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RESOURCE EFFICIENCY AND ORGANIC FARMING:

Facing up to the challenge

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Resource Efficiency and Organic Farming: Facing up to the challenge

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Executive Summary

As natural resources become increasingly scarce, the transition to a more resource-efficient economy must be a top priority over the coming years. The challenge for agriculture lies in securing sufficient food supply for future generations while reducing resource use and increasing resource recycling. The European Commission's *Roadmap to a Resource Efficient Europe 2020* addresses, among others, food and farming-related resources, proposes a number of policy instruments to address food consumption and waste recycling and calls for concerted action across a wide range of policies. This brochure contributes to the discussion by showing the potential that lies in organic farming models to confront the challenges ahead.

Healthy **soil** builds the foundation of food production, but is being threatened by degradation and erosion. Organic farming practices increase soil stability, organic matter content and therewith resilience to changing climate conditions. **Biodiversity** must be conserved and enhanced in order to deliver the ecosystem services we need for our food security. Organic farmland is rich in biodiversity; it bears on average 30% more species than conventional farmland, contributing to the maintenance of ecosystem services from pollination and nutrient recycling, to clean water and air.

The availability of **plant nutrients** is limited, but crucial to achieving sufficient crop yields. Organic farming is a pioneer in efficient use and recycling of these essential elements. The case of **nitrogen** (N) shows how organic farming can come to a sensible N-balance through legume crops, crop rotations, lower stocking densities and sensible manure applications, instead of relying on energy-intensive synthetic nitrogen. Organic farming practices also make an important contribution to sustainable **phosphorus** (P) and **potassium** (K) use by reducing nutrient inputs and outputs, replenishing P and K stocks through effective crop rotation, and recycling manure to close nutrient cycles.

Limited resources of fossil fuels as well as the occurrence of climate change highlight the most urgent reasons for improving **energy** efficiency in agriculture. Organic farming has the potential to use less energy due to the prohibition of synthetic fertilisers and pesticides. Lower stocking densities and lower inputs of concentrate feed also contribute to better energy balances.

Water is a precious resource, threatened by pollution and overuse, with the farming sector using 32% of water resources in the EU. Organic farming is a pioneer in the preservation of water quality, abstaining from using synthetic fertilisers and engaging in effective management of water sources by building up the soil and increasing its resilience to extreme weather events.

When we talk about resource efficiency, we must also consider the broader questions such as **land use**: Organic farming is often challenged for being less productive on a per area basis and therefore requiring more land for food production. This efficiency-focused viewpoint disregards the wider issue of long-term stewardship of land. Organic production scores better in integrating and making effective use of the landscape and ecosystem services. In terms of overall sustainability and conservation of natural resources, organic farming already delivers better on long-term food security.

Finally, the search for resource-efficient **food** systems cannot be conducted solely from the perspective of productivity. Today 40% of food is either lost or **wasted** each year. Therefore, the way we manage food distribution and the way consumers value food must be confronted and changed to develop societal responses that deal with food in a resource-efficient way.

Introduction

Today, across the globe, industrialised and industrialising countries are consuming the earth's resources at an alarming rate. It is estimated that if the entire world population had the ecological footprint equivalent to the average North American or Western European, we would exceed the planet's biocapacity up to fivefold (*Kitzes et al., 2008*). The global population is incessantly on the rise. More people on earth and changing consumption patterns highlight essential requirements for more basic human needs, such as food, shelter, energy and water. This suggests that a fundamental rethink of the way we manage our natural resources will be critical to realising a truly sustainable and inclusive future for all the world's citizens. Business-as-usual is no longer an option.

The food and farming sector must play a central role in this respect. For instance, the sector accounts for 32% of EU water consumption (*UN World Water Assessment Program, 2009*) and continues to poorly manage its nutrient supply, while, across the food chain, in the EU alone, up to 90 million tonnes of food is wasted every year (*Monier et al., 2010*). These factors, together with rising energy consumption, contribute to the growing problems of climate change and are closely related to other environmental, social and economic challenges confronting us today. Though agriculture is undoubtedly part of the problem, it can and must also be part of the solution. This has been underlined by a number of recent reports, including the *IAASTD Synthesis Report*, the *3rd SCAR Foresight Exercise* and the UNEP report *Towards a Green Economy*. The European Commission has taken up the challenge of minimising resource use in its *Roadmap to a Resource Efficient Europe* as part of its *Europe 2020* strategy for smart, sustainable and inclusive growth. The roadmap includes the aim to reduce resource inputs in food production by 20% by 2020. Nevertheless, more ambitious targets are needed in the more distant future. Reducing food waste and reasonable land use must be part of the overall strategy.

Organic farming practices today provide many solutions to the resource efficiency challenge in terms of nutrient management, energy use and water efficiency with the potential to produce further perspectives in the future. Relying on its strengths of taking a holistic approach to nature and working in line with ecological systems, organic farming relies on and supports healthy soils and thriving biodiversity, which can deliver a number of invaluable services that assist in the successful management of carbon and natural resources such as water and plant nutrients. To this end, this brochure seeks to address the important contribution organic food and farming systems can make to address the resource-efficiency dilemma and to explore the potential of the sector to respond to current and future challenges.

The foundations of food production

Soil

Soil is one of agriculture's fundamental resources providing services ranging from supplying a solid foundation for the production of food and fibre to managing carbon and contributing to climate change mitigation. We are indebted to soil for a number of reasons such as the key role it plays in the regulation of natural cycles with a major impact on nutrients, flora and fauna, and water to support nature and agriculture.

Soil is now increasingly threatened by a number of anthropogenic activities such as erosion (loss of topsoil and humus), humus and nutrient depletion, surface sealing, salinisation (excessive amounts of sodium, magnesium and calcium), contamination and compaction. 16% of EU agricultural land is threatened by water erosion, while up to 4% must confront the challenges associated with wind erosion (*EEA, 2003*). Organic matter is a good source of many nutrients and improves soil structure, with 95% of soil nitrogen to be found in organic matter (*Durán Zuazo & Rodríguez Pleguezuelo, 2008*). Yet, up to 45% of soils in the EU have a low organic matter content (*Rusco, Jones & Bidoglio, 2001*), and eroded soils can be responsible for 15-30% lower crop yields as compared to uneroded soils (*Schertz et al., 1989; Langdale et al., 1992*). As a result, there is a strong case to make for preventing erosion, given the fact that soil is effectively a non-renewable resource (*Jónsdóttir, 2011*). Removing land from cultivation also has serious implications for the maintenance of valuable soil sources. In the Netherlands and Belgium, over 7% of land is sealed, and conversion to built-up land grew by 3.4% across Europe from 2000 to 2006 (*EEA, 2010*). The cost of inaction to adequately protect soil is estimated to be at €38 billion per year (*European Commission, 2007*). Despite such evidence, there is still not sufficient political will for legislation that seeks to integrate, protect and maintain the fertility of soil across the EU. This is most alarming considering soil's importance as an essential resource for food cultivation and to combat climate change.

Organic farming maintaining healthy soil

Healthy soil is at the heart of organic agriculture. By respecting nature and natural processes and resources, and incorporating farming practices such as crop rotations, grass-clover leys, cover cropping, alley farming, agro-forestry, animal manure, integration of crop and livestock farming, and abstention from synthetic fertilisers and pesticides, organic farming contributes to a healthy ecosystem, good soil conditions and water environments. Organic farms generally have improved soils teeming with biodiversity, storing carbon and building humus (*Pfiffner & Mäder, 1997; Vasilikiotis, 2000; Hole et al., 2005; Esperschütz et al., 2007; Fließbach et al., 2007; Niggli et al., 2009; Zeiger & Fohrer, 2009; Niggli, 2010*). Even comparing organic systems to no-till agriculture, a system often hailed as reducing loss of carbon, but relying on chemical pesticides and synthetic fertilisers, showed organic to have more nitrogen and carbon (*Teasdale, 2007*). Applying reduced-tillage to organic systems also proves beneficial in terms of organic carbon content and biodiversity, at least during the conversion period from conventional to reduced tillage (*Berner et al., 2008*).

For soil to be able to breathe, live and perform its various vital functions, organic agriculture shows clear benefits over other forms of farming. Considering the fact that soil is effectively a non-renew-

The foundations of food production

able resource, organic farming with its soil-conserving measures is a shining model for resource efficiency.

Biodiversity

The importance of biodiversity has only been recognised recently as an integral part of a healthy ecosystem. Today, biodiversity is largely acknowledged as being indispensable to maintaining the planet as we know it. Biodiversity caters for the cleansing of air, water and soil; supports numerous soil functions such as nutrient recycling; provides pollination services helping crops grow, plants disperse, and bringing forth the next generation. It also regulates many more interactions with indirect impacts for humans, offering areas of respite and relief, generating tourism, giving scientific and poetic inspiration, providing aesthetic beauty, and helping regenerate the natural resources we so much depend on. Attempts are now being made to incorporate the importance and benefits of biodiversity in economic terms by means of *The Economics of Ecosystems and Biodiversity* (*TEEB*) to make the concept more accessible to citizens and policy-makers alike. While this will never do justice to the real, unquantifiable value of biodiversity, it brings us a step closer to gaining a greater understanding and appreciation.

Biodiversity is under threat from a range of anthropogenic influences. In agriculture, the main threats stem from intensification (i.e. high use of inputs and high stocking densities), specialisation, use of synthetic fertilisers and pesticides, land abandonment, climate change, invasive alien species and overgrazing (*Hole et al., 2005; SEBI, 2010*). These practices are preventing biodiversity from budding and thriving, to the detriment of all stakeholders. What is needed is a reversal of these trends towards more extensive agriculture, protection of high nature value farmland, recreating natural habitats around farms, and natural land management practices.

Organic farming working with biodiversity

Organic farming is a holistic, innovative and healthy form of agriculture respectful of nature and ecosystems. An overwhelming number of studies conclusively shows organic farmland to host more species and be beneficial to biodiversity (*Hesler et al., 1993; Drinkwater et al., 1995; Frieben & Köpke, 1995; Wyss, 1995; Wyss, Niggli & Nentwig, 1995; Pfiffner & Mäder, 1997; Brown, 1999; Hald, 1999; Kay & Gregory, 1999; Mäder et al., 2000; Mohamed, Lester & Holtzer, 2000; Mäder et al., 2002; Östman, Ekbom & Bengtsson, 2003; Wickramasinghe et al., 2003; Oehl et al., 2004; Bengtsson, Ahnström & Weibull, 2005; Fuller et al., 2005; Hole et al., 2005; Peng & Christian, 2005; Gabriel et al., 2006; Hartmann et al., 2006; Esperschütz et al., 2007; Fließbach et al., 2007; Gabriel & Tscharntke, 2007; Holzschuh et al., 2007; Pfiffner & Luka, 2007; Birkhofer et al., 2008; Kragten, Trimbos & de Snoo, 2008; Gabriel et al., 2010*) due to common practices such as crop rotation, leaving buffer strips, absence of synthetic pesticides and using breeds adapted to the area.

A sustainable agricultural model for our landscapes must be one that treats the essence of life, biodiversity, with the greatest care and gives it the freedom it needs to live and expand. Organic farming clearly shows itself as a humble host, catering to biodiversity's every need.

Balancing inputs and outputs

Nitrogen

Nitrogen (N) is in us and all around us, in abundant amounts. Despite this, nitrogen is one of the elements being singled out as a challenge for future farming and food security. The explanation for this paradox lies in its level of reactivity: most N is locked up as N_2 in the atmosphere, where it doesn't do much. To make it accessible, N must be available in reactive form, that is nitrate (NO_3^-) or ammonium (NH_4^+). This is made available to plants by means of microbial activity and biological nitrogen fixation by bacteria. N plays a key role in plant nutrition and photosynthesis, and is a component of chlorophyll and proteins.

The shortage of reactive nitrogen for plant production was solved temporarily with technical innovations, such as the Haber-Bosch process in the early 20th century, which greatly increased the availability of reactive nitrogen and thus food production. The number of humans supported per hectare of arable land increased remarkably from 1.9 to 4.3 persons between 1908 and 2008 (*Erisman et al., 2008*), and industrial production of N in 2008 in Europe was about 34 million tonnes, of which 43% was used for fertiliser production (*FAO, 2008*). Industrial nitrogen production requires high energy inputs, mainly supplied through fossil fuels. The efficiency of nitrogen use is thus highly correlated to energy use (see chapter on "Energy"), and the two must therefore be addressed and tackled in unison. The abundance of reactive nitrogen also spurred another development: that of environmental pollution in the areas of water, air, greenhouse balance, ecosystems, biodiversity, and soil. Policies incentivising farmers to produce more food (such as the CAP), can be partly blamed for this, encouraging farmers to use more artificial fertiliser and rear more livestock. Policies to increase biofuel production and use have also had a significant impact on the use of N, as they also require high fertiliser inputs, and thereby lead to further emissions of N into the atmosphere from combustion.

Currently, nitrogen pollution is costing the EU €70-320 billion a year, or €150-750 per EU citizen (*Sutton et al., 2011*). More than 50% of nitrogen discharged to water bodies can be attributed to agriculture (*RIVM, 1992; FAO, 1994*), while 15% of soils in the EU-25 were shown to have in excess of 40kg N per ha (*Bouraoui, Grizzetti & Aloe, 2009*). Further exacerbating the problem is that reactive N can undergo a number of transformations and affect numerous systems, making the actual extent of nitrate pollution difficult to quantify and assess, and the potential damage difficult to gauge (*Sutton et al., 2011*). While the EU has taken a number of strides in reducing pollution, for example with the Nitrates Directive in 1991, improving nitrogen use efficiency (NUE), defined as the share of nitrogen in a product leaving a farm compared to total nitrogen input to the farm, must become a priority area as well (*Tilman et al., 2002; Mosier, Syers & Freney, 2004; Galloway et al., 2008*). This is particularly important considering that NUE is still below 50% in many Member States (*OECD, 2000; Oenema et al., 2009; Sutton et al., 2011*). Another key focus area should be denitrification, as 40% of fertiliser applied to the soil is effectively wasted as a result of this (*Sutton et al., 2011*). Further, the amount of nitrogen shipped across the world in the form of fertiliser or farm products should be reduced where possible to prevent places of excessive nitrogen concentration (*UNEP, 2007; Galloway et al., 2008*).

Balancing inputs and outputs

Organic farming embracing sustainable nitrogen use
Simple steps towards sensible management practices can be undertaken by every farmer: minimising N-input in rainy seasons when N-leaching is most pronounced, avoiding adding manure at the end of a farming season, not adding manure *and* inorganic fertiliser, managing manure stores and compost facilities to prevent leaching, and growing cover crops. Organic farming is best placed to respond to the challenges of effective nitrogen management, with many beneficial practices already an integral part of organic farming systems. The abstention from synthetic fertilisers to enhance soil fertility and the rejection of monoculture farming in favour of a diversified crop rotation system, which creates a reciprocal take-up and supply of nitrogen in the soil, are key ways in which organic farming plays a pivotal role in preventing the over-application of nutrients. Other practices include lower stocking densities and the sensible use of nitrogen through farmyard manure and compost, making oversupply and hence excessive leaching very unlikely in organic farming (*Edwards et al., 1990; Younie & Watson, 1992; Eltun, 1995; Shepherd et al., 2002; Shepherd et al., 2003*). Organic farming thereby proves to be a model approach for sensible use of nitrogen, and farming in line with nature and natural processes.

Phosphorus and Potassium

As crucial elements in the development of all forms of life, phosphorus (P) and potassium (K) are fundamental to sustainable European and global food systems. The naturally-occurring elements P and K are found in rock and soil, where they are transferred across the food chain from plants to animals and humans who intake them either directly (plants) or indirectly (meat). They can then in principle be recycled through the application of animal manure and human sewage on the land as fertiliser. Over centuries, developments in sanitation, crop cultivation and international trade, however, have seen the end of a once closed-loop cycle of P, K and other nutrients. This has led to a growing dependency on mined phosphate and potassium to produce mineral fertilisers (*Ashley, Cordell & Mavinic, 2011*).

P and K are essential for plant growth and maintaining the fertility, productivity and hence the economic viability of a farm. Today, however, farmers face a series of problems related to the use of P and K. Firstly, large quantities of P, K and other nutrients are being lost from our soils (*Pimentel et al., 1995*). Secondly, there is a realisation that mineral phosphorus and potassium are non-renewable resources. Rock phosphate in particular is declining at an increasing rate (*Cordell, Drangert & White, 2009*). Finally, poor phosphorus management has a serious negative environmental impact on water quality leading to the eutrophication of aquatic environments (*Sharpley, Richard & Kleinman, 2001*).

Organic farming responding to potassium and phosphorus availability
There is growing evidence to show that organic farming is best placed to respond to the necessity of more efficient use of potassium and phosphorus. Mainstream farming systems are deeply dependent on large quantities of P and K in the form of mineral fertiliser to replace lost nutrients and maintain high yields. In contrast, organic farming works to limit inputs and recycle on-farm nutrients. EU organic standards are based on the principle of restricted use of external inputs and only accept the application of mineral fertilisers where required (*European Community, 2007*). Instead,

organic farmers rely on a number of practices to maintain sufficient levels of P and K on their farms such as the use of green manure and the recycling of animal manure, slurry and other organic material. As organic farmers seek to balance inputs and outputs, effective nutrient management across the entire farm holding is essential. Organic farmers are therefore encouraged to calculate the nutrient content of manures and composts before applying it to the land to ensure optimal management of nutrient budgets (*Watson, Topp & Stockdale, 2009*). Other practices such as multi-annual crop rotation are particularly important for increasing availability of P in the soil. A 21-year comparative study of bio-dynamic, organic and conventional systems, based on ley rotations in Switzerland, for instance, found that while inputs of N, P & K were 34-51% lower in organic systems, soil activity on organic farms observed faster phosphorus flux through the microbial biomass, which contributed to P supply among plants (*Mäder et al., 2002*). Other practices such as intercropping allow farmers to recover currently insoluble forms of P through the cultivation of legumes (*Kamh et al., 2002*). Supporting healthy root structures, mycorrhizal fungi and other plant dynamics to increase uptake of P and K through effective crop rotation design are practices typically adopted by organic farmers. Roots can release enzymes that allow organic matter to be broken down, which in turn release nutrients. In the case of green manure, large root structures allow large populations of microbes to develop, resulting in the discharge of P and K from organic matter. The incorporation of specific crops such as clover and chicory in crop rotations with their deep root architecture have been shown to be able to access available P and K and other nutrients and return them to the topsoil (*Organic Centre Wales, 2010*), and mycorrhizal fungi show good signs of improving NUE (*Hildermann et al., 2010*). These are practices that organic farmers are intrinsically best placed to deliver.

Despite the important role organic practices can play towards greater efficiency, the fact remains that these solutions fail to confront the urgent need to maintain additional sources of P and K beyond the farm-gate, in order to secure sufficient nutrient levels. A UK study found that the use of P and K reserves on organic arable land highlighted the necessity for organic farmers to secure P and K sources off-farm in order to ensure long-term stability of crop output (*Gosling & Shepherd, 2005*). Although the utilisation of on-farm resources is an integral part of the philosophy of organic farming, replenishing stocks through feed, bedding and animal manure inputs have allowed farmers to maintain sustainable nutrient supply. While such practices support the return of P and K to the soil, the use of human excreta is prohibited under current organic regulations (*European Commission, 2008*). Nevertheless, the average human excretes about 500 litres of urine and 50 litres of faeces per year. This translates to about 4kg of nitrogen, 1kg of potassium and 0.5kg of phosphorus - depending on one's food intake and geographical location (*Jönsson et al., 2004*). Due to human waste often being contaminated with heavy metals, hormones, pharmaceutical residues and other pathogens, nutrients in sewage are not recovered. Therefore, improvements could be made in this area through regulating chemicals and heavy metals in our environment better. Also, new technological advances in the form of ecological sanitation systems may hold the key to reclosing nutrient cycles (*Smith, 2009*). It is essential that further research is undertaken to develop sources of human sewage and ensure their safe and effective management and application (*Langergraber & Muellegger, 2005*).

While organic farming is on the right path, it must perform better in the future if it is to address the growing problems associated with diminishing supplies of P and K. Therefore, it is essential that organic agriculture is given the tools to conduct more research and optimise organic farming systems to sustainable phosphorus and potassium management.

Water

Currently, over-pumping of groundwater exceeds the ability of the earth to replenish levels by at least 160 billion cubic metres each year (*Postel, 1999; UN World Water Assessment Program, 2009*). Indeed, agriculture is identified as the largest user of groundwater reserves and responsible for significant pollution of water resources and environments. In the EU, water use in agriculture accounts for 24% of total water abstraction, rising up to 80% in some regions (*EEA, 2009*). With between 2,000 and 5,000 litres of water needed to produce daily food requirements for one person (*FAO, 2009a)*, the consequences of a growing population only serve to highlight the necessity to respond robustly to the twin challenges of depleting water resources and water quality protection. While the EU has tried to tackle these twin challenges with some success at Member State level by means of the Nitrates Directive (1991) and the Water Framework Directive (WFD) in 2000, many water bodies are still at high risk of failing to achieve good ecological status by 2015 (*EEA, 2010*) and efforts to reduce water pollution and the contamination of ground and surface waters from agricultural sources remain a constant challenge. Some progress has been achieved in the domain of pesticides leaching (*Power, 1999*), but poor management practices continue to have a negative impact on water quality in Europe (*Bommelaer & Devaux, 2011*). Current figures show that over 219 million kg of herbicides, fungicides, insecticides and growth regulators were used in the EU-25 in 2003 (*Eurostat, 2007*). Reducing excessive nutrient levels will also be essential to achieving good water status under the WFD (*EEA, 2010*). Since the further intensification of agriculture as a means to increase production would lead to more water pollution (*Parris, 2011*), policymakers acknowledge that more needs to be done to ensure sustainable use of water resources in the future. To this end, the European Commission is preparing a *Blueprint to Safeguard Europe's Water to 2020*, which seeks to ensure good water quality and adequate and efficient use of water quantities.

Organic farming protecting and managing our water resources

Organic farming systems have much to offer in terms of water quality and the management of water holding capacity, as they contribute to the **preservation and restoration of water quality**, protecting downstream users and water habitats that are rich in biodiversity. Since farmers often have very few incentives to undertake measures that prevent pesticides from escaping to water sources, environmental costs of pesticide pollution are still mainly transferred to society as a whole (*Pretty, 2008*). Organic standards prohibit the application of synthetic pesticides to protect water bodies. Although the use of manure and slurry still poses risks to water pollution, organic agriculture has not only significantly reduced its nitrate leaching rates (*Stolze et al., 2000*), but research shows that organic farming systems have the potential to continue to reduce leaching through sophisticated crop rotations, the use of green manures and the maintenance of catch and cover crops (*Heß et al., 1992; Heß & Mayer, 2003; Thorup-Kristensen, 2007*). Crop varieties with different root architecture could be another means to maintain and improve soil structure and enhance water infiltration.

Organic farming also demonstrates effective **water conservation capabilities**. As described in the "Soil" chapter, organic farming impacts positively on soil structure and enhances the water-holding capacity and hence availability of water. Increased humus content, for instance, allows the soil to absorb more water during periods of heavy rainfall, reducing the runoff of surface water and soil erosion (*Zeiger & Fohrer, 2009*). Greater holding capacity means that the soil can then supply plants with sufficient amounts of water in extreme droughts. Moreover, organically-managed crops have demonstrated their superior performance during such events, recording higher yields than their conventional counterparts (*Pimentel et al., 2005; Rodale Institute, 2011*).

These positive attributes have been well documented in successive long-term studies. Field trials in Switzerland, for example, found that organically-farmed soil is not only healthier and more resilient, but also has a greater ability to absorb water as compared to conventionally-farmed soil (*Mäder et al., 2002*). Results from the 30-year Farming Systems Trial at the Rodale Institute in USA observed similar benefits with organic cropping systems much better equipped to store and use water more efficiently, with higher yields in periods of drought (*Rodale Institute, 2011*). In water protection areas and near waterworks, organically-managed systems are clearly preferred and recommended for treatment and cost reduction reasons (*Wilbois, Szerencsits & Hermanowski, 2007; Haas, 2010*). There is also evidence to suggest that organic agriculture has the potential to use less water (*Wood et al., 2006*), but studies on the water footprints of organic and conventional farming are limited. As a result, more research needs to be undertaken and supported in this area in the future.

Organic farming is therefore best placed to respond proactively to the challenge of ensuring sustainable water use by protecting and enhancing water quality and due to its resilience during extreme climate events.

Energy

Fossil fuel scarcity and concerns over climate change are two of the main reasons for seeking ways to reduce energy input in agriculture. Though agriculture in the EU represents 2.2% of total energy use (*Eurostat, 2008*), every sector must play its part in tackling the energy and climate challenge, and there is potential for it to reduce its share even further.

Commonly, energy inputs to the farm are categorised into those consumed on-farm (direct), and those having a bearing on the farm process, or off-farm consumption (indirect). As such, all energy from fossil fuels, electricity use, gas use, etc. that have a direct impact on farm processes are classified as direct energy. Fertilisers and pesticides (manufacturing, packaging, storage, transport), field machinery (manufacturing, transport, maintenance), and intermediate inputs (chemically-treated crop seeds, feedstuffs) are treated as indirect energy inputs. Both are equally important for the calculation of energy consumption and needed for energy use comparisons among different systems. If we were to take into account the wider food chain, such as storage, processing, transport and consumer use, these elements could represent up to two thirds of total energy use (*Pimentel & Pimentel, 2008; Smil, 2008*). The challenge is thus to better quantify and document this in the future.

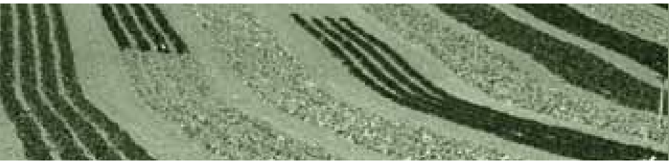
Balancing inputs and outputs

Organic farming working towards sustainable energy consumption

A study commissioned by the Danish government in 2001 found that conversion to organic agriculture would result in energy savings from 9-51% (*Hansen, Alrøe & Kristensen, 2001*). A number of studies concurringly found organic to score better in absolute terms (*Hansen, Alrøe & Kristensen, 2001; Gomiero, Paoletti & Pimentel, 2008*), while others found that on a per area basis, organic scored better, but on a production unit basis, efficiency was the same for both systems (*Mondalaers, Aertsens & Van Huylenbroeck, 2009*). Cormack (2000) found that the efficiency of organic decreases when calculated on a production unit basis, but still remains superior. All in all, a large majority of scientific studies have found organic farming to be more energy-efficient than conventional farming (*Berardi, 1977; Pimentel, Berardi & Fast, 1983; Halberg, Kristensen & Refsgaard, 1994; Alföldi et al., 1995; Cormack, 2000; Stolze et al., 2000; Hansen, Alrøe & Kristensen, 2001; Pimentel et al., 2005; Hoeppner et al., 2006; Deike, Palutt & Christen, 2008; Gomiero, Paoletti & Pimentel, 2008; Mondalaers, Aertsens & Van Huylenbroeck, 2009; Zentner et al., 2009; Gomiero, Pimentel & Paoletti, 2011; Rodale Institute, 2011*).

Lower energy consumption on organic farms is generally attributed to lower concentrate feeding, lower stocking rates, the absence of synthetic fertilisers, and the lack of synthetic pesticides. Synthetic nitrogen takes the lion's share of energy use in conventional farming (*Berardi, 1977; Cormack, 2000; Stolze et al., 2000; Hoeppner et al., 2006; MacRae, Frick & Martin, 2007; Mondalaers, Aertsens & Van Huylenbroeck, 2009; Zentner et al., 2009; Gomiero, Pimentel & Paoletti, 2011*). This is compounded by the fact that 40% of fertiliser input is effectively wasted due to denitrification (*Sutton et al., 2011*). While there are little differences in direct input of energy (as ploughing, cultivation, sowing and harvesting are largely similar for all systems) the non-use of synthetic pesticides can dramatically reduce energy consumption. However, this prohibition may be offset by mechanical weed control (*Alföldi et al., 1995; Pimentel, Berardi & Fast, 1983; Cormack, 2000; Stolze et al., 2000; Bos et al., 2007*). It also appears that different crops use different amounts of energy under conventional and organic methods. Bos et al. (2007), for example, found that peas, sugar beet and beans were more efficient under organic regime, whereas potato, leek and lettuce used more energy when produced organically as compared to conventionally.

In the end, differences in methodology, calculations, system delineation, along with the fact that there is no hard-and-fast definition of 'conventional' make it hard to generalise and compare findings over the various studies (*Cormack, 2000*). Factors such as soil type, farm philosophy, and climate can also have a significant effect on yields and energy use (*Shepherd et al., 2003*). The overwhelming scientific evidence already clearly demonstrates the fact that organic farming often uses less energy than conventional farming, but investments in research and training will be necessary to improve energy efficiency further.



Exploring resource efficiency from the land to the table

Land

With a continuously rising population, the land available per person is constantly decreasing. From 1963 to 2008 the amount of arable land per person decreased from 0.4ha to 0.2ha (*OECD/FAO, 2011*). Assuming a further rise in agrofuel production (an increase of 85% of agrofuel consumption in the EU alone for the period 2005-2020 is forecasted) the chances of more land becoming available are bleak (*OECD/FAO, 2011*). This increasing pressure on agricultural land will lead to more pressure on food security, nature and biodiversity. To further compound the issue, this decrease in available land per person is also being accelerated by losses in soil fertility (*OECD/FAO, 2011*) and soil degradation: 38% of the world's cropland is already degraded (*IAASTD, 2009*).

As land is a finite resource and pressures on land and competing forms of land use are increasing, it is clear that we cannot increase agricultural surface area, but approaches to alternative ways forward differ significantly. Solutions proposed by farm-input industries reach from intensification to increase productivity on the available amount of land, to erosion prevention through no-till agriculture; from greening the deserts up to vertical artificially-regulated farming towers. All these solutions generally involve increased fertiliser and pesticide use; the limits of which have been dealt with in previous chapters. Apart from them being environmentally-questionable, it is also highly doubtful whether energy resources and prices in the future will allow for the continued mining of finite phosphorus resources and production of energy-intensive nitrogen fertiliser or potassium.

Towards long-term sustainable land use with organic farming

Organic agriculture is often challenged for using more land per produced unit, but high productivity per land unit in conventional agriculture today is generally connected to high external inputs and environmental damage. As shown in previous chapters, the current level and manner of resource use is not sustainable, and limits in the availability of phosphorus, cheap energy, healthy soils and others will soon lead to serious constraints if production and consumption patterns are not changed.

The fundamental principles of organic farming are rooted in health, ecology, fairness and care. Organic farming effectively utilises and proactively maintains ecosystem services related to the land it uses. It is a knowledge-intensive type of farming that produces healthy food and healthy landscapes and can create employment by, among others, replacing chemical inputs with labour. Where land use is concerned, we must not only think in terms of efficiency, but also effectiveness, and organic farming puts land to effective, sustainable use.

The total output from the land in terms of food calories also depends on consumption patterns: producing grain directly for food or producing grain as feed for animals for the production of milk, eggs and meat makes a huge difference in output of food calories per hectare (*Pimentel & Pimentel, 2003*). Feeding livestock from grass/clover pastures rather than intensively from soy or wheat from the field leads to wider environmental benefits and a healthy and vibrant landscape. Thus, no matter how productive a field may be in terms of food production, if it is not put to sensible use it will never be effective in terms of closed-loop cycles, ecosystem services, and plant/animal health.

Exploring resource efficiency from the land to the table

The fact remains that organic agriculture is a proven recipe that through its holistic approach takes care of global environmental health. Technical solutions may solve one ill, but in so doing create or ignore others. No-till agriculture, for example, may prevent the loss of fertile topsoil, but generally implies more pesticide use with negative impacts on earthworms (*Frampton et al., 2006; Yasmin & D'Souza, 2010*); land use change may make more agricultural land available, but cause deforestation, climate change, and loss of biodiversity. By diverting money and energy into such projects, we are not only financing dubious endeavours, but also preventing resources from being used towards refining proven concepts such as organic farming.

Research into comprehensive, diverse farm systems, mixed cropping, agroforestry and nutrient recycling is necessary to find solutions that benefit society and the environment. Lastly, socio-economic challenges such as access to land, access to credit, independent training and advisory facilities for farmers as well as access to markets and fair prices must be solved to increase land productivity in a sustainable way. A broad approach towards innovation must be employed in order to make the best use of labour, land and other natural resources for food production (*TP Organics, 2010*). To explore possibilities of making additional land available without causing damage to nature, research streams could be diverted to projects investigating rooftop gardening and urban agriculture for domestic and community consumption. This could not least help to reconnect consumers with their food.

If we look at agriculture from a long-term perspective, we find that as organic agriculture takes a holistic ecological approach, it recognises that the yield one takes from the field is just as important as the soil health one leaves behind. By going beyond what the eye can see, and digging deeper into the (organic) matter, organic farmers understand that what one sees growing on the soil is connected to the inverted growth underneath. As our soils erode, our water levels deplete, flora and fauna vanish, and carbon is released into the atmosphere, we will eventually notice that it's not only a question of the amount of land one uses that determines productivity and sustainability (efficiency), but the interaction of the global whole that matters (effectiveness) – for the whole is more than the sum of its parts.

Food waste

Food systems must be viewed from both the perspectives of productivity and sufficiency in the context of production, distribution and consumption patterns, which have paradoxically resulted in both undernourishment and overconsumption. Current figures estimate that up to 1.3 billion tonnes of food produced worldwide is either lost or wasted. Causes of food loss and waste vary worldwide. In developing countries, food loss occurs mostly on the farm due to a lack of infrastructure, technical know-how and management practices in drying, storage and marketing. Post-harvest loss and processing waste account for approximately 40% of total food loss. In developed countries, retailers and consumers account for 40% of food waste (*Gustavsson et al., 2011*). With population growth on the rise, resulting in a greater demand for food by 2050 (*FAO, 2009b*), confronting our growing food loss and waste problems will play an important role in improving food security (*Nellemann et al., 2009*).

In the EU, up to 90 million tonnes of food is wasted by manufacturers, households and other sectors every year, approximately 180kg per person, generating up to 170 million tonnes of greenhouse gases (*Monier et al., 2010*). Western consumer lifestyles and attitudes to food have a significant impact on food waste. Improvements in food conservation, marketing strategies and increases in consumer choice often encourage over-purchasing, which in turn leads to food waste (*Garnett, 2011*). Factors influencing food waste can include a disconnection about how food is produced, demand for immaculate appearance standards, and the price of food relative to disposable income (*Monier et al., 2010; Parfitt et al., 2010*). The issue of food loss and waste, however, often focuses disproportionately on domestic waste, laying the blame on the consumer (*Evans, 2011*). Although consumers must take their share of responsibility, this perspective alone fails to take into account the productivist model that dominates current food and farming policies. Agricultural production over the last number of decades has become increasingly intensified, with significant negative implications for the environment (*Stoate et al., 2009*). Yet, while there is currently enough food produced to feed the entire world population, nearly 1 billion people suffer from chronic hunger (*Gustavsson et al., 2011; UNEP, 2011*). This clearly suggests that the food crisis is not alone about production, but how food storage and distribution is organised around consumption patterns. Systemic change taking into account different actors in the food chain will only occur if there is a movement towards truly sustainable food production and consumption patterns.

Sustainable consumption patterns confronting the food waste challenge

With the EU setting a target of reducing food waste by 20% by 2020 (*European Commission, 2011*) there are ways in which organic agriculture has the potential to contribute to saving our food from spoilage. Firstly, total spending on food in Europe is a fraction of total income compared to food expenditure in developing countries (*Meade, 2008*). In effect, consumers pay less now, but as taxpayers they pay more in responding to the long-term socio-economic and environmental consequences of cheap food. In contrast, the price of organic food is more realistic because it internalises many externalities and contributes proactively to the provision of public goods. Consumers need to be made aware of the real value of food. Therefore, EU policies which encourage consumers to act in favour of environmental protection and food waste prevention must be prioritised.

Over the last number of decades less than 5% of funding for agricultural research has been directed towards food loss and waste (*Kader, 2003*). EU research programmes must support studies that focus on eco-efficient systems, rather than on short-term technological improvements. We must build upon findings such as the result of a study in UK that found that appearance standards, which led to wastage of large quantities of quality produce, was a significant motivating factor for farmers in Norwich to turn to local supply chains (*Saltmarsh & Wakeman, 2004*). Research into producer-consumer relationships as well as targeted support for local supply chains could also provide many solutions. There is also a need for further exploration of the potential benefits and challenges associated with closed-loop supply chains. This could include the redistribution of food to alternative routes, the reuse of food for animal feed, and the recycling of unavoidable food waste through composting and producing biogas, bioenergy, and bioplastics (*Parfitt et al., 2010*). In this respect, separation of organic waste may be an effective way to recover nutrients and prevent unnecessary transport to landfill and the emission of methane from anaerobic digestion.

Concluding Remarks

The world is facing a serious decline in available resources and the European Commission has issued its Communication to achieving resource efficiency as part of its EU 2020 strategy. Agriculture must play its part in all this. Organic farming has proven it can prevail in the face of impending disaster through its ability to be more resistant and resilient. As shown in the different chapters, organic agriculture offers great benefits and potential for key resource efficiency challenges of agricultural importance, such as climate, soil, biodiversity and nutrients. Rather than simply focusing on remediation strategies, organic agriculture takes a proactive approach to resource depletion and offers environmentally-sound solutions to the problems posed by resource use. The way towards resource-efficient farming everywhere is still long, but organic farmers have taken the right steps forward and are acting as role models for others to emulate.

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