plant immune response by manipulating feedstocks, preparation methods, or microbial composition of the finished product.
- Evaluate the effectiveness and impact on whole farm ecology of using botanical and other insecticides compliant with the organic standards.
- Identify effective control methods favoring systemwide approaches for hard-to-control insects such as flea beetle, codling moth, aphids, thrips, stinkbug, yellow margin leaf beetle, corn borer, soybean aphid, and other virus vectors (such as white flies and aphids).

Diseases

- Explore how to manage soil microbial dynamics to enhance nutrient cycling and to develop disease-suppressive soils.
- Develop systems to produce healthy seedlings for transplanting.
- Evaluate biological seed treatments and conditioners for fungus control.
- Develop effective control methods for difficult to control diseases such as Asian soybean rust, powdery mildew, late blight (*Phytophthora*), blight, early blight (*Alternaria*), and mildew.
- Develop alternatives to copper and sulfur fungicides in organic production.

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Growers' Perspectives on Management of Plant Pests

Managing weeds, insects, and diseases is a primary challenge for organic growers. Farms are exposed to a continual influx of pollen, seeds, insects, and spores that arrive from many different routes: blown in on the wind, carried in rain or irrigation water, or transported by a variety of creatures including birds, mammals, and humans. Each of these has the potential to settle into a niche on the farm and develop into a pest, either competing with the crop for resources or directly feeding on or otherwise damaging the crop. Table 1 presents the five most commonly reported weed, insect, and disease pests by a cross-section of U.S. organic farmers polled in 1995.

Many organic growers and scientists who study organic systems think that a detailed understanding of the chemical and physical interactions within the farm's soil microbial community is the key to pest suppression. Experienced modern organic practitioners, who perceive their farms as functioning ecosystems, use ecological, systems-based approaches to managing pests. Rather than routinely apply protective materials, most organic practitioners use a combination of pest management strategies (see Table 2). In fact, they are required to do so under the National Organic Standards, which state, "The producer must use management practices to prevent crop pests, weeds, and diseases" [§205.206] (NOP 2002). The Standards present a menu of cultural practices that should be used before resorting to application of a "substance" to prevent or control pests, weeds, or diseases. This is another reason why meaningful organic research needs to be conducted under certified organic conditions, and why systems approaches are most needed to study organic agriculture.

Crop rotation is the most commonly used practice for organic pest control for two main reasons: crop rotation can disrupt weed, insect, and pathogen life cycles; and crop rotation improves soil quality,

Table 1. The five most commonly reported weed, insect, and disease pests by a cross-section of U.S. organic farmers polled in 1995 (data from Walz 1997).

Ranking	Weeds	Insects	Disease
1	Foxtails	Cucumber beetle	Powdery mildew
2	Pigweed	Flea beetle	Late blight (*Phytophthora)*
3	Quackgrass	Aphids	Blight
4	Grasses, in general	Colorado potato beetle	Early blight *(Alternaria)*
5	Lambsquarters	Codling moth	None

Table 2. The five most commonly reported weed, insect, and disease management practices by a cross-section of U.S. organic farmers polled in 1995 (data from Walz 1997).

Ranking	Weeds*	Insects	Disease
1	Mechanical tillage	Crop rotation	Crop rotation
2	Hand labor/handheld implements	Beneficial insect habitat	Resistant varieties
3	Crop rotation	Beneficial vertebrate habitat	Compost or compost tea
4	Cover crops	*Bacillus thuringiensis (Bt)*	Companion planting
5	Mulches	Beneficial insect, mite or nematode release	Sulfur or sulfur-based materials

*a statistically equivalent number of respondents reported they used the top three practices: 75% each.

which results in healthier plants. Crop rotation broadly stated can include any type of intentional crop diversity, such as sequential rotation, cover cropping, intercropping, relay cropping, use of living mulches, etc. Crop rotation is a management practice that can perform multiple functions on the farm, including providing a nutrient source, building organic matter, managing pests, and controlling erosion. Many organic practitioners have devised highly diverse multi-year rotations that are carefully designed to build soil quality, minimize pest niches, and optimize productivity and profitability. Many of these rotations involve periods of pasture and thereby bring the advantages of integrated crop and livestock production, including generation of on-farm nutrients and higher levels of biodiversity, to the system.

Many producers observe that aboveground plant diversity is related to belowground microbial diversity and soil health, which together result in enhanced health and quality of their crops.[1] One reason for the popularity of compost and compost tea for disease control is the presumed high populations of active beneficial microbes found in these materials. By competing with pathogenic microorganisms, compost and water extracts of compost (or compost tea) have been shown to reduce disease incidence and enhance plant health (see, e.g., Hoitink et al. 1997; Scheuerell and Mahaffee 2002). Soil microbiologist Elaine Ingham has popularized an understanding of the belowground "soil food web" in the modern organic farming community, and has developed a theory of how compost tea works that offers rich research opportunities (Ingham 2003).

Monitoring weather, scouting pest populations, and being aware of pest-conducive conditions is also fundamental to organic crop management. Integrated pest management or IPM uses monitoring and scouting to assess pest populations and determine when pest control interventions

[1] These ideas are not new, and have been eloquently set forth by earlier organic theorists such as Sir Albert Howard (Howard 1947).

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are required. If pests are at levels below an economic threshold (defined as a threshold at which economically significant crop damage occurs), no control action is taken; if pest populations threaten economic damage, control is applied. While IPM has been criticized as having "pesticide management objectives rather than pest management objectives" (Lewis et al. 1997), there is a role for "organic IPM" based on thorough knowledge of the biology of crop, insect, and disease species, pest predators, and the soil health conditions that inhibit or nurture their populations.

Much of the information on pest life cycles and their relationship to growing-degree-days has already been compiled, and the largest challenge has been placing the information into producers' hands at critical times when pest management is needed. However, as the Earth experiences prolonged climatic disruption, the delicate balance between insect populations and weather-related cues could be severely affected, to the point where new basic studies might soon be needed on the ways that insects are adapting to the changing climate and modifying their heretofore predictable patterns.

Recent research is addressing ways to manage aboveground biodiversity to regulate pest populations, including use of beetle banks to control crop-damaging larvae (Prasad et al. 2002), attracting wild birds to control insect pests (Jones and Sieving 2003), and utilizing vegetational corridors and flowering hedgerows to attract beneficial insects (Nicholls and Altieri 2004). These strategies are clearly linked to specific management practices.

The link between management practices and cultivating desirable levels of belowground biodiversity is not so clear; however, as molecular methods for identifying microbial communities and their functional attributes improve, goals such as intentionally designing crop rotations to "manage the resident microbial and rhizosphere communities" (Drinkwater and Snapp 2007) become attainable. An important organic research goal is for investigators and farmers to link specific management practices to cultivation of particular soil communities that enhance crop health and support whole farm systemic resistance to pest threats. Such an inductive approach may be contrary to traditional, deconstructionist pest management analyses, but better reflects how organic growers frame pest control challenges.

Because most organic crop growers operate on the premise that high quality soils are healthy soils, which yield healthy plants that are able to resist insect and disease pests and produce high-quality food, the relationships between above and belowground biodiversity, soil quality, plant health, systemic pest resistance, and crop quality need to be much more clearly elucidated by modern science.

In addition, organic growers want emergency treatments to be available in case a pest infestation threatens total loss, and therefore there is a place for development and testing of pest control materials that are compliant with the organic standards. Pest control materials can be an important complement to systems management. However, the preferred approach is to know how to manage elements of organic farming systems in order to minimize the ecological opportunity for pests to proliferate and cause damage.

Scientific Context

A growing body of scientific data supports the insight of organic growers that management practices directly affect soil quality parameters, which in turn influence plant health. A groundbreaking study was published by Kumar et al. in 2004, in which a hairy vetch cover crop was shown to differentially turn on metabolic pathways in tomato plants compared to plants grown under black plastic mulch. In the study, tomatoes grown after hairy vetch lived longer, had reduced disease incidence, and had delayed leaf senescence compared with tomatoes grown under plastic mulch. The investigators associated these results with differential gene expression triggered by the management practices, resulting in different levels of metabolic proteins in plant tissues. The authors state that the nature of the signal that determines the gene expression profiles has yet to be determined (Kumar et al. 2004).

If scientists are correct, the ability of crops to resist insect and disease attacks may arise from activity in the rhizosphere mediated by soil organic matter. The nature of signaling mechanisms is likely to be complex. It appears as if molecular signaling between plant roots and rhizobacteria occurs, as well as both antagonistic and cooperative activities amongst rhizosphere species (Cook et al. 1995). It is becoming increasingly clear that plants play an active role in determining the composition of microbial species in the rhizosphere, a relationship that provides opportunities to breed plants for traits—such as root architecture or exudate profile—that are synergistic with desirable rhizosphere communities (Drinkwater and Snapp 2007).

Substrate-dependent disease suppression has been thoroughly reviewed recently, and the authors present considerable evidence to support the notion that different amounts and quality of organic matter mediate general disease suppression (Stone et al. 2004); however, the active role of organic matter in these interactions needs much more investigation. Clearer characterization of organic matter fractions and their functions is also needed.

Phelan (2004) has developed a theory of biological buffering, in which a sustained influx of soil organic matter into the cropping system provides a resource base for the soil microbial community. The organic matter decomposers in the soil food web modulate mineral availability. Soils rich in organic matter mitigate changes in nutrient flow, moisture, and energy use, supporting greater stability in microbial population levels. Phelan suggests that a "more active" soil food web bestows greater crop resistance to insect and pathogen attacks (Phelan 2006).

A complex, diverse community of mostly unidentified bacterial and fungal species comprises a healthy and active, organically-managed soil food web population. Compant et al. (2005) review plant growth-promoting bacteria and discuss their role in producing allelochemicals and inducing systemic resistance to pathogens in host plants. Most studies of the role and function of these organisms have focused on plant growth-promoting rhizobacteria (PGPR), some of which are free-living within the rhizosphere while others establish populations on the surface of or even within plant roots. The chemical environment of the rhizosphere is influenced by root exudates – primarily organic acids, amino acids, and sugars. Organisms able to thrive in that environment would gain an ecological niche advantage. Thus the extent to which soil management nurtures rhizosphere conditions conducive to PGPR populations is an area of investigation that merits significant attention. These conditions will be strongly influenced by soil structure, crop type, tillage and fertility regimes, climate, and moisture levels.

The potential application of fungi to induce systemic resistance to crop plant pathogens has been long recognized because of the well-known mycoparasitic qualities of the fungus *Trichoderma* spp. (Chet et al. 2006). Other fungi that have demonstrated debilitating effects toward specific plant pathogens include *Gliocladium* spp., *Pythium oligandrum*, *Talaromyces flavus*, *Coniothyrium minitan*s, and *Ampelomyces quisqualis* (Brimner and Boland 2003). Disease control by *Trichoderma* spp. fungi is primarily due to the production of antibiotics or the secretion of enzymes that degrade the cell walls of fungi that are harmful to plant health (Chet et al. 2006). Some *Trichoderma* spp. may in addition penetrate plant roots and alter the biochemical makeup of the plant, which could account for induced systemic resistance in the colonized plants. Biocontrol microorganisms utilize numerous other mechanisms to suppress antagonists, including competing for nutrients, mobilizing soil nutrients for the host plant's uptake and use, manufacturing and secreting antibiotic or antifungal metabolites, and forming physical barriers against attack (Weller et al. 2002; Brimner and Boland 2003). Microbial biocontrol processes can be complex: in one example, disease suppression arises from the combined action of two types of microorganisms, each of which competes with a pathogenic fungus for a different nutrient (cited in Weller et al. 2002).

Well-documented cases of disease suppressiveness occur in monoculture systems, raising questions about the role of belowground biodiversity (Cook et al. 1995). A long-term organic comparison study showed that after 18 years, microbial biomass was significantly higher in organic rather than conventional soils; however, higher microbial diversity in organic plots was only found in a single season. This finding prompted the authors to state "the hypothesis that differences due to community energetics are explainable by functional richness and diversity of the soil microbial community needs further examination" (Fließbach and Mäder 1997).

Liebman et al. (2001) published a useful book for farmers and researchers on the ecological management of agricultural weeds that summarizes the literature and describes numerous areas where basic and applied research into ecological weed control is needed. The authors note that basic ecological data are lacking for many weed species and present other specific research needs, including managing weeds with insects and pathogens, reducing seed bank size via seed predation, documenting seed longevity in the soil, evaluating the effects of soil condition on seed survival, determining the response of seed growth rate to environmental factors, breeding crops for improved ability to compete against weeds, and developing methods for preserving residue at the soil surface during tillage.

There is a growing body of evidence that bacterial and fungal biocontrol agents can play significant roles in suppressing weeds within organic farming systems (Yandoc et al. 2004). While research is needed to determine which types of beneficial bacteria and fungi are most effective for biocontrol under specific soil, climate, and crop management conditions, scientists and producers should resist the temptation to investigate these tools within an input-substitution model of organic crop management. One perspective is that "what is lacking is not biocontrol organisms but the environment that supports high populations and activities related to biological control" (Stone et al. 2004). Some of the problems accompanying input-substitution models include the fact that field applications of PGPR are often marked by "poor rhizosphere competence" and compromised root colonization in the presence of indigenous microflora

(Compant et al. 2005), and that the proliferation of biological control fungi may pose potential risks to other beneficial soil organisms, particularly mycorrhizal and non-target saprophytic fungi (Brimner and Boland 2003).

To determine any correlation that may exist between the effectiveness of biocontrol microorganisms and soil quality indicators would be a key contribution to practical knowledge about biocontrol.

Citations

Brimner, T.A., and G. J. Boland. 2003. A review of the non-target effects of fungi used to biologically control plant diseases. Agric., Ecosyst. and Env. 100:3-16.

Chet, I., A. Viterbo, and Y. Brotman. 2006. Plant biocontrol by *Trichoderma* spp. Online document posted at http://www.weizmann.ac.il/Biological_Chemistry/scientist/Chet/Chet.html

Compant, S., B. Duffy, J. Nowak, C. Clément, and E.A. Barka. 2005. Use of plant growth-promoting bacteria for biocontrol of plant diseases: principles, mechanisms of action, and future prospects. Applied and Environmental Microbiology 71:4951-4959.

Cook, R.J., L.S. Thomashow, D.M. Weller, D. Fujimoto, M. Mazzola, G. Bangera, and D. Kim. 1995. Molecular mechanisms of defense by rhizobacteria against root disease. Proc. Natl. Acad. Sci. 92:4197-4201.

Drinkwater, L.E. and S.S. Snapp. 2007. Understanding and managing the rhizosphere in agroecosystems. In Cardon, Z., and J. Whitbeck, eds. The Rhizosphere—an ecological perspective. San Diego, CA: Elsevier Academic Press.

Fließbach, A., and P. Mäder. 1997. Carbon source utilization by microbial communities in soils under organic and conventional farming practice. In Insam, H., and A. Rangger, eds. Microbial communities: functional versus structural approaches. pp. 109-120. Berlin: Springer-Verlag.

Hoitink, H.A.J., A.G. Stone, and D.Y. Han. 1997. Suppression of plant diseases by composts. HortScience 32:184–187.

Howard, A. 1947. The soil and health: a study of organic agriculture. New York: Devin-Adair Co.

Ingham, E. 2003. Compost tea: promises and practicalities. Acres USA Vol. 33 No. 12. Dec. Online at http://www.acresusa.com/toolbox/reprints/Dec03_Compost%20Teas.pdf

Jones, G.A., and K. Sieving. 2003. Intercropping to create local refugia for natural enemies of arthropod pests: flowers and birds in organic agroecosystems. Final report submitted to Organic Farming Research Foundation, Santa Cruz, CA. Online at http://www.ofrf.org/publications/Grant%20reports/03.s.33.Sieving.Jones.pdf

Kumar, V., D.J. Mills, J.D. Anderson, and A.K. Mattoo. 2004. An alternative agriculture system is defined by a distinct expression profile of select gene transcripts and proteins. Proc. Natl. Acad. Sci. 101:10535-10540.

Lewis, W.J., J.C. van Lenteren, S.C. Phatak, and J.H. Tumlinson III. 1997. A total system approach to sustainable pest management. Proc. Natl. Acad. Sci. 94:12243-12248.

Liebman, M., C.L. Mohler, and C.P. Staver. 2001. Ecological management of agricultural weeds. Cambridge: Cambridge Univ. Press.

Nicholls, C.I., and M.A. Altieri. 2004. Designing species-rich, pest-suppressive agroecosystems through habitat management. Agroecosystems Analysis 43: 49-61.

NOP. 2002. Final Rule with request for comments. Online at http://www.ams.usda.gov/NOP/NOP/standards/FullText.pdf

Phelan, P.L. 2004. Connecting belowground and aboveground food webs: the role of organic matter in biological buffering. In Magdoff, F., and R.R. Weil, eds. Soil organic matter in sustainable agriculture. pp. 199-225. Boca Raton: CRC Press.

Phelan, L. 2006. Biological buffering vs. the Green Revolution: is modern agriculture exempt from the laws of ecology? Abstract for presentation at the ASA-CSSA-SSSA International Annual Meetings (November 12-16, 2006). Online at http://a-c-s.confex.com/crops/2006am/techprogram/P22852.HTM

Prasad, R., D. Henderson, and W. Snyder. 2002. Biological control of *Delia* spp. in cole crops with the rove beetles, *Aleochara* spp. and other natural enemies. Final report submitted to Organic Farming Research Foundation, Santa Cruz, CA. Online at http://www.ofrf.org/publications/Grant%20reports/01.s.27.Prasad.pdf

Scheuerell, S., and W. Mahaffee. 2002. Compost tea: principles and prospects for plant and disease control. Compost Sci. and Util. 10:313-338.

Stone, A.G., S.J. Scheuerell, and H.M. Darby. 2004. Suppression of soilborne diseases in field agricultural systems: organic matter management, cover cropping, and other practices. In Magdoff, F., and R.R. Weil, eds. Soil organic matter in sustainable agriculture. pp. 131-177. Boca Raton: CRC Press.

Walz, E. 1997. Final results of the third biennial national organic farmers' survey. Santa Cruz, CA: Organic Farming Research Foundation.

Weller, D.M., J.M. Raaijmakers, B.B. McSpadden Gardener, and L.S. Thomashow. 2002. Microbial populations responsible for specific soil suppressiveness to plant pathogens. Annu. Rev. Phytopathol. 40:309-348.

Yandoc, C.B., E.N. Rosskopf, and C.T. Bull. 2004. Weed management in organic production systems. In Lartey, R.T., and A. Caesar, eds. Emerging concepts in plant health management. Kerala, India: Research Signpost.

Yandoc-Ables, C.B., E.N. Rosskopf, and R. Charudattan. 2006. Plant pathogens at work: progress and possibilities for weed biocontrol. Online at http://www.apsnet.org/online/feature/weed1

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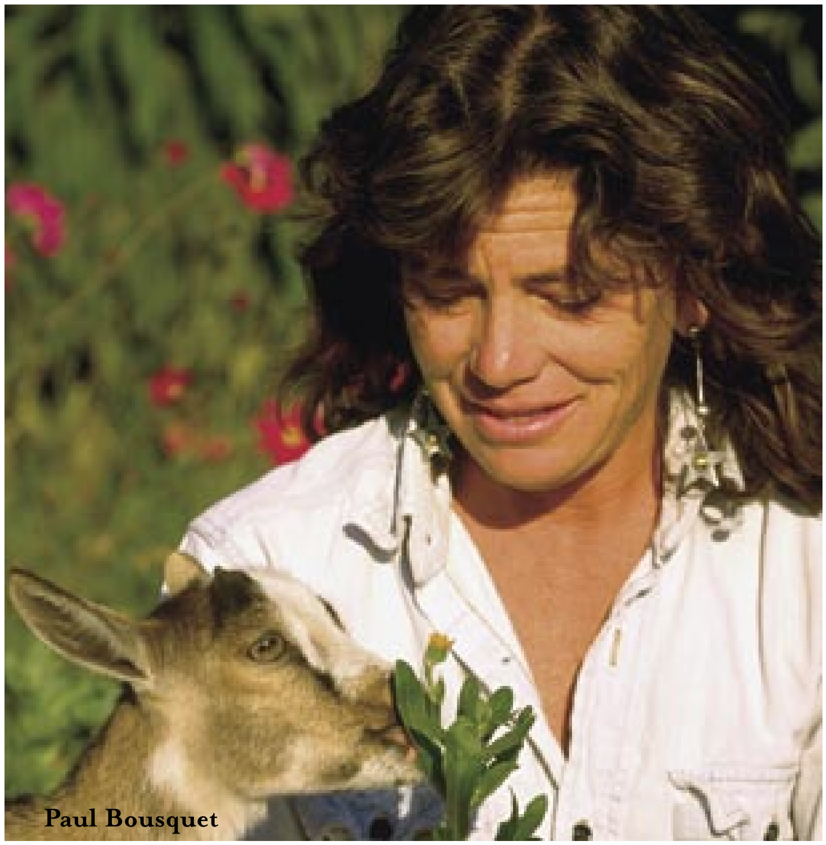
Chapter 3

Organic Livestock and Poultry Management Systems


Paul Bousquet

Summary of Research Goals

Rapid growth in the organic livestock and poultry sectors reflects heightened demand for organic meat, dairy, and egg products, but production challenges persist due to a lack of well-funded research efforts targeted at specific animal health care, pasture management, and nutrition issues. Producers rank animal health care as their highest priority for organic livestock research. Effective disease controls will require systems-based research on intensive grazing management, good nutrition, and strategic use of supplements and preventative treatments. Standard, economically viable rations to complement pasture and provide complete nutrition for all species of livestock and poultry within the constraints of the National Organic Standards also need to be developed. Breeding programs that emphasize adaptability to organic management systems are needed to enhance animal health and productivity.

Broad Research Outcomes

- Technical information sufficient to support increased U.S. production capacity to meet the existing and future demand for organic meat, eggs, and dairy.
- Health care protocols that are compatible with the National Organic Standards for each species of livestock and poultry.
- Standard organic livestock and poultry rations that fully meet animals' nutritional needs.
- Models of economically viable, integrated crop-livestock production systems.
- Identification of economic factors and management practices that reduce the risks of transitioning to organic production

Animal Health

Basic Research Needs

- Develop effective parasiticides for livestock.
- Conduct research on probiotics that could replace pathogenic microbes (in guts, on skin) with beneficial ones.
- Identify sources of amino acids for livestock and poultry rations that are compliant with organic standards.

Applied Research Needs

- Assess the effect of soil microbial communities on forage and pasture quality and any consequent effects on livestock health.
- Document pest and parasite ecology in pastures and determine how to disrupt parasite life cycles through rotation and other practices.
- Develop emergency health care treatments for poultry and livestock that are compliant with the National Organic Standards.
- Develop standard livestock and poultry rations that provide needed levels of amino acids, vitamins, and minerals from organic sources.
- Identify rations and feeding strategies that can reduce incidence of harmful pathogens such as *E. coli* O157:H7 in animals.
- Develop preventative health care practices for poultry and livestock.
- Study the role of water and air quality on poultry and livestock health.

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Crop-Livestock Integration

Basic Research Needs

- Study the effects of grazing crop residues on system health and subsequent crop yields.

Applied Research Needs

- Research the weed, insect, and disease control potential of poultry, hogs, cattle, and other animals grazed in orchard and crop systems.

Pasture Management and Systems Development

Applied Research Needs

- Determine how soil quality relates to forage and feed quality and then to end product quality.
- Assess the effect of soil microbial communities on forage and pasture quality and livestock health.
- Determine what nutritional and other benefits may be derived from consuming organic animal products such as meat, milk, and eggs.
- Develop complete protocols for organic pastured beef, hog, and poultry production systems.
- Evaluate innovative pastured livestock production systems developed in different countries for adaptation to U.S. conditions.
- Explore the role of weeds, native plants, trees, and shrubs in pasture and their potential to provide nutrient or medicinal benefits to livestock.
- Develop biological control methods for invasive and harmful weeds (e.g. star thistle).
- Develop production systems that offer access to the outdoors for different animal species at appropriate life stages, as required by the National Organic Standards.
- Develop management systems that specifically fulfill the animal welfare requirements of the National Organic Standards, and integrate them into all other production protocols.
- Develop hoop house methods for organic hog production that are compliant with the National Organic Standards.

Growers' Perspectives on Organic Livestock and Poultry Management Systems

Animals have played essential roles in agriculture for thousands of years. They provide humans with meat, milk and other dairy products, eggs, wool, and hides. In many parts of the world they still provide traction and transportation. Animals close nutrient cycles in many agroecosystems, most fundamentally by recycling the plants they graze back into nutrient-rich manure.

In the pre-industrial era, U.S. farms commonly produced a wide variety of animal products as well as crops. With increasing specialization in the modern age, animal enterprises have become separated from crop production. Conventional dairy, beef, pork, chicken, and eggs are now produced in highly specialized industrial operations.

Today's organic livestock industry reflects both traditional and modern paradigms of livestock production. Despite market pressures to specialize, organic agriculture is a niche in which highly diversified and well-integrated crop and livestock operations are surviving. At the same time, implementation of the National Organic Standards in 2002 opened the doors for large-scale industrial dairy, chicken, and egg producers to convert to organic management, fueling rapid growth in these organic market sectors. Certified organic livestock numbers increased 572% and organic poultry increased by 1,000% in the six-year period between 1997–2003 (USDA-ERS 2005). This phenomenal growth in organic livestock and poultry production has been accomplished by farmers with little research or marketing support from traditional sources such as land grant institutions or USDA. The organic industry has filled the information gaps largely with grower experience. Despite the best efforts of industry to recruit new farmers into organic dairy and meat production, the U.S. supply of organic meat and dairy is well below market demand.

Animal health care

Maintaining and improving animal health using practices that are compliant with the organic standards is the most pressing area of research in organic livestock and poultry production. A 2004 survey of organic livestock producers' research needs lists health-related topics as five of the top six research priorities (Riddle 2004). Troublesome areas in organic livestock health include internal parasite control for grazing ruminants and mastitis control in dairy cows. Fly management is also an ongoing concern in organic animal husbandry. Each of these topics is a significant issue for conventional producers as well.

There exists a well-established set of farmer-generated organic livestock production protocols that emphasizes intensive management of the livestock and their environment. Producer awareness of the many environmental variables that can affect an animal's health is the starting point for a systems approach to organic livestock production. Factors such as animal genetics, pasture and feed quality, nutrient profiles, stocking rates, housing and bedding quality, access to and quality of water, handling methods, presence of disease vectors (such as flies, rats, and starlings), and facility sanitation can all influence animal health and the quality of animal products. Management also should be tailored to life stage, or age of the animal, as health and nutritional requirements change over the course of an animal's life.

Some livestock health care practices appear to be accepted wisdom rather than scientifically proven techniques. Widespread use of diatomaceous earth (d.e.) to control internal parasites in organic livestock is one practice that is widely used despite the lack of scientific evidence supporting its efficacy (see, e.g., Osweiler 1997; Fernández et al. 1998). But organic livestock and poultry producers seem to find value in feeding d.e., a practice that merits further research into the use of this material. Other alternative health care practices such as using herbs, acupuncture, and homeopathy may also contribute to herd health, and require further study as options in organic livestock and poultry management.

Organic livestock producers work to the greatest extent possible to accommodate the natural behaviors of the cattle, chickens, pigs and other animals that they raise because they understand that stress negatively affects animal health, product quality, and production. Design of housing facilities plays an important role in accommodating natural behaviors and reducing stress. Hoop houses for hogs provide deep bedding in which they can root and forage; chickens benefit from being able to run outside as well as having a protected area to roost. Deep-bedded swine systems additionally may help interrupt parasite and disease cycles. Stocking rates are also important in optimizing production and minimizing stress. While organic livestock producers have their own approaches to these interconnected issues, they will benefit from scientific studies on how best to accommodate animals' natural behaviors and the effects of various housing arrangements and stocking rates on organic livestock health and productivity.

A related issue is animal genetics. The diversity of animal genetics has declined in the United States as a consequence of industrialized animal production that has narrowly focused on selecting traits related to maximizing production efficiency, achieved by rapid weight gain through high feed conversion efficiency and early maturity. The health and adaptability of the animals are secondary considerations if they are considered at all. In contrast, organic livestock producers want animals that are healthy and adaptable to a variety of conditions (see Chapter 4, Genetics and Breeding). The tradeoff for quality seems to be efficiency. Studies show that feed conversion efficiency in organic livestock production as measured by rate of gain is lower than in conventional systems. A study comparing organic and conventional beef production systems found that organic beef had an average daily gain (ADG) of 1.4 kg/day, while conventional beef had an ADG of 1.77 kg/day (Fernández and Woodward 1999). Lower rates of gain have also been found in hoop-house hogs (Gegner 2003) and pastured poultry (Lee 2000).

Pasture quality, soil quality, and nutrition

Pasture is of paramount importance to organic livestock and also many organic poultry producers. Well-managed pasture is considered a cornerstone of maintaining organic animal health. Organic dairy farmer Kathie Arnold describes why pasture has long been known as "Dr. Green": it provides fresh air, sunshine, and exercise for animals; supplies nutrients that aren't found in feed; and, in the case of dairy cows, provides natural hoof trimming (Arnold 2006). The National Organic Standards require that organically raised animals be given access to the outdoors and that ruminants be given access to pasture [§205.239 (a)(1-2)] (NOP 2002). This standard has generated significant controversy, as large-scale dairy and chicken operations entering the industry appear to be circumventing the access requirement in various ways.

Organic livestock producers recognize

that pasture quality is influenced directly by soil quality, which in turn influences product quality. As one example, meat and milk from pastured cows have less fat, more vitamin E, and higher levels of beneficial compounds such as omega-3 and conjugated linoleic fatty acids than grain-finished products (Robinson 2002). More research is needed to determine how soil quality relates to forage and then to end product quality, and what benefits may be derived from consuming organic animal products produced on pasture.

Organic practitioners build soil quality by applying mineral amendments and compost, and by using grazing rotations that allow each paddock a period of rest. Organic producers are careful to seed pastures with ideal combinations of plant species that will provide optimal nutrition throughout the year. Plant species mixtures are also important in hay production.

Alternative livestock researcher Jerry Brunetti champions the benefits of "biodiverse forage," seeding a wide variety of plant species into pasture that provide a spectrum of benefits including nutrients and medicinal properties. Brunetti cites Robert Elliot's "Clifton Park" system, based on the results from a multi-year trial that showed cows giving higher milk yields on a more diverse pasture. Brunetti comments:

> These results make the case that there is more to nutrition than the usual parameters surrounding protein, energy, total digestible nutrients, neutral detergent fiber, acid detergent fiber, and so on. Perhaps the diversity of such a mixture in a paddock provides critical trace elements of various plant hormones, enzymes, aromatic oils, tannins, amino acids, fatty acids, alkaloids, pigments, vitamins and their co-factors, unidentified rumen flora stimulants, etc. ... there is no substitute for diversity; there is no way to quantify all the possible and synergistic interactions among both identifiable and unidentifiable components. (Brunetti 2003)

Because organic livestock and poultry producers are required to use organic feeds and pasture, feed costs are higher in organic production. A 2003 USDA study on organic feed grain availability documented that organic feed costs ranged from 1.57–2.33 times higher than conventional feed costs (USDA 2003). Research is needed to design systems that make organic livestock production economically feasible and to investigate ways to decrease feeding costs. One approach is to investigate how to use byproducts of organic grain milling as alternative feedstuffs for poultry and livestock. For example, researchers at Iowa State have discovered that okara, a byproduct of tofu soybean extraction, holds promise as a protein source for hogs (Hermann and Honeyman 2004).

Developing standard rations to complement pasture and provide complete nutrition using feed ingredients that are compliant with the organic standards for all species of livestock and poultry is a fundamental research need.

Crop-livestock integration

Another important realm of investigation is how to optimally integrate crop and livestock systems in order to maximize profit, enhance soil, water, and air quality, and close nutrient cycling loops in the system to the greatest degree possible. Some excellent models of such systems exist in the carefully designed landscapes of permaculture, and in simpler systems such as the ley system of alternating pasture with crops in a multi-year sequence, a practice that was developed in the early days of British agronomy that has been adapted to many areas worldwide.

While modern-day specialization makes it less likely that a contemporary organic farmer in the U.S. will raise livestock in addition to their crops, some models of integrating crop and livestock operations have been well publicized and adopted by many organic growers. Integrating a pastured livestock and/or poultry operation with a vegetable production system has been popularized by farmer-writers such as Joel Salatin, Herman Beck-Chenoweth, Gene Logsdon, and Andy Lee. Salatin promotes integrating multiple pastured livestock operations (beef, pork, and poultry) with crop production and orchestrating a system in which each type of animal plays a role in the production of the other species.

In Midwestern field crop production, the most common form of crop-livestock integration is to extend the grazing season by putting cattle on corn stalks in the fall. Research conducted in Nebraska and in Iowa shows that grazing on residues does not decrease subsequent corn or soybean yields (Erickson et al. 2001, Clark et al. 2000). Grazing on corn stalks in the spring tended to increase subsequent soybean yields by 1.5 bushels/acre (Erickson et al. 2001). A good extension guide to grazing crop residues was published by Ohio State University Extension (McCutcheon and Samples 2002). More work could help popularize this practice among organic producers.

Another way to integrate animals into cropping systems is to use animal power to control weeds and insect pests. A 1993 University of Missouri Extension publication describes how geese can be effective in controlling weeds in cotton, nursery crops, strawberries, corn, and other crops (Geiger and Biellier 1993). Farmer researcher Jim Koan received OFRF funds to construct "guinea condos" to house guinea hen birds in his organic apple orchard in Michigan, and found that the guinea fowl reduced plum curculio damage in the orchard by 50% compared to a fowl-less control orchard (Koan pers. comm.). Goats are commonly used to browse large areas of land to control noxious weed growth. Animal activity has to be controlled to avoid damaging pasture or crops by overly enthusiastic grazing. While many anecdotal accounts exist on the best way to manage livestock for weed and insect pest control, this topic could be studied more systematically and the results made more broadly available for it to become a more mainstream practice.

Scientific Context

Animal health care

Most organic animal health care relies strongly on good nutrition and preventive practices such as low-stress living conditions and good sanitation. Compiling preventive health protocols for each species at each life stage would be useful to organic livestock and poultry producers. Together with developing standard livestock and poultry rations using sources of nutrients that are compliant with the organic standards, this information should provide fundamental guidance for maintaining good animal health.

One area of potential investigation involves feeding probiotics for disease prevention. Probiotics are products made with beneficial microorganisms that are consumed to protect the digestive system from infection with pathogenic microorganisms. Eating yogurt in order to introduce *Lactobacillus* spp. into the gut to aid digestion is a generic example of probiotic use. Because so many serious livestock diseases in the early stages of life involve infection of the digestive tract, probiotics are commonly fed to newly born calves, piglets, and chicks. USDA-ARS researchers have been studying the use of probiotics in reducing the incidence of *Salmonella* and *Campylobacter* in conventional poultry (Core 2004). The Organic Materials Review Institute lists 15 allowed microbial products and 3 allowed probiotics for use in organic livestock production (OMRI 2005).

Another important research task is to identify rations and feeding strategies that can reduce the incidence of harmful pathogens such as *E. coli* O157:H7 within animals. While more research on the topic is needed, evidence exists that levels of *E. coli* O157:H7 in cattle guts decrease when cattle are finished on hay, acidifying their stomachs, rather than on grain (Diez-Gonzalez et al. 1998). Systematic studies of feeding strategies that manipulate the pH and other conditions in the gut are needed to provide guidance for organic and conventional producers on how to reduce pathogen levels inside of animal digestive tracts and otherwise improve animal health and food safety.

Antibiotics are the treatment of last resort for organic farmers. According to the National Organic Standards, "All appropriate medications must be used to restore an animal to health when methods acceptable to organic production fail. Livestock treated with a prohibited substance must be clearly identified and shall not be sold, labeled, or represented as organically produced" [§ 205.238 (c)(7)] (NOP 2002).

Are there alternatives to antibiotics that are as effective at stopping severe infection quickly, and that are compatible with the National Organic Standards? Vaccinations are allowed under the National Organic Standards and play an important role in disease prevention. Probiotics as a feed supplement are being studied as substitutes for antibiotics. Some work has also been done on the potential of bacteriophages to control disease in poultry, but whether the use of a bacteria-infecting virus will be allowed in organic production is an open question.

Herbal preparations may seem to be an obvious alternative to antibiotics, and a number of natural substances such as garlic have known antibiotic properties. Still, most herbs are slow-acting and carry low dosages of the effective compound. Herbs that have stronger active compounds may also be toxic to the animal. Herbs may be effective preventatives or strengtheners, but are unlikely to play the role that antibiotics do in rescuing an animal from an acute infection.

Homeopathic practitioners claim to be able to control severe infections using their highly dilute solutions containing only traces—often non-detectable—of the active ingredient (Martini et al. 2002). However, clinical trials have shown homeopathy to be ineffective against severe infections (Hektoen 2002). Homeopathy is another practice that is likely more preventive than curative. Still, developing standard protocols for herbal therapeutic treatments and homeopathic approaches would be beneficial to organic livestock and poultry producers.

The need remains for fast-acting medical treatments for severe infections in organic livestock and poultry.

Anthelmintics

The main species of livestock that are produced on organic pasture are cattle (primarily for dairy, also for meat), sheep, and hogs (USDA-ERS 2005). Increasing numbers of poultry are being raised on pasture as well, but the most troublesome parasites in organic production systems are internal parasites of grazing ungulates. Effective and safe anthelmintic (intestinal parasite-killing) treatments are sorely needed for production of each type of organic livestock. Because of build-up in parasite resistance to commonly-used commercial anthelmintics, solutions to this problem would benefit conventional producers as well. Some small-scale studies on the effectiveness of alternative anthelmentics under organic conditions have yielded less-than-promising results (e.g., Allen et al. 1998; Exner 2004). Materials tested include diatomaceous earth, tobacco, pumpkin seeds, and oil of *Chenopodium*.

In the absence of effective anthelmintics that are compliant with organic standards, grazing management practices in combination with "nutritional interventions" appear to be the most effective parasite-control options open to organic livestock producers at this time (Eysker 2002). This is also the conclusion of farmer researcher Janet Allen. Allen received funding from OFRF to test the efficacy of alternative anthelmentic products including an herbal mix wormer, diatomaceous earth, garlic, and pyrethrum in controlling parasites in organic lamb. She found that none of these materials were effective in reducing parasite loads (Allen, pers. comm.; Allen et al. 1998).

Effective parasite management is very site- and climate-specific, species-specific, and dependent upon the animal's stage of growth. Approaches will differ over the course of the season as the parasites go through their own life cycles, which may involve intermediary hosts and/or periods of dormancy. Organic livestock producers must carefully balance the need to protect young animals from infestation with the need to expose them to a certain degree of pathogenicity in order to stimulate development of the animal's immune system ("premunition") (Haynes 1985, cited in Exner 2000).

Broad guidelines exist for moving animals on and off pasture at certain times of the year, but even careful pasture management will reduce infestation only in animals that are otherwise well-nourished and in good health.

Some lines of inquiry on livestock parasite management include:

- how to control parasite populations in pasture using management strategies such as preventive grazing or evasive grazing (Thamsborg 2002); multi-species or "mixed" grazing (Eysker 2002); or suppressive plant residues;
- investigating the potential of high condensed-tannin forages (for ruminants) and nematophagous fungi to reduce internal parasitism (Thamsborg 2002; Min and Hart 2003);
- developing sanitation-based strategies such as the McLean County system, in which young animals were kept separate from older ones; "facilities were cleaned and sterilized; and animals were transported from one field to another rather than walk down parasite-infested lanes" (Exner 2004);
- investigating the effectiveness of preventive treatments such as homeopathy, herbs, and feed supplements such as diatomaceous earth and kelp;
- determining threshold levels for parasite tolerance in healthy animals;
- identifying the most effective intervention periods.

Pasture quality, soil quality, and nutrition

Pasture and forage provide animals with nutritive and non-nutritive substances. Forage quality varies depending on plant parts consumed; age of plant; type of plant; location of pasture or range; stocking rates; and presence of secondary compounds in plant tissues (Lyons et al. 1996). Soil condition and resident nutrient levels, both partially determined by soil microbial activity, can influence the quality of forage and the proportions of nutrients to non-nutrients that it contains. The nature of the relationship between soil microbial activity and plant performance and quality is in the very early stages of scientific investigation. Some of these issues are addressed in the chapter on soil management (see Chapter 1). It is also important to recognize the effects of management on microbial life and subsequently on forage quality. For example, heavy nitrogen applications on pasture reduce the concentrations of copper, cobalt, and molybdenum in perennial ryegrass, orchardgrass, and red clover (Reith et al. 1984, cited in MacNaeidhe 2002). Major nutrient and trace mineral content of forages are influenced by a complex of management practices, the effects of which demand further research (MacNaeidhe 2002).

Protein and amino acids crucial to healthy animal development are difficult to provide from purely vegetarian diets. Seed meals resulting from the extraction of oils from oil seeds such as soybean, canola, and cotton contain high levels of protein, but are conventionally made from solvent extraction processes that are not allowed in organic production. Mechanical extraction is much more expensive, thus raising the cost of feeding organically acceptable protein to poultry and livestock (Bennett 2002). Synthetic versions of crucial nutrients are routinely added to conventional livestock and poultry feeds. Generally, these synthetics are not allowed in organic production, and identifying alternative sources has been a major challenge. Meanwhile, a temporary allowance has been made in the National Organic Standards for organic layer producers to use synthetic forms of methionine through 2008 because naturally occurring sources are limited. Sources of these and other nutritive compounds compliant with the organic standards need to be developed and commercialized to bring down production costs of organic livestock and poultry, and to provide the animals with optimal nutrition.

Some amino acids may be formed by microbial processes: lysine by microbial fermentation (Shah et al. 2002) and methionine by other microbial reactions (Mondal et al. 1996). Such manufacturing methods may offer potential for producing needed amino acids and other nutrients for use in organic livestock and poultry production.

Citations

Allen, J., M. Boal, and P. Doherty. 1998. Identifying and testing alternative parasiticides for use in the production of organic lamb. Final report to the Organic Farming Research Foundation. Online at http://ofrf.org/funded/reports/allen_98-03.pdf

Arnold, K. 2006. Producing quality organic milk from a healthy herd. In Gopalakrishnan, O., L. Melotti, J. Ostertag, and N. Sorensen, eds. Proceedings of the 1st IFOAM International Conference on Animals in Organic Production, St. Paul, MN, Aug. 23-25, 2006. pp. 171-176.

Organic Farming Research Foundation

Bennett, C. 2002. Organic diets for small poultry flocks. Manitoba Agriculture, Food, & Rural Initiatives. Online at http://www.gov.mb.ca/agriculture/livestock/poultry/bba01s20.html

Brunetti, J. 2003. Benefits of biodiverse forage. Acres USA Vol. 33 no. 10. October.

Clark, J., J. Russell, D. Karlen, D. Busby, L.J. Secor, B. Peterson, L. Pellack, C. Olsen, and S. Shouse. 2000. Effects of corn crop residue grazing on soil physical properties and subsequent soybean production in a corn-soybean crop rotation. A progress report. Armstrong Research and Demonstration Farm, Iowa State Univ. ISRF00-12. Online at http://www.ag.iastate.edu/farms/2000reports/arm/EffectsofCornCropResidu.pdf

Core, J. 2004. Probiotics protect poultry from pathogens. Agricultural Research Jan. 2004.

Diez-Gonzalez, F., T.R. Callaway, M.G. Kizoulis, and J.B. Russell. 1998. Grain feeding and the dissemination of acid-resistant *Escherichia coli* from cattle. Science 281:1666-1668.

Erickson, G., T. Klopfenstein, D.J. Jordon, W. Luedtke, and G. Lesoing. 2001. Impact of grazing corn stalks in the spring on crop yields. 2001 Nebraska Beef Report. Cooperative Extension, Univ. of Nebraska. Online at http://ianrpubs.unl.edu/beef/mp76.pdf

Exner, D. 2004. Controlling gastrointestinal parasites of livestock with organic materials. Final report to the Organic Farming Research Foundation. Online at http://ofrf.org/funded/reports/exner_99-84.pdf

Exner, D. 2000. Gastrointestinal parasites: natural and/or old-time treatments. Web page for Practical Farmers of Iowa, Parasite Management. Online at http://www.pfi.iastate.edu/OFR/Anthelmintics.htm

Eysker, M. 2002. Strategies for internal parasite control in organic cattle. In Hovi, M., and M. Vaarst, eds. Proceedings of the 5th NAHWOA Workshop, Rødding, Denmark, Nov. 11-13, 2001. pp. 59-67.

Fernández, M.I., B.W. Woodward, and B.E. Stromberg. 1998. Effect of diatomaceous earth as an anthelmintic treatment on internal parasites and feedlot performance of beef steers. Animal Sci. 66:635-641.

Geiger, G., and H. Biellier. 2003. Weeding with geese. Univ. of Missouri Extension pub. no. G8922. http://muextension.missouri.edu/xplor/agguides/poultry/g08922.htm

Haynes, N.B. 1985. Keeping livestock healthy. Pownal, VT: Garden Way Publishing.

Hektoen, L. 2002. Controlled clinical trials used in the evaluation of clinical effect of homeopathic treatment in farm animals. In Hovi, M., and M. Vaarst, eds. Proceedings of the 5th NAHWOA Workshop, Rødding, Denmark, Nov. 11-13, 2001. pp. 41-48.

Lee, Andy. 2000. What is pastured poultry? Online at http://www.lionsgrip.com/pastured.html

Lyons, R.K., R. Machen, and T.D.A. Forbes. 1996. Why range forage quality changes. Texas Agricultural Extension Service Bulletin B-6036. Online at http://animalscience.tamu.edu/ansc/publications/beefpubs/B6036-rangeforage.pdf

MacNaeidhe, F.S. 2002. Pasture management and composition as a means of minimizing mineral disorders in organic livestock. In Hovi, M., and M. Vaarst, eds. Proceedings of the 5th NAHWOA Workshop, Rødding, Denmark, Nov. 11-13, 2001. pp. 102-112.

Martini, A., P. Tambini, M. Miccinesi, and R. Bozzi. 2002. Homeopathic medicine: research data from Italy. In Hovi, M., and M. Vaarst, eds. Proceedings of the 5th NAHWOA Workshop, Rødding, Denmark, Nov. 11-13, 2001. pp. 32-40.

McCutcheon, J., and D. Samples. 2002. Grazing corn residue. Ohio State Univ. Extension Fact Sheet ANR-10-02. Online at http://ohioline.osu.edu/anr-fact/0010.html

Min, B.R., and S.P. Hart. 2003. Tannins for suppression of internal parasites. J. Anim. Sci. 81:E102-E109. Online at http://jas.fass.org/cgi/content/full/81/14_suppl_2/E102

Mondal, S., Y.B. Das, and S.P. Chatterjee. 1996. Methionine production by microorganisms. Folia Microbiol (Praha). 41:465-472.

NOP. 2002. Final Rule with request for comments. Online at http://www.ams.usda.gov/NOP/NOP/standards/FullText.pdf

OMRI. 2005. OMRI Brand Name Products List, Web Edition. accessed Aug. 1, 2005. http://www.omri.org/livestock_generic.pdf

Osweiler, G.D. 1997. Evaluation of diatomaceous earth as an adjunct to sheep parasite control in organic farming. Leopold Center Progress Reports 6:21-23. Leopold Center for Sustainable Agriculture Competitive Grant Report 95-34. Online at http://www.leopold.iastate.edu/research/grants/1997/1995-34_Alternative_Parasite_Control_for_Sheep_%5B_Organic_%5D.pdf

Reith, J.W.S., J.C. Burridge, M.L. Berrow, and K.S. Caldwell. 1984. Effects of fertilizer on the contents of copper and molybdenum in herbage cut for conservation. J. Sci. Fd. Agric. 35: 245-256.

Riddle, J.A. 2004. Organic livestock research survey. Minnesota Institute for Sustainable Agriculture report. Online at http://www.misa.umn.edu/vd/Organic_livestock_survey.pdf

Robinson, J. 2002. Pasture perfect. Mother Earth News April-May. Online at http://www.motherearthnews.com/whole_foods_and_cooking/2002_April_May/Pasture_Perfect

Shah, A.H., A. Hameed, and G.M. Khan. 2002. Fermentative production of L-Lysine: bacterial fermentation. J. Med. Sci. 2:152-157. Online at http://www.ansijournals.com/jms/2002/152-157.pdf

Thamsborg, S.M. 2002. Parasite control on organic sheep farms - options and limitations. In Hovi, M., and M. Vaarst, eds. Proceedings of the 5th NAHWOA Workshop, Rødding, Denmark, Nov. 11-13, 2001. pp. 92-101.

USDA. 2003. Organic feed for poultry and livestock: availability and prices. Online at http://www.ams.usda.gov/nop/ProdHandlers/FeedStudyJune2003.pdf

USDA-ERS. 2005. Data sets: organic production. Posted online at http://www.ers.usda.gov/Data/Organic/ and accessed 11/20/06.


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Chapter 4
Breeding and Genetics


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Summary of Research Goals

Organic growers and livestock producers require breeding programs that produce crops and animals which meet the unique needs and conditions of organic farming systems. Breeding crops and livestock under conventional management for use in organic systems fails to meet these needs. Organic crop breeding programs should focus on optimizing yields by considering such factors as insect and disease resistance, weed competition, good response to organic fertility sources, and good yield in biologically diverse systems. Organic livestock breeding should focus on selecting healthy, adaptable animals that perform well on pasture and that have disease and parasite resistance.

Broad Research Outcomes

- Organic breeding goals developed cooperatively between farmers and breeders.
- Breeding under certified organic conditions, both on-farm and on-station, to develop high quality crop varieties and healthy livestock breeds that are well-adapted to local organic production systems.
- Crop varieties and animal breeds that are compatible with each other in mixed crop-livestock systems.
- Access by breeders and organic farmers to a large diversity of plant and animal genetic resources maintained and protected in the public domain by public institutions.

Research Needs

Plants

- In general, breed crops for disease and insect resistance, good yield in a biologically diverse system, ability to compete with weeds, compatibility with intercrops, and good response to organic fertility sources.
- Breed crops suited for specific regions, climates, and soil types.
- Develop guidelines by which growers can select and save their own seed for their specific growing conditions.
- Conduct breeding work on minor crops that fill niche markets.
- Develop mechanisms for preventing or eradicating genetic contamination, such as breeding non-compatibility genes into organic crop varieties that would prevent them from accepting pollen from genetically modified (GM) hybrids
- Develop methods to breed out GM traits.
- Breed for horizontal resistance to pests.
- Work with older heirloom varieties and landraces as well as modern cultivars to identify and preserve useful traits.
- Work with wild relatives of crop plants to identify useful traits and to preserve diversity.
- Develop perennial organic agricultural systems by breeding perennial grain varieties.
- Develop organic crop varieties that are well-suited for grazing (e.g., short-statured, small-eared corn) and otherwise suited for integration with livestock production.

- Develop varieties of soil-building crops, and develop uses and markets for such crops, so that organic farmers will have more options to comply with soil-building crop rotation requirements.

Animals

- In general, select for healthy, adaptable animals with desirable behavioral traits and consistent production.
- Breed and select livestock and poultry for foraging ability and efficient use of pasture.
- Breed specifically for good performance under organic management.
- Preserve traditional livestock varieties.
- Identify non-production traits for which to breed, such as resistance to diseases and internal parasites, longevity of the animal's productive life, or durability in harsh climates.

Growers' Perspectives on Plant Breeding

In the early 1900s, breeding optimal traits into crop varieties in the U.S. began on a large scale, conducted primarily by land grant-based scientists using the new sciences of genetics and statistics. Since then, modern plant breeding has increased crop yields to an astounding degree. Average U.S. corn yields increased seven-fold between 1930 and the mid-1990s, while wheat, soybean, and cotton yields increased as much as four-fold in that time period (Fernandez-Cornejo and Schimmelpfennig 2004). With the significant exception of hybrid corn, most breeding of the other crops was conducted by land grant or USDA researchers (Duvick 2004), and improved varieties were released to all growers without any restrictions. Germplasm was kept in the public domain.

Within the past decade, commercialization of genetically altered crop varieties has changed the dynamics of public breeding dramatically. Cooperative agreements between industry and the land grants have resulted in increased restrictions on the varieties released by the land grants. Wheat breeder Stephen Jones, a critic of this trend, wrote, "Today virtually all of the public breeding programs now have confidential agreements with biotech firms to collaborate on gene insertion with the goal of varietal development" (Jones 2004). Varieties resulting from these agreements are released under binding regulations on how the seed may and may not be used, including strict prohibitions on farmers' ability to replant seed. Despite these issues and others, genetically modified (GM) crops are highly successful in the USA, where 85% of all soybean and 45% of all corn acres in the U.S. were planted to patented, GM varieties in 2004 (Pew Trust 2004).

From the organic perspective, modern plant and animal breeding is failing organic farmers by not developing varieties specifically selected for good performance under organic conditions. Many university-based researchers and conventional seed companies appear to believe that simply growing out conventionally-bred varieties under organic conditions is sufficient to meet organic farmers' need for organic seed—but this is not the case. See the discussion under *Scientific context* for more on this point.

Seed availability and desirable traits in organic production

Availability of organic seed is a critical issue for organic growers. Strong demand for organic seed is a relatively recent development that accompanied full implementation of the National Organic Standards in October 2002, which requires that certified organic growers use certified organic seed when the seed is "commercially available." The Standards completely ban the use of treated seed, highlighting the urgency to develop varieties that are able to germinate quickly without the protection of fungicides. Seed treatments that are compliant with the organic standards to protect germinating seedlings are also needed.

The organic seed requirement for organically certified crops, combined with increasing risk of organic crop contamination by GM gene sequences, has led to increased interest in organic variety development and seed production on the part of organic farmers. Organic growers are also very interested in seeing horizontal resistance developed in varieties bred for organic systems.

Organic farmers have two distinct needs relating to seed. The first is for well-adapted crop varieties that perform well under organic management; the second is for accessible, affordable, high quality seed

Two contrasting models in crop production: maximizing vs. optimizing yields

by Nick Maravell
Maryland organic crop and livestock farmer

In general, the primary goal of most modern breeding programs has been to maximize yield, and breeding for this single trait fits well with a model of agriculture based on *maximizing* rather than *optimizing* system output. While aspects of both models can be useful to an organic farmer, the research community has tended to investigate topics that are most useful to the maximizing model. This maximizing approach has many of its roots in the work of the 19th century German scientists Justus von Liebig and Karl Sprengel. Von Liebig's work emphasized the role of soil chemistry in making mineral nutrients available for plants, while Sprengel showed that micronutrients have a role in plant development.

Von Liebig placed little importance on humus, recycling wastes, soil biology, or soil physics and instead focused on the first element of the maximizing model, finding the most limiting chemical factor of the major nutrients (nitrogen, phosphorus, and potassium) in order to maximize yield. By placing all the attention on realizing maximum yield through chemical inputs, yield losses due to insects, weeds, and diseases were seen as exogenous impediments to yield rather than as the system's response to chemical management. This led to development of additional chemical inputs in the form of pesticides as techniques to correct these impediments, the second element of the maximizing model.

The third element of the maximizing model is narrowly focusing conventional plant breeding on a specific single trait, such as yield response to chemical inputs or resistance to pests, e.g., resistance to a specific race of root-damaging nematodes. This type of breeding tends to rely on one gene that carries the desired trait, and can be thought of as breeding for vertical, or narrow, resistance. It is based on classic Mendelian genetics and is qualitative in nature; that is, the desired quality (genetic trait) either works completely, or it does not work at all, as is the case when the nematode mutates or selectively adapts to defeat the plant's genetic resistance.

The three essential approaches to the maximizing model--chemical inputs for plant nutrition, chemical pesticides, and single-trait breeding--conceptually work well together because they all tend to ignore whole system dynamics. Indeed, it is far easier to deal with only one component of a farming system at a time and to simply mask nature's systemic responses with further additions of minerals and chemicals than to address the complexity of nature.

However, it is naive to think that intervention on one component will have no effect, good or bad, on the numerous other components of the system, and that identical opportunities and adversities will equally impact yield each season. Farming is a dynamic activity and, in the face of nature, the farmer has both significant and, at the same time, limited control over the final results. Because "You never know what nature will throw at you next" (as a farmer might say), a different farming model, focused on optimizing yields in "good years and bad," can over time be equally as productive and profitable as one managed according to the maximizing model.

This *optimizing* model in organic agriculture seeks stability and adaptability by emphasizing naturally occurring and self-regulating system dynamics. All of the concepts used in the maximizing model remain useful in the optimizing model but significant concepts need to be added, such as the importance of system dynamics, soil microbiology, nutrient recycling, and building soil organic matter for optimal plant growth and, ultimately, animal and human health and nutrition. High yield remains an important system output. However, yield is placed in the context of overall system stability and health, emphasizing a yield that is more resilient in the face of seasonal variations and adversities. While this model has roots going back to the earliest agriculturists and crosses a diversity of cultures, many organic farmers credit Sir Albert Howard as one proponent, but by no means the only proponent, of this model in the early twentieth century.

The implications of the optimizing model for breeding and genetics are significant and distinct from the maximizing model. Animals and plants need to have multiple traits that permit them to be managed for profitable yield while at the same time remaining healthy and making efficient use of the nutrients available, to the maximum extent possible, from on-farm sources. Resistance to pests and environmental adversities is viewed as a generalized characteristic; farmers might say this is a "tough" variety or a "sturdy" breed that is well-adapted to a specific region. This type of breeding relies on combinations of multiple genes and is referred to as providing horizontal, or broad, resistance (Robinson 1996). This resistance is called quantitative because the desired genetic characteristic is displayed in some quantity from very low to very high. Unlike vertical resistance, which tends to be all or nothing, horizontal resistance can provide some level of benefit to plants and animals in meeting a wide array of environmental situations and pest problems. Because it is hard to predict each season's future conditions, breeding for broad or horizontal resistance best prepares the farm manager for success.

that produces what a grower expects it to produce. *Crop quality* is improved through plant breeding, during which desired traits are identified, plants are crossed, and the best individuals are selected. Generally in organic production, desirable traits include:

- fast-setting canopy to shade out weeds, and other weed-competitive traits;
- quick emergence, including in cool soil temperatures;
- efficient extraction and use of organic fertility sources;
- resistance to drought, heat, frost, and other stresses;
- disease and insect resistance;
- good yield in a biologically diverse system;
- compatibility with intercrops;
- specific food and feed qualities, such as flavor and nutrient profiles, sought by organic consumers and livestock producers.

Seed quality is improved through careful seed production and conditioning techniques, including pathogen-free growing conditions, adequate isolation distances to prevent crossing or contamination with GM pollen, roguing (removal) of off-types, and careful processing to avoid seed damage or contamination by insects or disease. Typical indicators of seed quality include seed purity, high germination rates, high test weight, trueness to type, and absence of physical damage. While time-tested methods exist for producing high-quality seed, heightened efforts to apply these methods to organic seed production are needed to meet increasing demand.

Other issues

All major food crops have been developed from wild, weedy relatives. Many recently "discovered" minor or alternative crops (e.g., amaranth) also arose from the breeding of wild relatives. Continued development of such crops and markets for them can benefit organic farmers by providing more options for diversity in the field and in marketing.

Most consumers around the world reject genetically modified (GM) food crops. Whether or not such crops are safe to eat, people simply do not want to eat them. Organic farmers respect this and agree not to grow GM varieties. But GM pollen is impossible to control so long as GM crops are allowed to be grown outdoors. Contamination of their organic crop is a significant threat to the livelihood of organic farmers, particularly for organic corn and canola growers. Government regulators have allowed these potentially contaminating crops into the environment without establishing adequate protocols for keeping them from contaminating non-GM crops. Nor have regulators established legal liability for instances of genetic contamination. Protecting organic crops from contamination with GM pollen is a serious issue that requires new approaches to breeding.

Scientific Context on Plant Breeding

For vegetable crops, the organic breeding paradigm is to create "a genetically elastic (yet stable) phenotype that displays heterotic vigor ..., performs well under organic farming conditions, and is acceptable in the marketplace" (Peters 2005). This paradigm alludes to the role of the grower in identifying desirable traits. A Dutch researcher has presented a similar paradigm, specifying that "isophenic line mixture varieties, composed of lines being phenotypically uniform but genetically heterogeneous," are most promising for self-pollinating crop varieties (Lammerts van Bueren 2002).

Organic farmers have long assumed that the best way to develop crop varieties that will perform well under organic management is to select and breed from variety trials that are managed organically. Not all researchers share this view, yet recent research-based evidence supports the farmers' contentions. Murphy and Jones conducted a trial that compared yields of 35 winter wheat breeding lines grown under both organic and conventional management. Significant changes in rank among wheat breeding lines between organic and conventional systems indicated that the highest-yielding varieties in conventional systems are not the highest-yielding varieties in organic systems (Murphy and Jones 2005). Estimates of the genetic correlation coefficient between the management systems indicate that "alleles responsible for high yields in both organic and conventional systems are moderately to highly independent between systems" (Murphy and Jones 2005). They state that "these results support the hypothesis that varieties for organic agriculture should be selected within an organic production system to achieve maximum yield potential" (Murphy and Jones 2005).

Other evidence for the influence of management system on varietal performance comes from a USDA-ARS study that showed differential response of bean varieties to cropping system (Westermann et al. 2005). Another ARS project on rice showed that rice cultivar response varied by management system, with certain lines identified that "appear to offer a yield advantage when grown under organic conditions" (Bergman and McClung 2003). Considering the evidence and common sense, it is essential that organic breeding be done under certified organic conditions, both on-farm and on-station.

Similar debate occurs over whether modern crop varieties perform better under organic management than older crop varieties, which presumably were selected under conditions more similar to "organic" management. Patrick Carr at North Dakota State University has studied this question. While his work shows that conventionally-bred lines can perform well under organic management, it does not indicate that conventionally-selected lines are the best for organic systems. Carr concludes that "modern cultivars of hard red spring wheat that were developed and selected using synthetic agrichemicals are adapted to environments under certified organic management" (Carr et al. 2006). Stephen Jones, in his organic wheat breeding program at Washington State University, uses older varieties to identify and supply high-quality baking and milling traits that can then be used to improve disease-resistant modern varieties for organic production systems. Doug Rouse at the University of Wisconsin has been investigating the performance of heirloom potato varieties under organic management and found that many older varieties produce high yields when grown organically (Rouse and Jansky 2004). It appears that older "heirloom" and modern crop varieties both have valuable traits to contribute to organic breeding programs.

Pest resistance and weed competitiveness

A groundbreaking study published by Zhu et al. in 2000 reported that planting mixtures of rice varieties into thousands of adjacent Chinese rice paddies restricted the spread of the fungal disease rice blast to acceptable levels requiring no fungicide applications. The varietal mixture created a physical barrier to the spread of fungal spores, and the researchers also found evidence for an "immunization" effect of the rice variety mixture. Zhu et al.'s work demonstrated that increasing the land area planted to mixtures can help reduce the spread of plant disease vectors. They call for follow-up work on identifying effective crop mixtures, and on breeding varieties specifically for use in such mixtures.

Plant breeder J. H. McCormack reports that in some brassica varieties, "there is a loose association between insect resistance and disease resistance" (McCormack 2005). He attributes this to plants which, when selected for resistance to insects, develop ancillary resistance to the opportunistic diseases that move in when plants are attacked by the insects. He reasons that production of protective phytochemicals in response to insect attack could also protect the plant against certain disease organisms. This type of cross-resistance might be attained in more crop varieties if breeders are aware of such possibilities.

Murphy and Jones established split-plot competition nurseries to try and "decompose the sources of the total variation between organic and conventional systems" (Murphy and Jones 2005). They found that "weed pressure contributes significantly to the variation between organic and conventional systems and that wheat varieties can be selected for improved weed competitive ability" (Murphy and Jones 2005). They are now investigating other sources of variation between the systems, including disease pressure and nitrogen use efficiency.

Growers' Perspectives on Animal Breeding

In contemporary America, most animal production has been separated from crop production and takes place in industrialized confinement facilities. Modern livestock and poultry breeds have been selected to maximize meat or milk production in this highly artificial environment with no attention paid to the animals' ability to live in a natural setting and insufficient attention to animal health.

Single-trait breeding has sometimes led to the development of abnormal animals. Animal scientist Temple Grandin documents how single-trait breeding, which focuses on selecting for only one or two production-related traits at a time, has produced unintended consequences, including avicidal roosters (Grandin 2005).

In contrast, organic livestock and poultry producers value completely different traits in their animals. These are reflected in the requirements for gourmet poultry production in France. The French premium Label Rouge pastured poultry is produced from special breeds specifically selected for their slow growth rates and high quality meat (Fanatico and Born 2002). The poultry must be grown in the open air, be fed a natural, cereal-based feed, and allowed to strengthen and grow for about twice as long as conventionally produced poultry. The U.S. Organic Standards require that certified organic animals have "access to outdoors" and an all-organic diet. Livestock and poultry breeds are needed that are well-adapted to these requirements.

Broad organic animal breeding goals include selecting for healthy, adaptable animals with desirable behavioral traits and consistent production (Idel 2006). Other traits desirable for organic production include resistance to diseases and parasites; ease of breeding and birthing; strong legs and feet; good hair or feather coats; good feed efficiencies when fed organic rations; meat, milk, and egg qualities desired by the organic market; and the ability to graze, since pasture is required for organic ruminants.

Many aspects of meat quality are affected by production system and by animal genetics. Studies show that pasture-based meats contain higher levels of beneficial conjugated linoleic acids than confinement-produced meats and have equivalent taste and texture characteristics (e.g., Sonon et al. 2004, in which the pastured beef was also certified organic). For organic production, it is important to breed animals that perform well under pastured conditions.

Just as it is important to conduct organic plant breeding under certified organic conditions, organic livestock breeding needs to be conducted under organic conditions in order to select animals that perform well on organic farms.

Scientific Context on Animal Breeding

There has been very little published research to date on organic animal breeding in the United States. Almost all organic livestock and poultry improvement efforts are made on-farm. The dearth of information on organically-adapted animal breeds is a significant problem that can be addressed by establishing publicly funded organic animal breeding programs.

Global biodiversity

Successful organic crop and animal breeding in the future depends upon the use of new genes and germplasm to continually revitalize crop and animal varieties. Therefore supporting organic breeding means protecting plant and animal biodiversity worldwide, maintaining existing germplasm and gene collections, and ensuring public access to germplasm and gene resources. Biodiversity is harbored in wild populations of plants and animals as well as in traditional varieties and breeds developed by agrarian peoples around the world. Biodiversity in nature and in the settled countryside is threatened by a variety of forces including the growing human population, genetic contamination with modified DNA sequences, and industrialization of agriculture and food systems.

Robust organic breeding programs require conservation of genetic diversity to provide raw materials for traits, including insect and disease resistance. Sources of genetic diversity also need to be isolated enough or specifically protected to prevent contamination by genetically modified pollen.

Case Study:
Public breeding in the land grant system

Stephen Jones, head of the Washington State University winter wheat breeding program, works closely with growers to identify desirable traits from heirloom varieties and to trial promising wheat varieties in their organic fields. Together with Kevin Murphy, he has also initiated an "evolutionary participatory breeding program" that works with growers to develop varieties specifically suited for conditions on their farms (Murphy et al. 2005). Specific goals of Jones's winter wheat breeding program include optimizing weed competitiveness, improving nutrient use efficiency, and enhancing beneficial plant-microbe interactions (such as that between wheat roots and vesicular-arbuscular mycorrhizae). Strong emphasis is placed on breeding for high-quality baking and milling traits. Jones's team is combining desirable quality traits of older varieties with disease-resistance traits of newer varieties.

One unique aspect of the organic wheat breeding program at Washington State is the work on developing perennial wheat varieties (Lammer et al. 2004; Scheinost et al. 2001). Fred Kirschenmann points out that perennials represent the mature development of plant ecosystems and suggests that "we may need to find ways to adapt to perennialization's evolutionary advantage" (Kirschenmann 2004), thus solving many problems of contemporary agriculture. Jones has found it a less complicated task then originally thought to re-integrate a perennial trait into wheat, and is studying the effectiveness of the perennial varieties in buffer strips and borders to help control erosion and provide wildlife habitat.

Jones's program tests varieties in organic growers' fields, with the breeding nurseries managed the same as the rest of the growers' wheat. Jones utilizes this diversity of management practices to identify general traits that make wheat suitable for organic production, such as stripe rust resistance, medium height, allelopathic potential, and long coleoptiles. Jones has also certified a total of 15 acres at two Washington State University research stations to ensure that selection is conducted under conditions similar to those found on organic farms.

Citations

Bergman, C., and A. McClung. 2003. Effects of organic cultural management on end-use quality characteristics of rice. USDA-ARS technical abstract. Accessed online 1/9/03.

Carr, P.M., H.J. Kandel, P.M. Porter, R.D. Horsley, and S.F. Zwinger. 2006. Wheat cultivar performance on certified organic fields in Minnesota and North Dakota. Crop Sci 46:1963-1971.

Duvick, D. 2004. The current state of plant breeding: how did we get here? In Sligh, M., and L. Lauffer, eds. Proceedings: Summit on Seeds and Breeds for 21st Century Agriculture. pp. 71-85. Summit held Sept. 6-8, 2003, Washington, D.C.

Fanatico, A., and H. Born. 2002. Label Rouge: Pasture-based poultry production in France. ATTRA Livestock Technical Note. Online at http://www.attra.org/attra-pub/PDF/labelrouge.pdf

Fernandez-Cornejo, J., and D. Schimmelpfennig. 2004. Have seed industry changes affected research effort? USDA-ERS Amber Waves. Online at http://www.ers.usda.gov/AmberWaves/February04/Features/HaveSeed.htm

Grandin, T. 2005. Animals in translation: using the mysteries of autism to decode animal behavior. New York: Scribner.

Idel, A.M. 2006. Agro-biodiversity and animal breeding—endangered by global privatisation. In Gopalakrishnan, O., L. Melotti, J. Ostertag, and N. Sorensen, eds. Proceedings of the 1st IFOAM International Conference on Animals in Organic Production. pp. 88-95.

Jones, S. 2004. Breeding resistance to special interests. Organic Farming Research Foundation Information Bulletin No. 14. Online at http://ofrf.org/publications/ib/ib14.pdf

Kirschenmann, F. 2004. New seeds and breeds for a new revolution in agriculture. In Sligh, M., and L. Lauffer, eds. Proceedings: Summit on Seeds and Breeds for 21st Century Agriculture. pp. 45-54. Summit held Sept. 6-8, 2003, Washington, D.C.

Kutka, F. 2004. New hope for variety crosses? Corn Culture: the newsletter for American OP corn breeders. Volume 2004. Planting Issue.

Lammer, D., X.W. Cai, M. Arterburn, J. Chatelain, T. Murray, and S. Jones. 2004. A single chromosome addition from *Thinopyrum elongatum* confers a polycarpic, perennial habit to annual wheat. Journal of Experimental Botany 55:1715-1720.

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Lammerts van Bueren, E.T. 2002. Organic plant breeding and propagation: concepts and strategies. Dissertation Wageningen Univ. abstract.

McCormack, J.H. 2005. Brassica seed production: an organic seed production manual for seed growers in the Mid-Atlantic and Southern U.S. version 1.1. Downloaded from http://www.savingourseed.org/Survey/BrassicaGuideSurvey.html

Murphy, K., D. Lammer, S. Lyon, B. Carter, and S.S. Jones. 2005. Breeding for organic and low-input farming systems: an evolutionary-participatory breeding method for inbred cereal grains. Renewable Agriculture and Food Systems 20: 48-55.

Murphy, K.M., and S.S. Jones. 2005. Breeding wheat for organic systems. Presented at the ASA-CSSA-SSSA International Annual Meetings, November 6-10, 2005. Abstract online at http://crops.confex.com/crops/2005am/techprogram/P3888.HTM

Peters, S. 2005. Plant improvement of vegetable crop populations for organic systems. Presented at the ASA-CSSA-SSSA International Annual Meetings, November 6-10, 2005. Abstract online at http://crops.confex.com/crops/2005am/techprogram/P6485.HTM

Pew Trust. 2004. Genetically modified crops in the United States. Pew Initiative on Food and Biotechnology Fact Sheet. Online at http://pewagbiotech.org/resources/factsheets/display.php3?FactsheetID=2

Robinson, R. 1996. Return to resistance: breeding crops to reduce pesticide dependence. Davis, CA: agAccess.

Rouse, D., and S. Jansky. 2004. Identification and characterization of potato clones for organic production systems. Progress report posted on Current Research Information System database. Online at http://cris.csrees.usda.gov/cgi-bin/starfinder/0?path=fastlink1.txt&id=anon&pass=&search=R=25695&format=WEBLINK

Scheinost, P.L., D.L. Lammer, X. Cai, T.D. Murray, and S.S. Jones. 2001. Perennial wheat: the development of a sustainable cropping system for the U.S. Pacific Northwest. Am. J. of Alt. Ag. 16:147-151.

Siemon, C. 2005. *Salmonella* contamination and antibiotic resistance on pasture poultry and conventional poultry farms. Report on 2005 On-Farm Research Project, Southern SARE. Online at http://www.southernsare.uga.edu/winnerfiles/05winners/2005onfarmwinners.htm#os05025

Sonon, R.N. Jr., D.C. Beitz, A.H. Trenkle, J.R. Russell, and R. Rosmann. 2004. Conjugated linoleic acid (CLA) concentrations in beef tissues from cattle finished on pasture initially with limited grain. Presented at American Society of Animal Science/American Dairy Science Association annual national meetings, July 2004, St. Louis, MO. This study was partially funded by OFRF.

Westermann, D., M. Kay, H. Teran, C. Munoz-Perea, R. Parrott, K. Mulberry, D. Fullmer, J. Smith, R. Allen, J. Wright, M. Dennis, R. Hayes, and S. Singh. 2005. Differences in dry bean cultivars for nutrient and water use in response to seven organic and non-organic cropping systems and their significance to breeding. Presented at the ASA-CSSA-SSSA International Annual Meetings, November 6-10, 2005. Abstract online at http://crops.confex.com/crops/2005am/techprogram/P1769.HTM

Zhu, Y., H. Chen, J. Fan, Y. Wang, Y. Li, J. Chen, J. Fan, S. Yang, L. Hu, H. Leung, T.W. Mew, P.S. Teng, Z. Wang, and C.C. Mundt. 2000. Genetic diversity and disease control in rice. Nature 406: 718-722.

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APPENDIX 1 — Mission and goals of SCOAR

Mission Statement

SCOAR is a collaboration of producers, scientists, and others. Its mission is to plan and promote research and information-exchange for understanding and improving organic agricultural systems.

Goals

1. Cultivate a peer-level process of mutual learning and democratic collaboration among a diverse community of organic farmers & ranchers, scientists, extensionists, consultants, consumers and others for pursuit of the project Mission.
2. Create a shared understanding of organic agriculture as an ecological approach to managing agricultural systems.
3. Identify and characterize research and information-exchange priorities pertaining to the Mission, through various activities and documentation of those activities.
4. Advance the state-of-the-art of organic systems research, including on-farm, participatory, whole systems, and multi-farm studies.
5. Increase access to the knowledge, skills, and practices of successful organic producers by developing and implementing models for networking and information sharing among organic producers and scientists.
6. Encourage the use and implementation of SCOAR's results.

APPENDIX 2 — Scientific Congress on Organic Agricultural Research (SCOAR)-sponsored meetings at which organic research priorities were documented

1. The Inaugural Assembly of the Scientific Congress on Organic Agricultural Research, January 23-24, 2001, Asilomar Conference Center, Pacific Grove, California.
2. Workshop at Upper Midwest Organic Farming Conference, La Crosse, Wisconsin, March 17, 2001. Focused on upper Midwest regional issues.
3. The Second Assembly of the Scientific Congress, Nov. 4-5, 2001, Rock Hill, South Carolina. Focused on southern regional issues.
4. Workshop at the Western Sustainable Agriculture Working Group meeting, February 8, 2002, Santa Fe, New Mexico. Focused on grazing and dryland crop production issues.
5. Workshop at the Association for the Study of Food & Society/Association for Food & Human Values joint conference, June 15, 2002, Chicago, Illinois. Focused on socioeconomic issues.

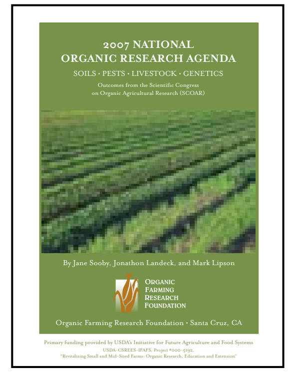
Organic Farming Research Foundation's

2007 National Organic Research Agenda

SOILS • PESTS • LIVESTOCK • GENETICS

by Jane Sooby, Jonathan Landeck, and Mark Lipson

The 2007 National Organic Research Agenda (NORA) presents a catalogue of research needs for organic agriculture. Based on a series of scientist/producer meetings held by the Scientific Congress on Organic Agricultural Research (SCOAR), this volume emphasizes topics related to soils, systemic management of plant pests, organic livestock and poultry management, and breeding and genetics.



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