Chapter 14
Organic Farming: Pros and Cons for Soil Health and Climate Change

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14.1 Introduction

Soil health was a key founding principle for the development and practice of organic farming, as evident in one of its original precepts (here in the words of Lady Eve Balfour 1943) that “the health of soil, plant, animal and man is one and indivisible”. Modern organic farming represents a merging of different streams of thought from a number of sources (Paster and Boeringa 1980; Merrill 1983; Harwood 1990; Tate 1994; Conford 2001; Heckman 2006). Briefly, the early organic movement focused strongly on issues of human nutrition and health, as well as the promotion of soil fertility through the use of composts and other organic fertilisers. Pesticides did not become a major issue in organic agriculture until the publication of “Silent Spring” (Carson 1963) generated widespread public concern. The Limits to Growth report of the Club of Rome, and the energy crisis of 1973 drew attention to the sustainability of resource use (Lockeretz 1990). During the 1980s and 1990s, other issues also increased in importance, in particular nature and biodiversity conservation, animal welfare, social justice issues relating to fair trade with developing countries and most recently the potential of organic agriculture to contribute to rural development and reductions in greenhouse gas emissions.

As described in this book, increasing concentrations of CO_2 and other greenhouse gases in the Earth’s troposphere are leading to global warming and changes in precipitation patterns, which will impact soil processes and agricultural systems (IPCC 2007). The changing climate, together with the changes in global markets, is driving short to medium-term modifications in farming systems at local and regional levels. It is therefore timely to consider the implications of climate change for maintenance and enhancement of productivity and soil health within organic farming systems. In this chapter, I will also consider what role organic farming

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systems can play to support mitigation and adaptation actions in response to climate change, as a result of either increased expansion of organic farming systems or adoption of practices from organic farming by conventional farming systems.

14.2 Definition of Organic Farming Systems

Intensification of conventional agricultural production over the last century has been marked by increased use of mechanical and manufactured inputs and increased specialisation of production and has resulted in spectacular increases in productivity. In contrast and almost contemporaneously, the organic farming movement has developed principles and recommendations for farm management from a biological/ecological conception of nature reflecting an underpinning recognition of the importance of the relationships and interactions between organisms – plant and animals, both aboveground and within the soil. Consequently, regulation of the agro-ecosystem through biological processes is central to organic farming systems, while these processes have become somewhat marginalised in the management of conventional farming systems (Giller et al. 1997). The objectives of environmental, social and economic sustainability at local and global scales lie at the heart of the underpinning principles governing organic farming globally (IFOAM 2005; Kristiansen et al. 2006). In parallel with the global agreement of guiding principles, organic farming systems are now legally defined by reference to production standards in many countries (Vogl et al. 2005; Courville 2006). These standards allow organic products to be assured within the global food market.

As organic farming has developed, acceptable production practices have been recorded in technical guides and handbooks. Detailed descriptions of the practices of organic farming are available (e.g. Lampkin 1990; Siebeneicher 1993; Kristiansen et al. 2006), and therefore I will give only a simplified overview here. In organic cropping systems, rotations/mixtures are designed with a strong awareness of the crops' impacts on soil physical condition and their biological interactions. The use of manufactured fertilisers is prohibited (or at least significantly restricted), and hence there is a focus on the inclusion of N-fixing crops and nutrient recycling to reduce the need for external inputs. Consequently in comparison to conventional systems where nutrients are often supplied in immediately plant-available forms, organic farming systems place a greater reliance on chemical and biological processes within the soil to release nutrients in forms available for plant uptake (Watson et al. 2002a) and standards often refer specifically to the need to maintain the biological activity of the soil, alongside fertility (e.g. Defra 2006). Crop health is maintained through complex interactions and feedback among soil, crops, pests and inputs. Crop rotation and cultivation practices have been identified by farmers as key disease control strategies in organic farming systems (Park and Lohr 2005), for example, by separating crop hosts so that soil-borne pathogen levels are diminished. Pest control strategies are largely preventative, rather than reactive;

the balance of cropped and uncropped areas, crop species and variety choice and the temporal and spatial pattern of the crop rotation seek to maintain a diverse population of pests and their natural enemies and disrupt the life cycle of pest species. Weeds are controlled at manageable levels by managing the rotation (crop choice, timing of sowing, cultivations, etc.) to ensure that direct control measures (e.g. hand weeding) can succeed in preventing crop losses (Barberi 2002; Turner et al. 2007). Consequently, in comparison to conventional systems where external inputs are often the primary tactical response to pest, disease and weed control, in organic farming systems external inputs are permitted only as supplementary tools but only to particular crops and with prior independent consent.

The implementation of the principles of organic farming across the world in diverse climates leads to a great variety in the types of farming systems which produce organic food. The resulting products include all types ranging from vegetables, meat, bread and milk to organic cola and ready meals. During the 1990s, policy support for organic farming increased globally as a result of a gradual convergence of policy goals for land management with the underlying objectives of organic agriculture, including environmental protection, animal welfare, resource use sustainability, food quality and safety, financial viability and social justice (Lampkin et al. 1999). Recent years have seen very rapid growth in organic farming, particularly in Europe and the USA, but also in many other regions of the world including China, Latin America and Africa. Worldwide, organic agriculture occupies 31 million ha of certified crop and pasture lands and more than 62 million ha of certified wild harvested areas (FAO 2007). However, data showing the growth of the organically farmed area or the size of the market for organic food globally hide great variability within and between countries, as a result of the regional distribution of farm types and current farming intensity. Where farming practice is low intensity with relatively few external inputs, conversion is also often less onerous. Equally there are, in general, a larger proportion of mixed farms managed organically than specialised dairy or arable units; mixed farms are able to integrate more easily the practices required by the organic standards.

In the late twentieth century, increasing awareness of the environmental impact of conventional farming systems (e.g. the impact of pesticides on wildlife or fertilisers on water supplies, loss of soil through erosion) led to the development of modified practices and changes within all farming systems. Doran (2002) grouped these approaches into four key integrating management strategies that are likely to improve soil health and increase sustainability: maintaining soil organic matter; minimising soil erosion; balancing production and environmental outcomes; and improving utilisation of renewable resources (see Chap. 1 also). Reduced use, rather than elimination, of certain chemical inputs is a key factor distinguishing low-input sustainable agriculture (USA) and integrated farming systems (Europe) from organic farming; reduced tillage approaches are more common in alternative conventional than in organic systems. The requirements for legal definition in the marketplace and associated requirements for robust independent certification also provide a clear dividing line between organic food systems and other alternative farming systems. The issue of the relative contributions of organic, low-input and integrated systems to soil health and their role in adapting to and mitigating climate change is outside the scope of this review; where comparisons are made, it is prevalent current conventional practices which are compared with organic farming.

14.2.1 Impacts of Organic Farming on Crop Yields

Comparison of organic and conventional farming and food systems is fraught with difficulties – there is no clear definition of what conventional is, and even within legally defined organic systems there is significant variation in practices. Before 2000, most studies seemed to suggest that in temperate cropping systems, where most studies had been carried out, organic arable crops yielded around 60–80% those of conventional systems (see review by Stockdale et al. 2001). More recent studies in cropping systems trials suggest that organic systems can be as productive as comparable conventional systems (Posner et al. 2008). However, yields in organic systems are more weather dependent and in organic row crops (such as maize, soybean) only approach conventional yields in years, where all the planned mechanical weed control opportunities were not disrupted by weather conditions (Posner et al. 2008). Yields of forage crops are often similar to conventional crops with no difference in feed quality (Stockdale et al. 2001; Posner et al. 2008). Where organic management practices have significantly altered soil conditions, then yield increases are also seen when compared with conventional production. For example, where compost additions almost doubled soil organic matter content, vegetable production in intensive organic irrigated Mediterranean increased significantly (Melero et al. 2006). In developing countries, the UNDP (1992) concluded that organic farming methods seem able to provide outputs, with fewer external resources, supplying a similar income per labour day similar to those of high input conventional approaches where bought in inputs often substitute for labour. Studies commonly show large increases in yield, compared with current cropping practices, where local farmers adopt organic farming systems, reaching levels similar to those of high input systems in tropical environments (FAO 2007). Direct comparisons of yields are often difficult outside controlled trials because of the differences in the farming systems adopted under high input compared with organic management, for example cultivar selection, rotation design and nutrient management, length of time under organic management, and differences between farms in the management skill of the farmer. Furthermore, absolute yields are subject to considerable annual and site to site variability due to disease and pest outbreaks, soil type, seasonal weather patterns, etc. However, at the scale of cropping systems, organic systems often contain fewer cash crops, due to the use of land for green manures and increased integration of livestock into cropping systems; this reduces absolute yields from organic farming systems relative to those from conventional production (see detailed consideration of these issues in Kirchmann and Bergström 2008).

The role of organic systems in supporting development in the tropics and meeting global food demand has been studied, much discussed and disputed (Pretty et al. 2003; Badgley et al. 2007; Hudson Institute 2007; Kirchmann and Bergström 2008). A significant number of critical voices raise concerns that organic agriculture is not capable of meeting the world's growing food needs due to lower productivity per unit area (e.g. Borlaug 2000; Trewavas 2002). However, recent work using the International Food Policy Research Institute's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) and extensive farming systems data showed that even at high levels of conversion to organic agriculture (up to 50%) in Europe and North America, there would be relatively little impact on the availability of food and price changes would be limited (FAO 2007). Posner et al. (2008) also found that there was no reason that yields would decrease significantly under organic management in temperate climates; good farmer management of both conventional and organic systems is the key to sustained, good yields. Barron (2006) found that in developing countries, organic farming delivered increased yields, yield stability and improved livelihoods for small-scale farmers where there was both limited access to technology-driven adaptation and restricted opportunity for commodity production for international markets. Generally in such regions, socio-economic factors operating at regional scale constrain farming system development as much as local climate. Better use of on-farm resources rather than farming system per se is the key to improving farm system productivity. For the case of sub-Saharan Africa, conversion to organic farming practices of up to 50% of the agricultural area was estimated to increase food availability and decrease food import dependency, with negligible changes in prices and no changes in current malnutrition rates (FAO 2007).

14.2.2 Description of Case Study Systems

Watson et al. (2008) highlight the need to ground all future comparative work in improved understanding of all farming systems and their environments. Consequently, the discussion of the impacts of organic farming systems on soil health, and of climate change on organic farming, in the remainder of this chapter will be made with reference to two contrasting particular (but generalised) model organic cropping systems:

1. Cool temperate mixed cropping systems common in Northern Europe and America
2. Intensive irrigated crop and vegetable production under Mediterranean climates common in California and Southern Europe

Figures 14.1 and 14.2 identify the key components and practices of these representative systems and highlight distinctions from comparative conventional practice.

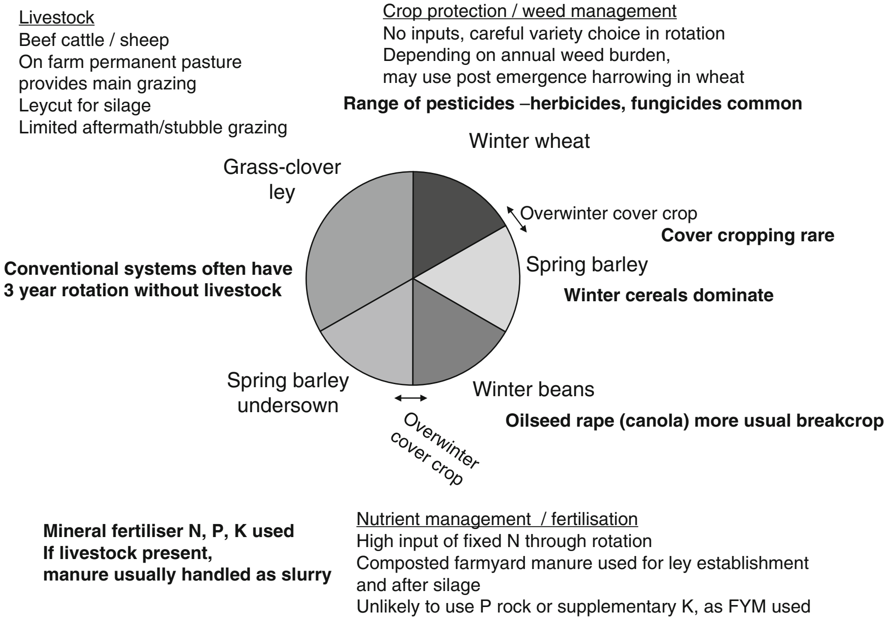


Fig. 14.1 Typical 6-year organic rotation common in cool temperate climates, forming part of a mixed farming system. Segments show approximate length of each cropping phase within the rotation. Text in *italics* identifies key distinguishing practices used in conventional systems

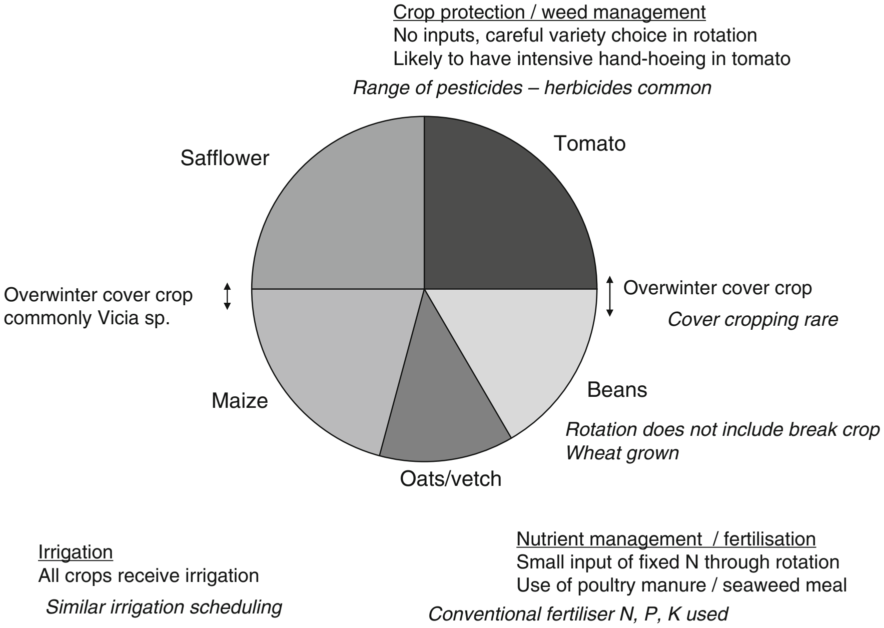


Fig. 14.2 Typical 4-year organic rotation common in Mediterranean climates, adapted from descriptions of systems in Clark et al. (1998). Segments show approximate length of each cropping phase within the rotation. Text in *italics* identifies key distinguishing practices used in conventional systems

14.3 Impacts of Organic Cropping Systems on Soil Properties and Processes

Most studies considering the impact of organic farming systems have compared organic with paired conventional systems. There are also a number of long-term cropping systems experiments that have been used to study changes in soil properties through time (Raupp et al. 2006). Most of these studies have been carried out in temperate rain-fed arable systems with many fewer studies in other key farming systems and climates. Published research into organic farming, however, is increasing rapidly (Watson et al. 2008), and it is expected that these gaps in systems studied will reduce. To be able to draw conclusions that relate to the system or other factors used for comparison such as soil texture, there is a crucial dependence on the premise that these are the only varying factors (Yeates et al. 1997), and consequently any comparisons between farming systems are fraught with difficulty as truly paired systems are very difficult to find in practice. Comparison of crop rotations is an interesting example. As soon as the crops or even varieties within a rotation are changed, the impacts of that rotation on soil properties and processes are likely to change (Stockdale et al. 2006), irrespective of whether the farming system is organic or conventional. However, it is also a fact that under given soil and climatic constraints, the most productive choice of crops and varieties in a rotation will differ depending on whether the system is managed conventionally or organically. Thus, are any differences between the biophysical aspects of the rotation due to the system or the rotation? It is also important to separate out those aspects of the system which need to be assessed at the whole systems level, i.e. those which are dominated by interactions or large-scale ecological processes (e.g. impacts on farm energy use), and those which can be reliably compared at the small plot scale (e.g. changes in soil organic matter) (Watson et al. 2008). In future the application of systems approaches to statistical comparison derived from ecology and/or biometrics may increase the robustness of comparisons at systems levels and allow the identification of key variables driving the observed differences.

In this section, I will briefly review the current evidence for the impacts of organic cropping systems on soil health and then draw this together with reference to the model systems outlined in Figs. 14.1 and 14.2. Time since conversion to organic management is a key factor affecting the extent to which differences between farming systems are observed, and, where possible, in the following sections I have only included comparisons, where the farming systems have been in place for at least one full rotational cycle.

14.3.1 Impacts on Soil Organic Matter and Its Fractions

Increases in organic matter in soils under organic management are widely reported (Reganold et al. 1993; Scow et al. 1994; Nguyen et al. 1995; Loes and Ogaard 1997;

Clark et al. 1998; Drinkwater et al. 1998; Shepherd et al. 2002). Where organic farming practices significantly increase inputs of organic matter to a cropping system compared to the conventional equivalent (e.g. Melero et al. 2006), then significant increases in soil organic matter are not unexpected. Higher levels of C in the “light fraction” of soils have been measured in organic farming systems (Wander et al. 1995; Bending et al. 2004; Leite et al. 2007), have been linked to inputs of fresh organic materials as crop residues, etc., and are thought to represent a more biologically active pool (Haynes 2005). Many organic farming systems have an increased proportion of leys and green manures in crop rotations compared with their conventional equivalents, and these include the regular incorporation of crop residues and manures into the soil. Nonetheless, increased inputs of organic matter to soil in organic systems compared with conventional systems are not a certainty (Shepherd et al. 2002). Furthermore, the size of the pool of soil organic matter is critically dependent on differences in the quality as well as the quantity of organic matter input (Janssen 1984). For example, inputs of organic carbon are closely matched in the DOK systems comparison trial, although the quality of the organic carbon is changed as a result of manure management (Mäder et al. 2002); as the degree of humification of the incorporated manure increases (as a result of increased duration and improved composting), higher levels of soil organic matter are measured (Birkhofer et al. 2008). Changes in the amount and quality of soil organic matter drive/underpin many of the other changes in soil biological and physical properties discussed in detail in the following sections (see Chap. 2 also).

14.3.2 Impacts on Soil Biota: Population Size, Activity and Diversity

A range of positive and negative effects on belowground ecology have been observed as a result of the application of contrasting management systems (see Chap. 8), but Hole et al. (2005) found more reports of positive impacts of organic farming systems on belowground species than studies where there were no difference or negative impacts. Bengtsson et al. (2005), as part of a meta-analysis considering all aspects of biodiversity in organic farming systems, showed that despite the considerable heterogeneity among studies, soil organisms were generally more abundant in organic farming systems. Effects on bacterial biomass and activity were unclear, whereas positive impacts on earthworm, collembolan, mite and fungal populations were confirmed. For groups that can be resolved to the species level, for example collembola, carabids, differential effects of systems are found for different species. In general, given a particular climate/soil combination, it is the amount and quality of organic matter inputs which interact with management disturbance such as tillage or grazing to control the size, structure and diversity of the soil ecosystem. Stockdale and Watson (2009) recently reviewed the evidence for the impact of organic farming systems on soil biota and hence only a summary is presented here.

The main factors leading to the increases in populations and activity observed in organic arable systems are the size and quality of the carbon inputs (Bossio et al. 1998; Gunapala and Scow 1998; Berkelmans et al. 2003; Fließbach et al. 2007). Breland and Eltun (1999) proposed that the higher returns of organic matter, as a result of the inclusion of ley and green manure crops in an organic arable rotation, were able to offset the impact of increased tillage. However, it is important to note that the differences between phases of the rotation in any system can be of the same magnitude as differences between organic and conventional systems (Elmholt 1996; Watson et al. 1996). Interaction between tillage and organic matter inputs within the constraints set by climate and soil texture rather than management system per se dominantly controls the size and activity of the soil microbial biomass in arable systems (Cookson et al. 2007; Esperschütz et al. 2007).

Higher arbuscular mycorrhizal colonisation has been shown in organic than conventional paired cropping systems (e.g. Sattelmacher et al. 1991; Ryan et al. 1994; Bending et al. 2004). Gosling et al. (2006) summarised evidence from 13 studies showing greater root colonisation, larger numbers of spores and greater diversity of arbuscular mycorrhizal fungi in organic than conventional systems. Increased inputs of organic matter, increased diversity in crops and lower levels of available soil P were considered to be the main differences between the organic and conventional systems that led to the differences in arbuscular mycorrhizal fungi. Earthworm populations are generally higher in organic than conventional systems (Reganold et al. 1993; Mäder et al. 2002). Peigné et al. (2009) found that earthworm population size in organic systems is controlled by the interacting effects of soil moisture regime, inputs of organic matter/manure and tillage regime. Organic farming has also been shown to increase the abundance and species richness of arable weeds (e.g. Roschewitz et al. 2005). This clearly has benefits for plant species diversity and can therefore impact on aboveground insect populations as a result of increases in niche diversity (Clough et al. 2007).

In pastoral systems, much smaller differences in soil biodiversity are seen between organic and conventional systems, and differences in management are also often smaller. Taken together the data collected in grassland systems suggest that decomposition pathways in low intensity and/or organically managed grassland are likely to be more complex/diverse than under high-intensity conventional grassland (Yeates et al. 1997; Eason et al. 1999; Mulder et al. 2003; Oehl et al. 2003). Long-term system studies have found fundamental differences in soil food web structure between conventional and less intensive cropping systems (Brussaard 1994, The Netherlands; Crossley et al. 1989, USA; Andren et al. 1990, Sweden). It has been suggested that with high management intensity, the bacterial community dominates the microbial component, while, in less intensive systems, the fungal community is the dominant microbial component. Such differences influence nutrient cycling and have implications for the efficient use of nutrient inputs and losses of nitrate by leaching (De Ruiter et al. 1994; Pankhurst et al. 1994).

14.3.3 Impacts on Soil Structure, Aggregate Stability and Erosion Risk

Measurable changes in soil physical properties can take decades to establish. Anecdotal evidence of increased ease of cultivation on conversion to organic farming systems is readily gathered from organic farmers. Several authors have measured higher aggregate stability and increased porosity under organic arable cropping than under a conventional comparison (e.g. Jordahl and Karlen 1993; Siegrist et al. 1998; Pulleman et al. 2003; Papadopoulos et al. 2009). Stability of soil structure at the millimetre to centimetre scale is largely driven by the short-term management of crop residues and fresh organic matter inputs (Pulleman et al. 2003; Papadopoulos et al. 2009). Incorporation of organic matter and stabilisation within soil microaggregates is more strongly related to the long-term history of organic matter management at any site (Papadopoulos et al. 2009).

Increases in the depth of the A horizon of the soil have also been recorded for organic systems, which may result from decreased bulk densities and/or decreased soil losses through erosion (Reganold et al. 1993; Gerhardt 1997). Lower rates of run-off and soil erosion have been measured in organic systems (Logsdon et al. 1993; Reganold 1987). However, several research studies have found no significant differences in the soil physical properties between organic and conventional farming systems (e.g. Droogers and Bouma 1996). Siegrist et al. (1998) also found no differences in soil particle detachment between organic and conventional systems. Changes in soil structure may lead to relatively small changes in aeration and water holding capacity of soils under organic management. However, Droogers and Bouma (1996) showed using simulation of water-limited yields that consequent improved plant-soil water dynamics can result in improved yields. Increased early season infiltration and water holding capacity have been suggested as the key factors supporting greater yield stability in drought years in organic cropping systems (Lotter et al. 2003).

14.3.4 Impacts on pH, Nutrient Status and Eutrophication Potential

Increased soil pH has been measured in some organic systems (Scow et al. 1994; Clark et al. 1998). However, frequent and/or long-term cropping with legumes is known to increase rates of soil acidification (Yan et al. 1996) and consequently in unlimed plots, Kirchmann et al. (2007) measured a more rapid decline in pH in an organic than in a control conventional system. Application of lime on acid soils is not restricted under the organic regulations, and maintenance of optimum pH levels for the cropping system is a key strategy for both organic and conventional farming systems.

Clark et al. (1998) showed that most changes in soil chemical properties could be predicted from a consideration of the inputs and outputs of nutrients to the system.

Nutrient budgets are a useful tool to summarise the nutrient status of complete systems (Watson and Atkinson 1999). Depending on farm management and the balance of imports and exports of nutrients, nitrogen, phosphorus and potassium budgets range from deficit to surplus in organic farming systems (Fagerberg et al. 1996; Nguyen et al. 1995; Nolte and Werner 1994; Wieser et al. 1996; Watson et al. 2002b). Balanced budgets are often more easily achieved in mixed farming systems (Berry et al. 2003).

Nitrogen budgets are generally positive for both conventional and organic systems (Goss and Goorahoo 1995; Halberg et al. 1995; Nguyen et al. 1995), while organic farming systems may be limited by nitrogen deficiency during crop growth (Berry et al. 2002); such budgets indicate that there is often an annual surplus of nitrogen, which may be lost by nitrate leaching. De Neve et al. (2006) measured lower nitrate concentrations in soils on organic farms; Smolik et al. (1995) also measured reduced nitrate loadings in an organic system. However, Kristensen et al. (1994) measured similar nitrate concentrations in the soil in autumn in organic and conventional farms using manure and suggested that there was no inherent difference in the leaching risk from conventional and organic farming systems. Eltun (1995) measured nitrate leaching losses directly from organic farming and found they were half of those measured in paired conventional systems. Such startling differences are not common in the literature, but following a comprehensive review, Kirchmann and Bergström (2001) found that average leaching of nitrate from organic farming systems over a crop rotation period was lower than in conventional agriculture. However, leaching losses are strongly related to the previous crop, cultivations and the presence of winter green cover and hence can vary significantly throughout any rotation. Much larger leaching losses of N (2–3 times the total N loss) have been measured following the cultivation of grass-clover leys than at other points in the rotation (Watson et al. 1993). Stopes et al. (2002) found that leaching losses vary by a factor of seven when comparing seasons and points in the rotation. Management practices (cultivation timing and crop establishment) are therefore critically important immediately following the incorporation of "green" legume crops to prevent losses of nitrogen, which will restrict the yield of the following crop and also cause significant environmental impact through nitrate leaching. Reduced emissions of ammonia from livestock housing in organic systems may occur due to the increased use of straw for bedding. However, handling and spreading manure can result in significant losses of ammonia (Hartung 1992). In livestock systems, the nitrogen surplus and eutrophication potential tends to increase with increasing stocking density (Berry et al. 2003; see Chap. 10). Taken overall, there is no evidence that organic farming systems have a higher risk of nitrate leaching than conventional systems; indeed organic cropping systems may show a slightly lower eutrophication potential on an area basis (Di and Cameron 2002). When leaching amounts are expressed in relation to crop yields, Korsaeth (2008) found that there was no significant difference in leaching loss between conventional and organic systems. However, modifications to the conventional cropping system were able to reduce leaching per unit product below those of the organic system (Korsaeth 2008). Eutrophication potential cannot be simply expressed in terms of the cropping system (organic vs. conventional); instead the crop rotation design, amounts and timing of N input, and the use of countermeasures such as catch crops and timing of tillage need to be known to predict leaching risk (Kirchmann and Bergström 2001).

14.3.5 Impacts on Greenhouse Gas Emissions

Carbon dioxide emissions and energy use are usually closely linked. Detailed comparisons of the energy efficiency of production systems have been carried out since the 1980s (e.g. Pimentel et al. 1983). A range of approaches and methods have been used, however, and consequently the data are difficult to compare directly; Gomiero et al. (2008) provide a critical summary.

On-farm energy requirements (linked to tractor hours and hence fuel use) are often higher on organic than conventional farms. Wood et al. (2006) found that on-site energy requirements were 22% higher for organic than conventional farms in Australia and linked this to weed control and manure spreading operations coupled with lower labour intensity on the organic farms. Improved soil structure (see Sect. 14.3.3) may reduce fuel use during cultivation in organic systems, and there are a range of opportunities for organic farming systems to further reduce direct energy consumption. Ahlgren et al. (2009) demonstrate that it is theoretically possible for an organic farm to be self-sufficient in tractor fuel (derived from biomass grown on the farm); however, the proposed solutions are of high technological complexity and not yet implementable at commercial scale or reasonable cost. The indirect use of energy embedded in inputs such as fertilisers, herbicides and pesticides is less than half that on comparator conventional farms (Wood et al. 2006). Consequently, many studies show that the overall energy use of organic farms is lower than a conventional comparator, whether assessed on an area or per tonne of product basis (see summary of analyses to date in Wood et al. 2006; Gomiero et al. 2008). However, due to variations in management for particular crops in different systems, simple comparisons between systems are not easy; for example, organic potato crops may show both lower and higher energy consumption compared to conventional systems per tonne of potatoes (Gomiero et al. 2008).

In addition to direct and indirect CO_2 emissions as a result of energy use, agriculture is a major contributor to the global emissions of methane and nitrous oxide (50 and 60% of global anthropogenic emissions, respectively; IPCC 2007) (see Chaps. 9 and 10). However, there is very little measured data available to assess the overall greenhouse warming potential of organic farming systems in comparison with conventional practice. Wood et al. (2006) showed that the greenhouse gas intensity of conventional farms was on average twice that of organic farms; however, this excluded emissions of methane from animals and emissions of N_2O from soils and fertilisers. Nitrogen surpluses in organic farming systems tend to be lower than those for conventional systems, which indicate a lower potential for gaseous nitrogen emissions from soil. However, estimated and measured N_2O

emissions show no clear differences between organic and conventional farming systems (Flessa et al. 1995; Reitmayr 1995; Syvasalo et al. 2006). Lower stocking rates in organic farms are likely to result in lower methane and N_2O emissions per hectare, even though emissions per animal are likely to be similar in organic and conventional systems.

14.3.6 Interactions at a Farming Systems Level

Although soil forming/land capability factors (climate, geology, topography, ecosystem) determine the boundary conditions for soil quality in any location as a result of their impact on inherent soil properties, soil health tends to be enhanced where management and land-use decisions take the multiple functions of soil into account and to deteriorate where decisions focus solely on one function, most often crop productivity (Doran 2002). Hence, we might expect better soil health, and consequently better overall environmental performance, in organic farming systems. Sandhu et al. (2008) calculated the total value of ecosystem services delivered in conventional and organic arable landscapes in New Zealand; while the overall value of ecosystem services delivered by organic systems was higher on average than for conventional systems, there was significant overlap on a field by field basis (Fig. 14.3), so that some conventional fields deliver more ecosystem services than organic fields.

Low-input approaches have been developed and implemented, particularly in degraded ecosystems, using farmer participatory approaches which also increase the skill and understanding of the local farming community (e.g. Scoones and Thompson 1994). In degraded areas, application of composts has been shown to increase crop yields compared with typical field practice and with matched inputs through chemical fertilisers (e.g. doubling of yields compared to field with no inputs and small increases compared to use of chemical fertilisers in Tigray, Ethiopia; Edwards 2007). Other minor impacts such as reduced crop pest problems

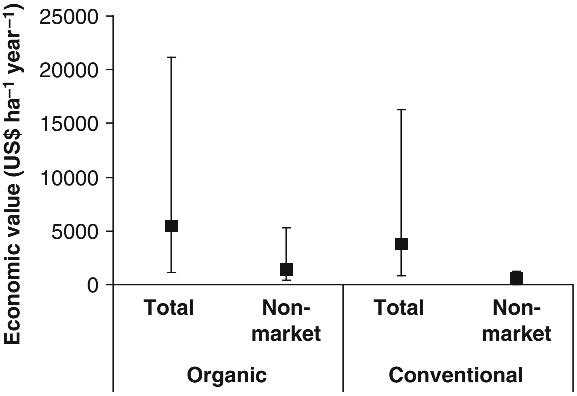
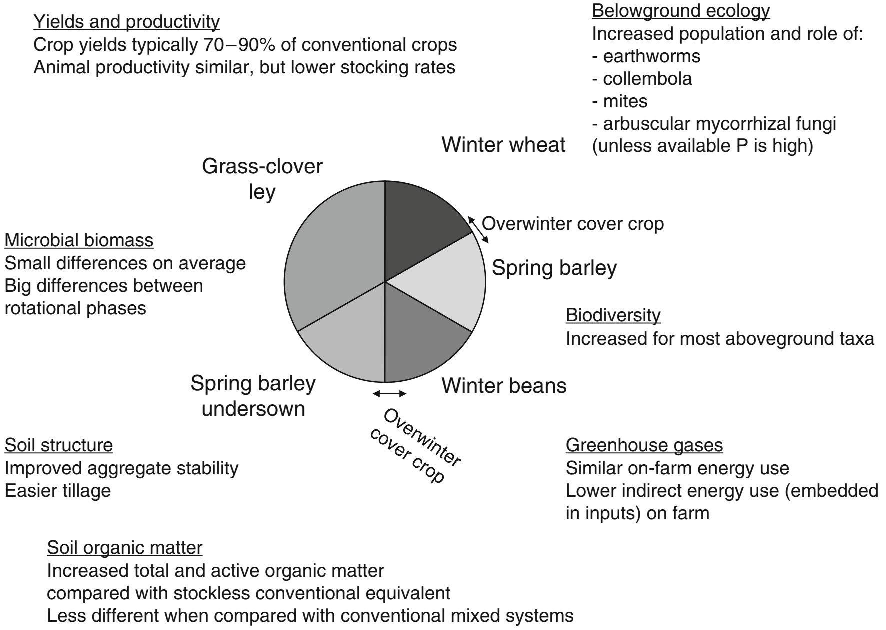


Fig. 14.3 Mean and range of economic value (total and non-market) of ecosystem services measured in organic and conventional fields ($n = 29$). Redrawn from data provided Table 1 in Sandhu et al. (2008). Non-market ecosystem services were significantly higher in organic fields

and increased soil moisture retention have also been noted where compost is used (Edwards 2007). However, there has been little evaluation in practice of the management options that are recommended as more sustainable: “For the most part sustainable agriculture projects assume that the practices they promote will improve sustainability without ever measuring the results to see if this is actually the case” (Holt-Giménez 2002). Most of these recommended low-input strategies advocated for all agricultural systems, for example use of cover crops, green manures, animal manure and reduced tillage, are already embedded in organic farming systems and lead to increases in soil organic matter levels compared to the levels typical of intensive conventional management approaches, where residues are removed/burnt, tillage is intensive and no inputs of organic materials are made (Matson et al. 1997). Reduced tillage approaches have been adopted in many arable farming systems (see Chap. 9); however, they are not widely used in organic farming systems as a result of the need to use tillage-based seedbed preparation approaches for weed management where herbicides are not available. Best practice options for soil management are not restricted to organic farming. Even within organic systems which, according to their principles, have a more integrated approach to crop production, often a narrow input-substitution approach to soil management is taken (as an example, see the farmer perceptions revealed in Kaltoft 1999). Low-input strategies require intensive use of information to design effective rotations and management strategies that ensure synchronisation of nutrient release with plant demand, given the wider quality of nutrient sources available; productive and sustainable low-input systems require high levels of farmer knowledge. The decisions of land managers, driven by their underlying values, perceptions and level of understanding, are often the critical factor determining soil health.

Integrating the information gained from paired farm comparison and field trials for the model farming systems (Figs. 14.1 and 14.2) indicates that while overall yields are reduced in organic farming systems, on average there can be significant improvements in soil health as a result of the adoption of organic farming practices (Figs. 14.4 and 14.5). These can lead to significant improvements in resilience under current climatic conditions. In Nicaragua, the introduction of sustainable land management practices (contour ploughing, contour ditches and bunds, incorporation of legumes in rotations and as inter-crops, use of compost, live fences and woodlots) was shown in the study following Hurricane Mitch to have reduced topsoil losses very significantly compared to conventional neighbours (Holt-Giménez 2002). In dry temperate climates (Australia), Wood et al. (2006) showed much lower water dependence of organic farms compared to the conventional comparator – but differences between the farming types are strongly dependent on crop/livestock type. It has been suggested that organically managed crops have higher resistance to drought conditions and higher cropping system yield stability – Gomiero et al. (2008) drew together available data and suggest that yields can be 70–90% greater than conventional systems under severe drought. Yield resilience is a very important benefit under more marginal conditions for crop growth (Fig. 14.5), especially where irrigation inputs are fixed (or decreasing); Melero et al. (2006) found



Yields and productivity
Crop yields typically 70–90% of conventional crops
Animal productivity similar, but lower stocking rates

Belowground ecology
Increased population and role of:
- earthworms
- collembola
- mites
- arbuscular mycorrhizal fungi (unless available P is high)

Microbial biomass
Small differences on average
Big differences between rotational phases

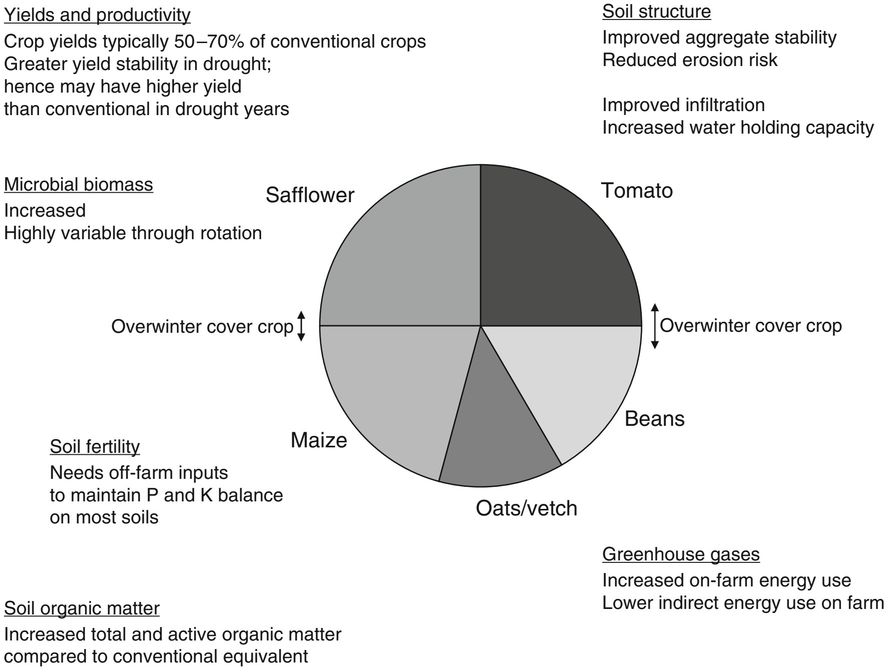
Biodiversity
Increased for most aboveground taxa

Soil structure
Improved aggregate stability
Easier tillage

Greenhouse gases
Similar on-farm energy use
Lower indirect energy use (embedded in inputs) on farm

Soil organic matter
Increased total and active organic matter compared with stockless conventional equivalent
Less different when compared with conventional mixed systems

Fig. 14.4 Impacts on soil health expected from the implementation of a typical 6-year organic rotation common in cool temperate climates, forming part of a mixed farming system



Yields and productivity
Crop yields typically 50–70% of conventional crops
Greater yield stability in drought; hence may have higher yield than conventional in drought years

Soil structure
Improved aggregate stability
Reduced erosion risk

Improved infiltration
Increased water holding capacity

Microbial biomass
Increased
Highly variable through rotation

Soil fertility
Needs off-farm inputs to maintain P and K balance on most soils

Greenhouse gases
Increased on-farm energy use
Lower indirect energy use on farm

Soil organic matter
Increased total and active organic matter compared to conventional equivalent

Fig. 14.5 Impacts on soil health expected from the implementation of a typical 4-year organic rotation common in Mediterranean climates that increasing soil organic matter through compost application in organic systems increased yields of melon/watermelon crops compared to the comparative conventional system where compost was not applied.

14.4 Impacts of Climate Change on Farming Systems and Relevant Adaptation Measures: The Role of Organic Farming

It is well known that soil and environmental conditions interact to define regional patterns in agricultural systems creating agro-ecoregions (Graef et al. 2005), such as the Corn Belt (USA), Wheat belt (Western Australia), etc. In the UK, Gabriel et al. (2009) have studied the spatial aggregation of organic farming and found that currently conversion to organic farming is less common in the UK where soil types and climates are strongly suited to arable production and most common within areas where conventional farming is typified by small, mixed and dairy farming systems; increased ruralisation also favours conversion to organic production systems. It appears that current uptake of organic (and other alternative) agricultural systems is driven by a combination of factors in both the physical and socio-economic environment which interact with personal farmer motivational factors (Kaltoft 1999). Hendrickson et al. (2008) reviewed the role of environmental drivers in determining the uptake of low-input practices (as outlined above in Sect. 14.2; Doran 2002) within conventional systems in the Great Plains of the USA, using surrogate indicators (crop diversity and pasture/cropland ratio). Different trends in uptake of practices were seen in different states linked to annual rainfall. Hendrickson et al. (2008) suggested that there are other factors, such as landform, length of growing season coupled to the availability of irrigation that predispose farmers to adopt integrated low-input systems as a strategy to provide economic stability in variable conditions. While climatic regions set some constraints to the adoption of particular practices or agricultural systems, it is clear that the direct impacts of climate change will be only one driver of change in farming systems; changes in markets and agricultural policy will have an equally significant impact.

Modelling of climate change indicates that for most regions there will be changes in both means and extremes of temperature and rainfall which will affect the designation of current agro-ecoregions (e.g. Lobell et al. 2008). However, it is important to note that in any region, day length will not be affected and consequently, for some crops, suitability regions may not simply move towards higher latitudes. Porter and Semenov (2005) showed using experimental data and modelling that negative impacts on the yield and quality of wheat would occur more often than under current conditions. They also showed that increased occurrence of short periods of extreme temperatures or precipitation would have significant impacts on crop development especially C and N sink formation and activity. Changes in climate at any location will also modify the ability of the crops to respond to other factors, for example increased nutrient supply or improved plant protection (Porter and Semenov 2005). Porter and Semenov (2005) showed by modelling that the predicted changes in climate will have relatively little impact on average cereal yields in the UK; the largest impacts on yield are expected to occur where crops are currently being grown close to the edge of the climatic optimum, for example wheat may not be cultivable in the Mediterranean by 2050. In each region climate/soil interactions will hold the key in determining the suitability of current cropping patterns and farming systems under changing climates. Furthermore, direct climate change impacts on crop choice and rotation design will be largely indistinguishable for organic and conventional systems. Nevertheless, organic systems are likely to be more resilient to the anticipated impacts of climate change on temperature and rainfall, due to changes in organic matter and soil structure that currently increase resilience to drought (see Sect. 14.3.6).

Climate change factors will impact on the physiological processes, activity and phenology of pests and their natural enemies (Stacey 2003). However, accurate prediction of likely impacts depends on how all the species involved (plant, pest and predator/parasite) react to changing patterns of temperature, humidity and cloud cover (Stacey 2003). This may lead to different patterns of disease/pest risks, new pest and diseases and failure in existing methods of pest control including biological control. Stacey (2003) suggests that increased variability in weather patterns will result in increased difficulty for farmers in designing management practices, which reduce pest control impacts on yield and/or quality due to the complex interactions between biological and environmental factors. Climate change impacts on pest and disease risk will be largely indistinguishable for organic and conventional systems; however, the multi-factorial approach to develop networks of partial solutions for pest and disease management routinely used in organic systems are likely to become more common in conventional systems.

Action taken at farm scale can modify the potential impacts of climate change; farm decision making can reduce the vulnerability of farming systems to climate change impacts (Reidsma et al. 2009). However, there will be interactions between inherent land properties (land capability) and management in determining the local impact of climate change. While for many farmers, the introduction of sustainable land management practices very significantly reduced the topsoil losses that resulted from Hurricane Mitch (Holt-Giménez 2002), on slopes >30% even these practices were not sufficient to confer agro-ecological resistance in storms with high rainfall intensity. Consequently, for some areas the only safe option may be to withdraw land from cultivation in the light of the predicted increased frequency of extreme events. Modelling suggests that there may be increasing abandonment in currently marginal areas; however, variability in the scale and geographical location of predicted impacts (e.g. the extent of the wheat cultivation zone) between modelling scenarios is high (e.g. in Europe, Audsley et al. 2006; Berry et al. 2006).

In temperate Northern European climates, the predictions are that changes in climate will lead to increases in crop yields overall and that the range of crops available for cultivation will increase (Ewert et al. 2005); so there will be relatively little impact to the crop rotation in the first of our case study systems (Fig. 14.6).

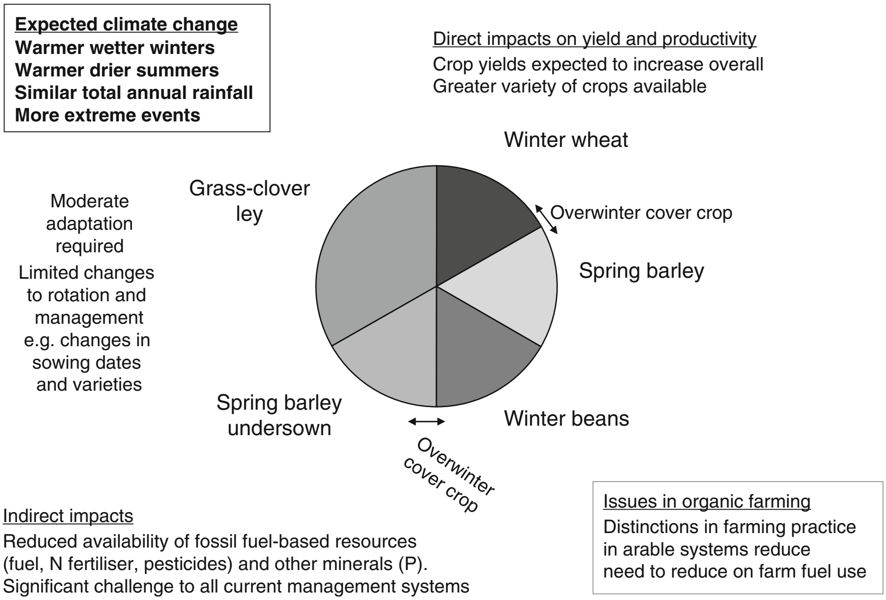


Fig. 14.6 Predicted climate change and its direct and indirect impacts for a typical 6-year organic rotation common in cool temperate climates, forming part of a mixed farming system. Issues for organic farming systems highlighted

The simplest adaptation options available to farmers, which include changes in varieties and sowing dates, may be sufficient even under the changed climates in temperate regions. However, under Mediterranean conditions, water shortages will drive agricultural change increasingly restricting yield and the land available for cropping (Metzger et al. 2006). Irrigation is currently a key strategy to reduce yield variability of high value crops in Mediterranean conditions (Reidsma et al. 2009). However, reducing rainfall is also likely to increase competition for water for irrigation, and adaptation strategies may need to include the increased use of wastewater in crop irrigation. Due to infrastructure limitations, this is likely to significantly reduce the area of irrigated cropping. With much lower amounts of water for irrigation, drought will severely restrict the range of crops available for cultivation in the Mediterranean case study system (Fig. 14.7) whether in organic or conventional systems. In marginal rainfall areas, one of the common approaches currently taken by farmers is to vary the amount of land used for crop production with land fallowed where insufficient water reserves are considered to have been accumulated (Hendrickson et al. 2008). In these areas that are marginal for cropping, increased organic matter levels in organic farming systems increase soil moisture retention and may allow more frequent cropping. Under Mediterranean conditions, it will be increasingly important to adopt new approaches and to design rotations and management strategies that are able to exploit ecological synergies in the use of water and nutrients (Tanaka et al. 2005). The focus in organic systems of

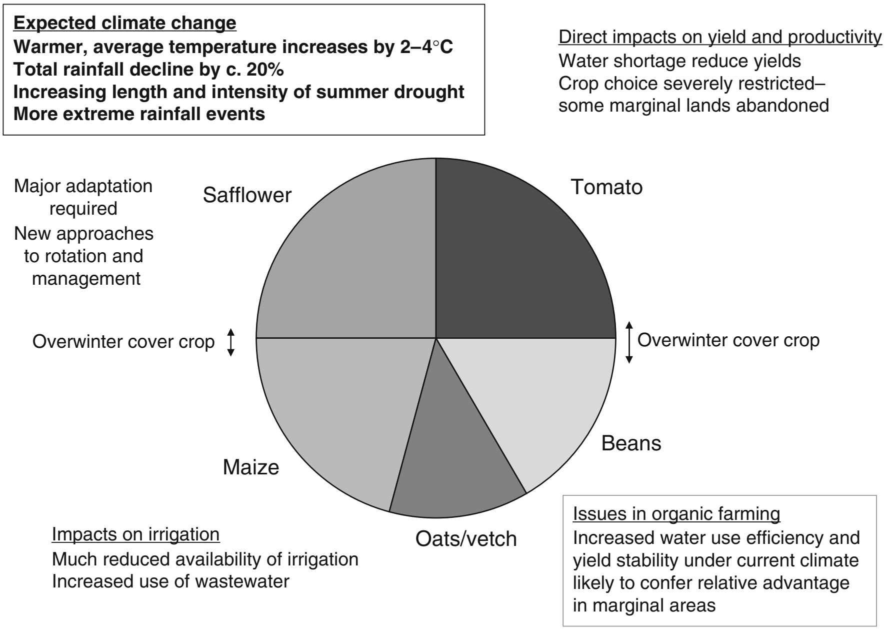


Fig. 14.7 Predicted climate change and its direct and indirect impacts for a typical 4-year organic rotation common in Mediterranean climates. Issues for organic farming systems highlighted

designing ecologically adapted rotations under current climatic constraints may give organic farmers a head start. Opinions on the role of using gene modification (GM) to improve crop stress resistance including drought tolerance range from extremely optimistic to very sceptical (Marris 2008). Hervé and Serrah (2009) also highlighted that most of these studies are still a long way from producing crop varieties that could greatly improve drought adaptation or water productivity in the field, because the traits targeted are very complex. If such an approach was successful, current organic standards would prohibit GM varieties for organic systems, and hence there may be greater divergence in the varieties cultivated in organic and conventional systems in the future than has been the case to date.

Alongside the changes to the climate itself, it seems almost certain that fossil fuel-based resources, including nitrogen fertiliser and pesticides, will become increasingly expensive and scarce (Kirschenmann 2007). Increasing scarcity of other mineral resources, for example phosphate rock, also seems likely. Consequently, a search for appropriate agronomic techniques may mean an increased focus on the approaches used in the past (Hanson et al. 2007) and now only used commonly in reduced input systems. Examples of these approaches include diverse crop rotations, crop mixtures and local recycling of waste to land. Hence, recommendations for the development of productive farm systems for the future highlight principles that are largely familiar to organic farmers, but nonetheless challenging. Examples of recommendations are outlined by Kirschenmann (2007):

Post modern farms will likely need to:

i) be energy conserving;
ii) feature both biological and genetic diversity;
iii) be largely self-regulating and self-renewing;
iv) be knowledge intensive;
v) operate on biological synergies;
vi) employ adaptive management;
vii) feature ecological restoration rather than choosing between extraction and preservation, and;
viii) achieve optimum productivity by featuring multiproduct, nutrient-dense, synergistic production on limited acreage.

Many of the approaches/management strategies for improving soil health and agricultural sustainability recommended by Doran (2002), described above and also see Chap. 1, are already well understood by both farmers and agronomists. However, the economic costs of better management practices (including negative short-term impacts on productivity) might mean low rates of adoption of these practices by farmers. Appropriate policy structures are essential therefore to enable action for medium- to long-term effectiveness to be adopted in the short term (Holt-Giménez 2002). The increased policy focus on carbon sequestration in agricultural systems as part of climate change mitigation strategies may provide a mechanism that directs support to farmers and also promotes adaptation (see Chaps. 1 and 5; Smith et al. 2000).

Can the adoption of organic farming systems help to reduce vulnerability to climate change of the farm, its ecosystem services and the community in which it is embedded? Such a question requires a consideration not only of the risk resulting from changes in the physical environment but also the adaptability of the social and economic structures, which help to determine the capacity of the system to anticipate, cope and recover (Berry et al. 2006). Tompkins and Adger (2004) argue for the urgent development of adaptive systems for working with natural resources under current climatic conditions to increase the ability to adapt to climate change and other factors, such as changes in market demand in the future. Consequently, developing farmers' skills to understand and manage their farming systems in relation to climatic variation now will enhance resilience to climate change through knowledge based rather than technologically reliant innovation. One of the biggest advantages organic farmers may have is not only that they have built resilience into their soils through increasing organic matter levels, but also that they themselves have already been converted to an adaptive way of working, which encourages considered strategic responses rather than quick-fix solutions. For example, Lohr and Park (2002) observed higher willingness and capacity to innovate when comparing organic farmers with conventional farmers in approaches to insect management. Preventing land degradation, supporting biodiversity and the supply of a range of ecological goods and services may be as important as maintaining yield in the light of climate change; a focus on short-term protection of productivity may lead to medium- to long-term yield loss and misleading conclusions in assessments of the sustainability of farming systems (Gomiero et al. 2008). Adaptation will also require a change of focus in agricultural research and extension so that the environment is no longer viewed as an adversary to be overcome through inputs and mechanisation (Hendrickson et al. 2008), rather the environment may need to be viewed as a partner in agro-ecosystem development.

14.5 Conclusions

Maintaining soil health is central to the principles and regulations which govern organic farming systems. In order to create locally adapted profitable systems, many organic farmers have converted from input/technology-driven management to adaptive management approaches. This combination of practice and philosophy means that organic farming systems are inherently well placed to cope with and adapt to climate change: maintenance of soil health and application of adaptive management are key foundational steps for successful adaptation of farming systems in the light of climate change. However, variability within farming systems means that all organic farming systems do not currently achieve these ideals, and that all conventional farming systems do not fail to achieve them. There is currently a lack of data for many farming practice/climate combinations even under current climate conditions to allow comparison of conventional and organic systems. Research and development in organic farming systems, which has been gradually increasing, is likely to underpin developments in farming practice that can be exploited by all farmers to support adaptation to climate change.

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