Agroecology and Permaculture: Addressing Key Ecological Problems by Rethinking and Redesigning Agricultural Systems

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Hathaway, Mark (2015). Agroecology and permaculture: Addressing key ecological problems by rethinking and redesigning agricultural systems. *Journal of Environmental Studies and Sciences*, May 2015. DOI: 10.1007/s13412-015-0254-8

The final publication is available at: http://link.springer.com/article/10.1007/s13412-015-0254-8

Abstract

This paper explores how industrial agriculture is a key contributor to many ecological problems and how redesigning agricultural systems using agroecological principles and methods could address many of these problems. Agriculture uses 85% of freshwater and, directly or indirectly, produces nearly half of all greenhouse gas emissions. Industrial agriculture accounts for a large proportion of these ecological costs and also depends on high energy use and toxic chemicals. Agroecology presents an alternative paradigm of production based on ecological principles such as recycling wastes, minimizing energy and water use, maximizing genetic diversity, regenerating soil and increasing its carbon content, integrating livestock and crops into a holistic system, and promoting other beneficial biological synergies. Moreover, agroecological methods have the potential to actually boost production and farm incomes, particularly in the global South. Permaculture, perhaps the most widely practiced form of agroecology, also provides an ethical framework and principles that serve as a basis for discerning actions that enable the design of diverse, sustainable systems suited to a wide variety of cultural and ecological contexts. Widespread adoption of agroecological methods and permaculture principles could significantly reduce energy, pesticide, and freshwater usage while simultaneously restoring degraded soil, sequestering large quantities of carbon, creating more biodiverse agricultural systems, and satisfying human needs for healthy, nutritious food. As well, engaging in ecological agriculture may encourage practitioners to develop genuinely ecological dispositions and worldviews that enable them to approach problems and discern actions from a perspective that systematically promotes sustainability and social justice.

Keywords: industrial agriculture, water, greenhouse gases, food, soil, biodiversity, carbon sequestration, ecology, agroecology, permaculture

Agroecology and Permaculture: Addressing Key Ecological Problems by Rethinking and Redesigning Agricultural Systems

Agriculture is arguably the most important human endeavor, both because it is the principle source of our food (Pimentel 2011) and because nearly half of all people work as farmers, 95% of whom live in the global South and roughly half of whom are women (Pimbert 2009). Agricultural lands (cropland, managed agro-forestry, and grazing lands) occupy nearly half of Earth's land area (Smith et al. 2007) and rival forests as the largest terrestrial biomes (Foley et al. 2005). Due to its scale, the environmental impacts of agriculture are significant, but this is particularly true in the case of industrial farming, "capital-intensive, large-scale, highly mechanized agriculture of crops with monocultures of crops and extensive use of artificial fertilizers, herbicides and pesticides, with intensive animal husbandry" (Knorr and Watkins 1984).

Geoff Lawton, an Australian permaculture teacher living in Jordan, says that "all the world's problems can be solved in a garden" (as quoted in Ferguson and Lovell 2013). While this statement suffers from some hyperbole, it also contains an important truth: Insofar as the current model of industrial agriculture is a major contributor to many of the world's most pressing ecological problems – including water and energy usage, climate change, and pollution by toxic chemicals, as well as social problems such as poverty and hunger – these problems can only be effectively addressed by fundamentally changing our agricultural systems.

This paper endeavors to give a broad overview of the key ecological impacts of industrial agriculture including energy use, water consumption and pollution, and greenhouse gas (GHG) emissions. It then explores how agroecology – understood here as an applied science that "uses ecological concepts and principles for the design and management of sustainable agroecosystems where external inputs are replaced by natural processes such as natural soil fertility and biological control" (Altieri and Nicholls 2012) – moves away from the industrial paradigm to create more sustainable agricultural practices combining both traditional knowledge and modern ecological science. Next, permaculture design is examined as a framework providing additional insights into how agroecology may be applied in particular circumstances to create viable, just, sustainable, and regenerative agricultural systems. Finally, the paper explores how agroecological systems address key ecological problems as well as some of the challenges involved in implementing agroecological approaches. The paper concludes by presenting a specific example illustrating agroecology's potential to sustainably produce high-quality food for a growing human population.

This paper is meant to provide a global overview rather than examine agriculture in one particular context. In the case of industrial agriculture, most of the specific examples and statistics are drawn from North America, albeit some examples of industrial farming in the global South introduced via the "green revolution" are also considered. With respect to agroecology and permaculture, this paper focuses primarily on broad perspectives and principles that underpin these approaches although a sampling of techniques and methods used in a variety of contexts are provided to illustrate key points.

The Ecological Impacts of Industrial Agriculture

Agriculture, in many respects, can be seen as the last frontier of the industrial revolution. Until the end of World War II, most farming was organic (agrochemical and antibiotic free), labor intensive, largely local (with the exception of certain plantation-grown crops), based on mixed-farming methods that recycled animal and crop wastes, and characterized by cultivating diverse crops that were rotated or inter-cropped as polycultures (Mazoyer and Roudart 2006; Vandermeer 2011; Worthington 2001). Even today, three quarters of the world's 1.5 billion peasant farmers working on 350 million small farms producing half of the world's food primarily use more traditional techniques while only 30% of food is produced using industrial methods (Altieri and Nicholls 2012; ETC Group 2009).

Over the past sixty years, however, industrial farming has taken root, first in North America and Europe, but increasingly in all parts of the globe. This new model of agricultural production uses a variety of chemical inputs (fertilizers and pesticides), seeks out economies of scale involving ever-larger plots of machine-cultivated land, employs specialized farms concentrating on one or a few crops or livestock species, and uses increasingly uniform varieties of seed and breeding stock. A variety of factors have contributed to this trend (Mazoyer and Roudart 2006; Perelman 1972; Pollan 2006; Shiva 2008), including:

- The availability of fossil fuels and farm machinery, as well as the increased availability of chemical fertilizers and pesticides (originally due to surplus ammonium nitrate from explosive production and the conversion of chemical industries following World War II), which enable the cultivation of large monocultures with little human labor;
- The influence of a capitalist, industrial paradigm and government policies that promote specialization, comparative advantage, and global trade of agricultural production;
- The introduction of high-yielding hybrids (and later, of genetically modified varieties) that respond well to agrochemical applications and mechanized harvesting that have increasingly displaced open-pollinated varieties that could be saved and replanted; and
- The growing domination of agricultural markets by large transnational corporations controlling seeds and agrochemicals as well as agricultural production and distribution.

In many ways, the industrial food system has moved from raising crops and animals on farms to "manufacturing" food using highly specialized processes in operations that resemble outdoor factories. These consume ever-larger amounts of energy (particularly hydrocarbons), convert soil into a net carbon emitter, significantly contribute to GHG emissions, undermine soil fertility, reduce biodiversity, introduce chemical toxins into ecosystems, and use or pollute vast quantities of water. While this form of agriculture has arguably increased productivity at a time when human population growth has skyrocketed, these increases are not sustainable in the long term.

Monoculture, chemical dependence, and the loss of diversity

To facilitate mechanized cultivation, industrial farming tends to cultivate vast fields of only one crop variety (Tilman 1999) – referred to as monocultures – often without adequate rotations. These artificially simplified ecosystems are heavily dependent on external inputs, particularly chemical fertilizers (since monocultures rapidly deplete nutrients in the soil) and pesticides (because they are more vulnerable to infestations which spread more easily in fields lacking diversity). Over time, chemical fertilizers rich in nitrogen, phosphorous, and potassium ("NPK" fertilizers) deplete the soil of essential micronutrients and destroy beneficial soil organisms that facilitate the transfer of nutrients to plants (Shiva 2008). In turn, this may reduce the nutritional quality of food (Worthington 2001). Since the advent of industrial agriculture, more than 17% of vegetated land has suffered from human-induced degradation of soils due to "poor fertilizer and water management, soil erosion and shortened fallow periods" as well as "continuous cropping and inadequate replacement of nutrients removed in harvested materials or lost through erosion" (Tilman et al. 2002).

Instead of a chemical growing medium, soil can best be understood to be a dynamic ecosystem which "produces life because it itself is alive" (Suzuki et al. 2007). A single gram of soil may contain up to a billion bacteria, a million fungi, and tens of thousands of protozoa. Soil is precious – it can take from 200 to 1000 years to produce a single inch of topsoil, but we are losing 75 billion tonnes of soil or nearly 10 million hectares of farmland per year to erosion – equivalent to almost a quarter of Canada's total arable land. More than a third of the world's arable land has been lost since large-scale industrial agriculture began in the 1950s (Pimentel et al. 1995).

Pesticides – while initially boosting yields – become increasingly ineffective over time as pests become resistant to them, yet they often also kill microorganisms and fungi that are essential to soil health as well as beneficial species that help control destructive organisms (Pimentel 1996). Meanwhile, approximately a million people are poisoned by pesticides annually, 20,000 of whom die (Pimentel 1996). It is more difficult to quantify longer term health effects, both in humans and other species. Altieri and Nicholls (2012), however, estimate that the 324 million Kg of pesticides used in the US each year result in $8 billion of indirect environmental and social costs – including loss of wildlife, fisheries, pollinators, and human illnesses.

When the green revolution introduced new seed varieties, agrochemicals and other industrial methods in the Punjab, India during the 1960s, crop yields increased. By 2008, however, production was declining, soil fertility was seriously degraded, and water had been polluted by nitrites and pesticides (Shiva 2008). Indeed, worldwide yields in many areas using industrial methods are declining (Rosset et al. 2011). It appears that while chemical fertilizers initially increase yields, they become less effective over time – requiring ever greater amounts of fertilizer to maintain productivity (Tilman et al. 2002). Fertilizer run-off also causes algae blooms and oxygen depletion in rivers and oceans (Foley et al. 2005). Furthermore, as oil prices increase, fertilizers and pesticides become increasingly expensive – particularly for small landholders.

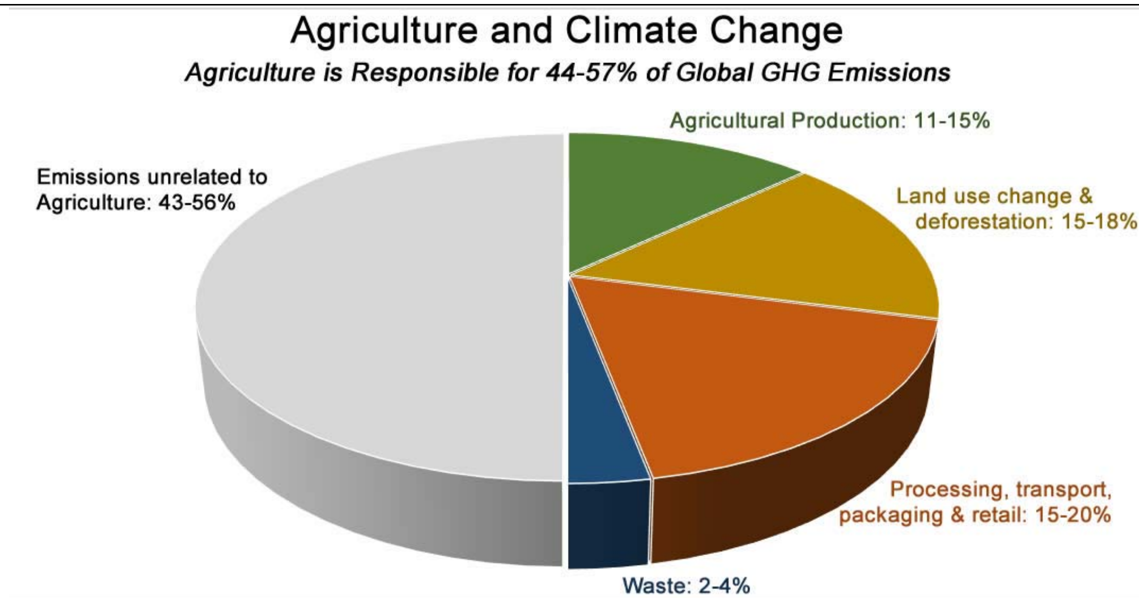
Industrial agriculture seeks out food varieties primarily based on factors such as shelf life, uniformity, durability for long-distance transport, ease of harvest, productivity (or responsiveness to chemical fertilizers), and (in the case of many genetically modified varieties) the ability to withstand the application of herbicides – not nutritional value. As a few varieties gain dominance, thousands of traditional cultivars and landraces disappear – essentially resulting in a massive loss of biodiversity and traditional knowledge. Three-quarters of food varieties once cultivated (many the fruit of centuries of selective breeding) disappeared during the 20th century (FAO 1998). In turn, the global food supply has become more vulnerable to catastrophic losses from diseases, such as happened during the Irish potato famine (partially the result of a dependence on a single variety of potato susceptible to late blight) (Rhodes 2012). More recently, with the Fusarium fungal disease threatens the single, genetically uniform Cavendish variety that dominates world banana production (Butler 2013).

High energy use

The purported efficiency of industrial agriculture depends on relatively inexpensive supplies of fossil fuels – in part to provide chemical inputs such as fertilizers and pesticides. Furthermore, many common food items travel thousands of kilometers to reach our tables. An Ontario study calculated that 58 common food items that could be grown locally – but were instead transported long distances – travelled an average of nearly 4500 km (Xuereb 2005). It takes between 7.3 and 10 calories of energy inputs – mostly from fossil fuels – to produce, process, and distribute a single calorie of food energy using industrial methods in the United States (Neff et al. 2011). About 20% of that energy (1.5-2.0 calories) is used directly in food production with the remainder used for processing and transportation (Heller and Keoleian 2000). A single head of lettuce with 110 kcal of food energy shipped from California to New York requires 750 kcal of fossil fuels for irrigation and 4,140 kcal for transportation (Pimentel et al. 2008). If the price of petroleum rises sharply (as may happen if we reach “peak oil”), this globalized system dependent on cheap transportation – and on chemical inputs – may cease to be viable (Neff et al. 2011). Furthermore, to keep global temperature increases below 2 C, the use of petroleum needs to fall dramatically; indeed, 80% of current fossil fuel reserves must remain in the ground (McKibben 2013).

Greenhouse gas emissions

The use of NPK fertilizers also contributes significantly to GHG emissions. Two-thirds of nitrous oxide (N_2O) emissions – responsible for about 6% of the greenhouse effect – come from chemical fertilizers. N_2O has nearly 300 times the warming effect of CO_2 and remains in the atmosphere almost indefinitely (Bruges 2010). Fertilizers also contribute to GHG emissions via energy use – 30% of energy used in US agriculture, for example, goes into the production of chemical fertilizers. The IPCC estimates that agriculture is responsible for about 12% of GHG emissions (Smith et al. 2007), but the non-governmental organization GRAIN (2011) has carried out research indicating that the emissions are much higher if indirect emissions – such as those related to the transport of agricultural commodities as well as changes in land use patterns are considered. In total, approximately 50% of all GHG emissions may be attributable to agriculture.



Agricultural Production (11-15%): Emissions from agriculture (machinery, irrigation, agrochemicals, etc.).

Land use change (15-18%): Emissions from converting forests, wetlands, and savannahs into agricultural lands.

Processing, transport, packaging, and retail (15-20%): Emissions associated with distribution systems.

Waste (2-4%): Emissions produced by production that is wasted and dumped in landfills, etc.

Fig. 1 (GRAIN 2011)

Soil is the largest land-based carbon sink, holding more carbon than the atmosphere and all terrestrial vegetation combined (Swift 2001). Yet, agriculture can turn soil into a net carbon emitter. While the depletion of carbon sequestered in soil began with the advent of agriculture millennia ago, modern industrial farming has greatly accelerated this process. Many soils that once had a 20% carbon content now hold an average of only 2% (Rhodes 2012). Overall, soils have lost 30 to 70% of their carbon content depending on the specific place, soil type, and degree of degradation (Bates 2010). Indeed, between 25 and 40% of excess CO_2 in the atmosphere today probably originates from the destruction of soils (GRAIN 2011).

Water Consumption

Agriculture accounts for 85% of global freshwater consumption (Foley et al. 2005). To produce a single kilogram of wheat takes an average of 1300 liters of water, while rice requires 3000 liters, and beef 15,500 liters (Chapagain and Hoekstra 2004). A single, 50-gram bag of salad requires about 50 liters of water while a chocolate bar needs an astounding 27,000 liters (Rhodes 2012). Nations in the South exporting food to the North are therefore also effectively exporting massive quantities of water “embedded” in this food. In areas suffering water scarcity, producing food for export may significantly contribute to drought and desertification (Shiva 2008). Such food production may also involve the extraction of groundwater reserves which “is almost universally unsustainable and has resulted in declining water tables in many regions” (Foley et al. 2005).

Much of the crop yield increases obtained during the green revolution may be attributed to increases in water usage. As Shiva (1991) explains, many of the “miracle” plant varieties used in industrial agriculture are those that are particularly responsive to irrigation water and chemical fertilizers. Much of the increased weight in crop yields is actually due to greater water uptake caused by metabolic changes associated with chemical fertilizers. For example, some high-yielding varieties of wheat produce 40% more grain, but require three times as much water. Therefore, their productivity in terms of water use is less than half of traditional varieties. In the absence of additional water and chemical fertilizers, the green revolution hybrids perform worse than many traditional varieties. As freshwater becomes scarcer, the viability of these crops will become increasingly questionable.

The wastes – particularly manure – generated by large-scale livestock operations also contributes to water pollution: Farms in Canada produce nearly 126 million tonnes of manure annually (Beaulieu 2004) compared to only 550,000 tonnes of dry sludge produced by municipal sewage systems (LeBlanc et al. 2009) – but in most cases, farm wastes are not treated. Agriculture is the main source of surplus phosphorus and nitrogen in waterways (Foley et al. 2005) and contributes significantly to the creation of hypoxic dead zones at the mouths of many major rivers, such as the 18,000 km^2 dead zone at the mouth of the Mississippi (McIntyre et al. 2009).

Clearly, agriculture – particularly its industrial variant – has contributed significantly to a number of key ecological problems. Foley et al. (2005) note that industrial agricultural practices "may be trading short-term increases in food production for long-term losses in ecosystem services, including many that are important to agriculture." Moreover, industrial agriculture based on monocultures is particularly vulnerable to weather events (and infestations) associated with climate change compared to more diverse, ecological alternatives (Altieri and Nicholls 2012). Furthermore, as water resources become more limited and petroleum-based fuels and fertilizers become more expensive, industrial agriculture may not be able to sustain the production increases required for growing populations (Rhodes 2012). Currently, the world actually produces more food than is required to provide a healthy diet for its entire human population and could sustain up to ten billion people (Altieri and Nicholls 2012) – especially if grain currently used for livestock or biofuels was diverted to human consumption; however, climate change as well as oil and water shortages may cause production to fall in the future. Because of this, alternative forms of agriculture are needed that can simultaneously increase productivity – particularly in the most impoverished areas of the globe – as well as reduce water and energy usage, decrease chemical and biological pollution, increase crop resilience, and sequester carbon in soils. As will be demonstrated in the upcoming sections of this paper, agroecological methods of farming have the potential to achieve all these goals while simultaneously providing a sustainable livelihood for millions of farmers worldwide.

Agroecology

Early accounts of the Europeans arriving in the Americas portray their surprise at the bounty, beauty, and equity of many of the indigenous food systems encountered on these continents. These varied from complex agroforestry systems in North America's eastern woodlands and the Amazonian basin to sophisticated methods enabling Andean peoples to farm in harsh climatic conditions (Mann 2005). Indeed, around the world traditional and indigenous peoples developed productive food systems uniquely adapted to their local ecosystems and cultures. As Miguel Altieri (2009) notes:

> The persistence of millions of agricultural hectares under ancient, traditional management in the form of raised fields, terraces, polycultures (with a number of crops growing in the same field), agroforestry systems, etc., document a successful indigenous agricultural strategy and constitutes a tribute to the "creativity" of traditional farmers. These microcosms of traditional agriculture offer promising models for other areas because they promote biodiversity, thrive without agrochemicals, and sustain year-round yields. The new models of agriculture that humanity will need… will be rooted in the ecological rationale of traditional small-scale agriculture… Such systems have fed much of the world for centuries and continue to feed people in many parts of the planet.

Today, many of these traditional agricultural methods are being rediscovered and recovered. Simultaneously, the convergence of two scientific disciplines – ecology and agronomy – is exploring a new vision and set of practices called *agroecology*, which applies "ecological science to the study, design and management of sustainable agroecosystems" (Altieri 1995). There are many variants of agroecological systems that can include organic agriculture[1], permaculture, natural farming, and biodynamic methods. Often, agroecologists dialogically integrate autochthonous traditions to create a new synthesis of knowledge and practices using participatory approaches (Altieri and Nicholls 2012). In contrast to the extractive, manufacturing paradigm of industrial agriculture, agroecology seeks to create synergistic agricultural systems that mimic the natural processes of a mature ecosystem and replace external inputs while taking "greater advantage of natural processes and beneficial on-farm interactions in order to reduce off-farm input use and to improve the efficiency of farming systems" (Altieri and Nicholls 2012) by:

- recycling nutrients from organic matter to enhance the biotic activity and fertility of soil,
- minimizing losses of water, energy, and soil nutrients,
- increasing genetic diversity and using mutually beneficial planting and antagonists to create inter-cropped polycultures that better resist plagues and sustain soil,
- promoting beneficial biological synergies and interactions to enhance ecological services, and
- integrating livestock and crops into a holistic system.

Can these agroecological systems actually produce enough food to meet the needs of all people in the world? Oliver De Schutter (2010), the UN Special Rapporteur on the right to food, concludes that not only does agroecology greatly boost productivity (by an average factor of over 100% in rural Africa[2]), but that it also can reduce rural poverty (by boosting production and

[1] Not all organic methods (such as those using monocultures and external inputs), however, are agroecological. In contrast, agroecological approaches *are* generally organic – albeit generally less focused on formal organic certification (Altieri and Nicholls 2012).

[2] Another US study (Liebhardt 2001) comparing organic and industrial agriculture concluded that organic farming yields averaged 95% of those obtained with industrial methods, but with far

reducing the need for costly inputs), improve nutrition (by growing more diverse, nutritious food), and contribute to ecological sustainability (including adaptation to climate change and water conservation). In Asia, the use of one particular agroecological method called the System of Rice Intensification (SRI) has increased rice yields by 20-30% (and up to 50% in some cases) while reducing water usage by 50% and seed usage by 90%, often with the use of no chemical inputs (Altieri and Nicholls 2012; Sinha and Talati 2007). Moving to the kind of integrated polyculture system usually employed in agroecology increases yields by an average of 20 to 60% over monocrop systems (Altieri et al. 2012).

While agroecological practices are more labor-intensive than industrial farming methods – particularly during the initial implementation stage – agroecology creates an efficient system that naturally resists plagues and pests (for example, by using polycultures) and which also creates better working conditions for farm laborers by introducing shade trees and eliminating the need for chemical pesticides. Rather than relying on external capital, chemical inputs, or even labor, agroecological systems "rely on the efficiency of biological processes such as photosynthesis, nitrogen fixation, solubilization of soil phosphorus, and the enhancement of biological activity above and below ground." Therefore, "the 'inputs' of the system are the natural processes themselves, this is why agroecology is referred to as an 'agriculture of processes'" (Altieri and Nicholls 2012).

At the same time, agroecology is knowledge intensive, "based on techniques that are not delivered top-down but developed on the basis of farmers' knowledge and experimentation" (De Schutter 2010). Agroecology requires that most crop and livestock breeding takes place locally

less energy and external inputs. The same study noted, however, that only 1% of agricultural research dollars were spent investigating organic methods, so that the potential to improve organic yields is potentially large.

to create varieties uniquely adapted to specific ecological conditions; it therefore necessitates "the development of both ecological literacy and decision-making skills in farmer communities" through appropriate investments in research and education (De Schutter 2010) Beyond the simple transmission of technical knowledge, this involves the development of practical, scientific problem-solving skills as well as the socialization of knowledge where farmers and other producers share their insights. This knowledge intensity aligns closely with the principle of empowering food producers while building local knowledge to strengthen people's food sovereignty, defined by the international small farmers' organization, La Via Campesina (2007), as "the right of peoples to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and their right to define their own food and agriculture systems." De Schutter (2010) also notes that, "in principle, agroecology can benefit women most, because it is they who encounter most difficulties in accessing external inputs or subsidies," albeit to a significant extent this also depends on how agroecological education programs are conceptualized and implemented.

In terms of concrete methodology, agroecological systems use crop rotations and polycultures to maintain soil fertility and minimize pest problems. As well, agroforestry systems are often incorporated to create a favorable microclimate for cultivation, stabilize soil, contribute organic matter, provide nitrogen fixation, and enhance nutrient uptake from deeper soil horizons. Cover crops and mulching reduce water evaporation, control pests, and stabilize soil temperature, suppress weed growth, and enrich soil. Finally, crop-livestock mixtures recycle nutrients (Altieri and Nicholls 2012).

At the heart of agroecology is a fundamentally different way of thinking based on a different set of values from industrial farming. While industrial methods see food as something to be manufactured from a set of raw materials, agroecology understands agriculture as an ecological system based on cyclic, symbiotic relationships. While industrial agriculture seeks to maximize yield measured in narrow, short-term, quantitative terms, agroecology seeks to maximize sustainable productivity for the long term, taking into account qualitative aspects such as nutritional quality, biodiversity, and working conditions. These values implicit in agroecology become more explicit when one considers permaculture.

Permaculture

Permaculture – founded by Bill Mollison and David Holgrem in the 1970s – is perhaps the most widely known form of agroecology. Permaculture is an integral system of design "based on direct observation of nature, learning from traditional knowledge and the findings of modern science" which simultaneously embodies "a philosophy of positive action and grassroots education" aiming "to restructure society by returning control of resources for living: food, water, shelter and the means of livelihood, to ordinary people in their communities" (Permaculture Activist Magazine as quoted in Veteto and Lockyer 2008). In developing permaculture, Mollison was influenced in his approach by his work with Aboriginal Tasmanians, by Taoism, the ecosystems perspectives of ecologist Howard Odum, the work of Masanobu Fukuoka on natural farming, and Percival Yeoman's keyline planning and landscape analysis (Mollison 1979). Permaculture attempts to create sustainable designs that mimic patterns found in natural ecosystems, drawing particularly on whole systems thinking (Holmgren 2007) which focuses – not so much on individual elements – but on the relationship between them and the way they interact to form a functional, integrated whole (Peeters 2012). In one sense, permaculture is broader than agroecology since it may be understood as both a movement and philosophy promoting design principles that can be applied beyond agriculture: "The overall aim of these design principles is to develop closed-loop, symbiotic, self-sustaining human habitats and production systems that do not result in ecological degradation or social injustice" (Veteto and Lockyer 2008).

Ferguson and Lovell (2013) note that, while permaculture is probably the best known agroecological movement, it has been relatively neglected in scholarly circles. Academic search engines returned 6 to 21 times as many results for agroecology as opposed to permaculture while general purpose-oriented searches returned 7 to 11 times the results for permaculture over agroecology. Ferguson and Lovell (2013) conclude that there is "sparse representation of permaculture in the scientific literature" and that this relative lack of academic research "is incommensurate with" both "a high level of general interest" in permaculture and its widespread practice in North and South America, Europe, Australia, and parts of Asia and Africa. Similarly, the international development community tends to focus on agroecology while neglecting permaculture. Despite this, Ferguson and Lovell (2013) conclude that:

> Permaculture has contributions to offer the project of agroecological transition. Principles and themes in the permaculture literature largely complement, and sometimes provide useful extension of, those found in the agroecology literature. The permaculture approach to agroecosystem design and practice offers a distinctive perspective and emphasis on the value and potential of perennial crop species, polyculture, integrated water management, and the importance of agroecosystem configuration.

Permaculture also provides a simple ethical framework guiding all its designs summarized in three simple points (Holmgren 2007; Rhodes 2012):

1. **Care for Earth:** Including the nurture of soil, forests, and water; working with nature; and preventing damage to ecosystems.

2. **Care for people:** Including looking after one's self, kin, and community; working with others; assisting those without to access healthy food and clean water; and designing sustainable systems that produce life's necessities.

3. **Fair share:** Including setting limits on consumption and reproduction; redistributing surplus production to those in need; building economic lifeboats; and modifying lifestyles.

Permaculture then provides a set of twelve principles that create a framework for design while allowing for a wide range of methods applied in specific contexts (Holmgren 2002; McManus 2010):

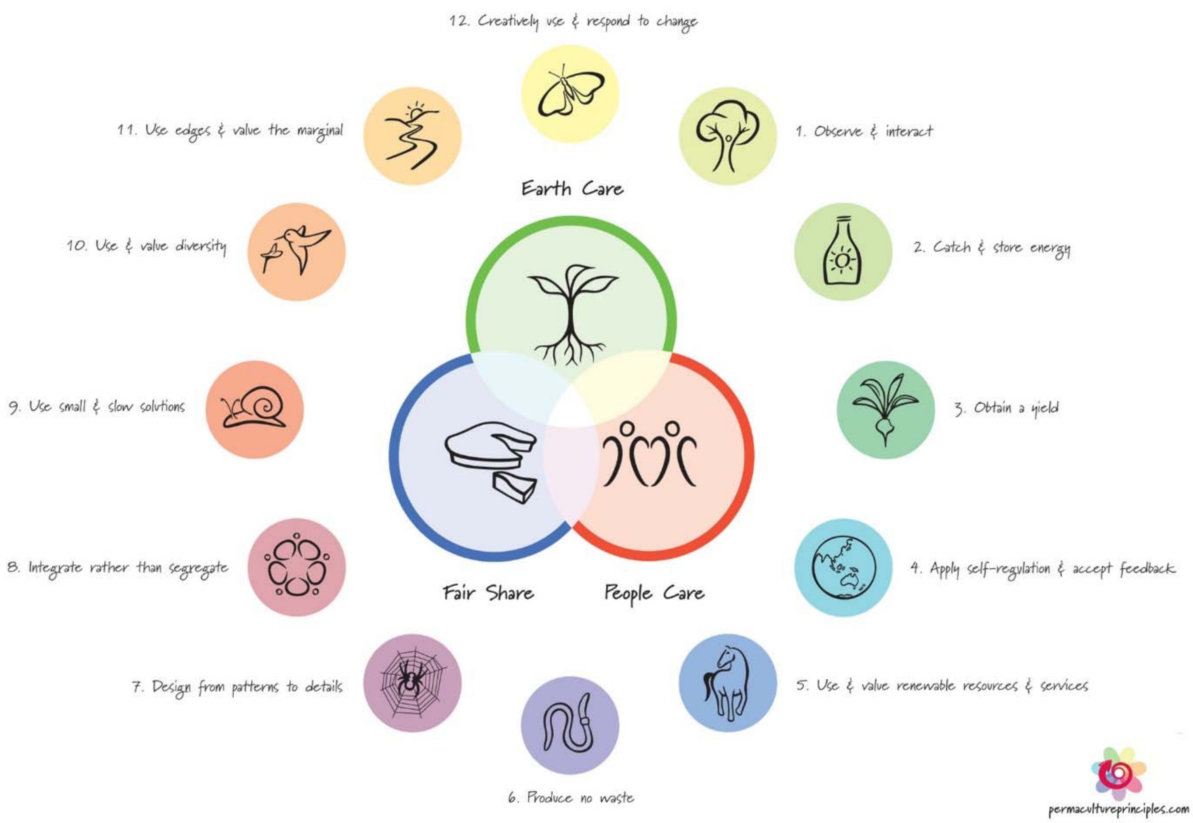


Fig. 2*:* Permaculture Ethics and Principles (Telford 2015)

1. **Observe and interact:** Design begins with prolonged and thoughtful observation of place.

2. **Catch and store energy, nutrients, and water:** Collect energy and water while they are abundant and store them for times of need.
3. **Obtain a yield:** Ensure that the system can produce necessities in the most self-reliant manner possible.
4. **Apply self-regulation and accept feedback:** Create appropriate negative feedback loops to maintain a healthy system balance.
5. **Use and value renewable resources** like sunlight and rainwater; employ processes that regenerate soil; avoid external inputs.
6. **Produce no waste:** Recycle all wastes as useful resources.
7. **Design from patterns to details:** Use nature's patterns as templates for effective design.
8. **Integrate rather than segregate:** Design with synergistic relationships in mind (such as mutually beneficial polycultures rather than monocultures).
9. **Use small and slow solutions:** Start small, experiment, and use local resources. Smaller, simpler solutions are easier to maintain than larger, more complex ones.
10. **Use and value diversity:** Diversity increases resilience, making the system less vulnerable to failures.
11. **Use edges and value the marginal:** The interface between different zones is often the most interesting and creative place.
12. **Creatively use and respond to change:** All ecological systems have an evolutionary dimension. Observe changes taking place and intervene carefully at the right time and place.

The way these principles are actually implemented in a given context can vary widely. Ferguson and Lovell (2013) note, however, that the techniques used by permaculture are generally similar to those used in many other agroecological systems, albeit sometimes with a distinctive vocabulary (such as “food forests” for agroforestry or “plant guilds” for synergistic polycultures). They conclude that permaculture can be best understood as a “conceptual framework for the evaluation and adoption of practices, rather than a bundle of techniques” where the two key criteria for evaluation are ecosystem mimicry (model using the structure and function of natural ecosystems as guides to imitate) and system optimization (identifying leverage points where small interventions may significantly improve performance).

A well-functioning permaculture system will be characterized by a wide variety of species, spaces, and zones; a diverse and plentiful yield of food, fiber, and other useful products; sufficient ecological complexity and stability to facilitate energy and water storage while ensuring resilience as conditions change; and the ability to be self-sustaining using local, renewable resources without external inputs (Peeters 2012). In practice, permaculture often uses a multi-layered system of trees and plants along with livestock with different zones (in roughly concentric circles, with the inner-most zone requiring the most monitoring and human labor and the outermost requiring the least), and relies on perennial crops as much as possible to reduce soil disturbance and human labor. A forest garden – characterized by the “stacking of functions” using different layers – would be a fairly typical kind of permaculture system. By some estimates, this kind of system can feed up to 25 people per hectare, or about double of what is possible using industrial agricultural systems, albeit supporting a different diet less dependent on cereal grains (Rhodes 2012). This layered system is illustrated below:

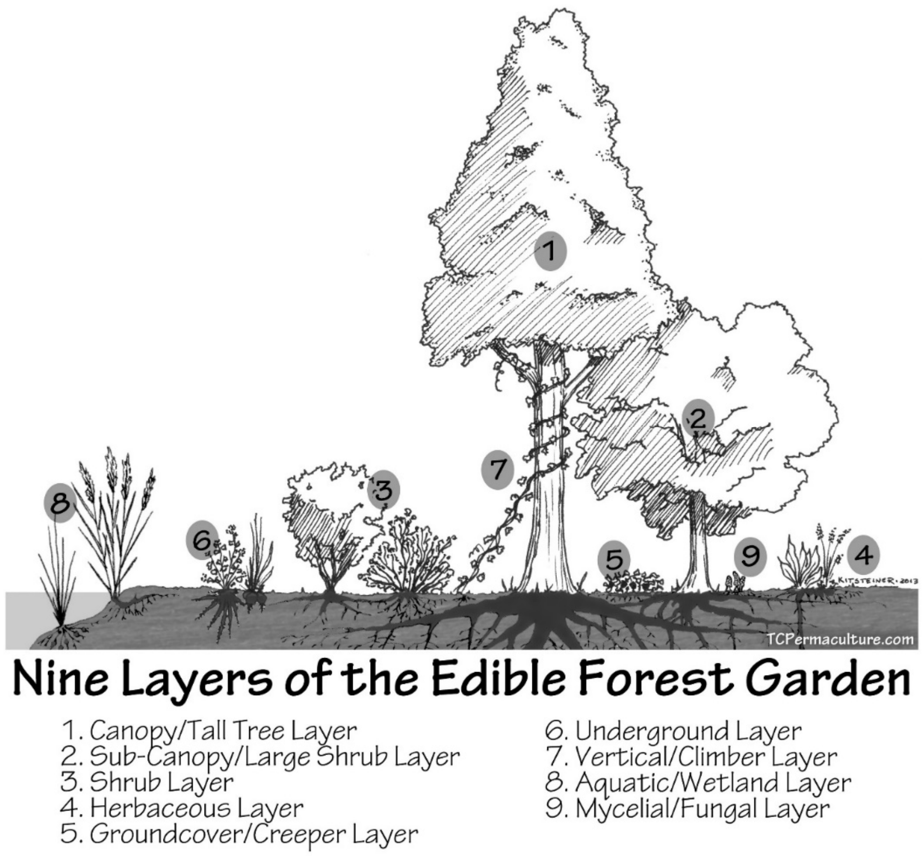


Fig. 3*:* Layered polyculture forest garden (Kitsteiner 2014)

Another example of a closed-looped permaculture system is aquaponics which combines aquaculture and hydroponics without using external inputs: Water enriched with fish effluents is used to grow vegetables and fish food, which in turn produces enough to also feed the fish (Holmgren 2002). Such a system produces vegetables far more quickly and abundantly than traditional soil-based methods with the added bonus of simultaneously producing edible fish. Similarly, systems have been designed which enable fish and ducks to live in rice paddies where the animals fertilize the rice and control pests. Rice, eggs, and meat are all produced simultaneously on the same piece of land. A rice paddy can be converted to this system using minimal labor and a spade together with some scraps of bamboo to create a screened trench to protect the fish during the hot daytime hours (Coleman 2004).

Addressing Ecological Challenges through Agroecological Approaches

Moving from an industrial to agroecological approach to agriculture has the potential to greatly reduce chemical and biological pollution, curb GHG emissions, enhance carbon sequestration in soil, and diminish both energy and water usage. The following subsections will explore each of these areas in more detail.

Minimizing chemical fertilizer and pesticide use

Agroecological systems focus on building healthy soil with a high percentage of organic matter and generally avoid the use of chemical fertilizers by using cover crops, animal manure, agroforestry, and synergistic companion plantings in an integrated system which maintains soil fertility (Altieri 2009; Altieri and Nicholls 2012). Similarly, pesticide use is greatly reduced – and in most cases completely eliminated – by avoiding monocultures more vulnerable to diseases and plagues and by using natural pest controls (Uphoff 2002). In Cuba, farms that have shifted from industrial to agroecological methods have reduced agrochemical use by 77% since 1988 while increasing production by 145% (Rosset et al. 2011). Because of this, both the fossil fuel energy used to produce these chemical inputs and N_2O GHG emissions from fertilizers have also been significantly reduced.

Reducing energy consumption and greenhouse gas emissions

Agroecological systems based on perennial plantings largely eliminate the use of heavy machinery for planting and harvesting and reduce soil disturbance and erosion. To the extent that agroecology focuses on localized production, it also reduces energy used for transporting food. In terms of energy efficiency, small Cuban farms using agroecological methods have energy efficiencies (energy output to input) ranging from 10:1 to 30:1 (Altieri et al. 2012) while food produced using industrial methods in the US typically have an efficiency on the order of 1:1.5 or less – i.e. more energy is expended than is produced in food energy. Even larger-scale organic (not necessarily agroecological) farms in the US use 15 to 45% less energy than those using industrial methods (Gomiero et al. 2008). Given that 12-15% of GHG emissions are directly related to agricultural production (GRAIN 2011), the potential for reducing emissions appears to be substantial. This potential is even greater if the move towards agroecology is accompanied by re-localizing production to minimize the energy used in agricultural transportation and processing associated with a further 15-20% of emissions.

Moreover, agroecological systems have immense potential to restore agricultural soils' capacity to sequester carbon. The Rodale Institute in Pennsylvania has demonstrated that agroecological methods that rebuild organic components in soil can increase carbon content by 1% per year, reaching 30% after thirty years and sequestering 8,233 Kg of CO_2 per hectare per year. Not only does this provide a valuable carbon sink, but sequestering carbon in soil (largely via mycorrhizal fungi) makes crops more resistant to droughts, pests, and diseases. By one estimate, in the US 1.5 billion tonnes of CO_2 could be captured each year, equivalent to about one quarter of US fossil fuel emissions (Rhodes 2012). The Rodale Institute (2014) itself is more optimistic, estimating that regenerative agroecological methods could capture 100% of current global CO_2 emissions.

While requiring more investigation, additional carbon could be sequestered in soil using biochar – a special kind of charcoal produced by burning carbon-rich material (like crop wastes) in an extremely low-oxygen environment. Biochar was discovered by examining the rich *terras pretas* (dark soils) traditionally produced by indigenous peoples in the Amazon basin using charcoal, pottery shards, and other substances. Unlike other forms of carbon, biochar does not decompose quickly (even in tropical soils), yet it can significantly improve soil fertility, especially if first inoculated with beneficial microorganisms. Indeed, biochar creates a kind of "reef" for beneficial microorganisms in soil – a single gram of biochar has a surface area of roughly 500 m^2 (Bruges 2010). Globally, if even 20% of all crop residues were converted into biochar, more than 650 million tonnes of CO_2 equivalents could be sequestered by this method each year (Bates 2010). Some more optimistic projections posit that biochar could reduce greenhouse gas levels in the atmosphere to pre-industrial levels by 2050, but only if emissions are also significantly reduced (Bruges 2010).

Conserving and protecting water

Agroecological systems use contoured swales and other forms of surface impoundment, basins, and berms to both capture water and slow its flow, encouraging infiltration into the soil. Redundant systems are also encouraged with particular emphasis given to storing water first in soil, then surface impoundments, and finally tank storage (Ferguson and Lovell 2013). Increasing organic matter in soil increases its ability to retain water by up to 100% (Gomiero et al. 2008) while cover crops and agroforestry can further decrease water evaporation. Together, these techniques make it possible to greatly reduce – and in many cases eliminate – the need for irrigation. Given that irrigation accounts for up to 90% of net surface and non-renewable ground water consumption (Döll et al. 2009; Wada et al. 2012), agroecology's potential for reducing water usage is immense. Simultaneously, agroecology reduces water contamination by avoiding both the use of agrochemicals and by eschewing intensive livestock operations (integrating livestock into mixed systems or using pulse grazing).

Conclusions

It is evident that agroecological methods can play a significant role in addressing key ecological problems, particularly climate change and water shortages, while still producing sufficient food for all. Indeed, agroecological systems are more resilient to major weather events and may actually ensure a more secure food supply than industrial methods in a world threatened by growing water and energy shortages. Simultaneously, agroecological practices embody values and ways of thinking that, over time, may encourage genuinely ecological dispositions and worldviews that enable practitioners to approach problems and discern actions from a perspective that systematically promotes sustainability and social justice.

It is also clear, however, that more research is needed to fully understand the advantages and challenges of implementing agroecological systems. Ferguson and Lovell (2013) note that several challenges remain in this regard – particularly in the case of permaculture. Often, permaculturists tend to make "overarching or oversimplifying claims" that are not easily substantiated, for example that "humanity already possesses all the knowledge necessary to replace current land use with permaculture systems in all contexts." In general, permaculture literature tends to downplay the risks and challenges of creating sustainable agroecosystems. Permaculture has also suffered from a relative isolation from mainstream science and there has been little research into permaculture in academia. While agroecology as a whole may suffer from these inadequacies to a lesser extent, there is still the need for research to improve agroecological methods, explore its full potential to address pressing ecological and social concerns, and overcome the obstacles that may impede its widespread adoption.

In general, it seems easier to imagine the transition of small-scale farms in the global South to agroecology (as explored in some detail by Altieri and De Schutter), both because many of these farms are still labor-intensive and because agroecological methods often build on traditional farming methods and knowledge. The formulation and implementation of policies to encourage the conversion of areas currently dominated by industrial agriculture to agroecology may be much more challenging. Generally, agroecological methods involving polycultures are difficult to cultivate and harvest using machinery, and are thus more labor-intensive (albeit newly designed farm implements might reduce this labor somewhat). This would almost certainly require that more people work the land while the average size of farms would need to significantly decrease. While polycultures may produce a wider variety of foods than monocultures, a smaller percentage of that food may be in the form of cereal grains, thus necessitating changes in diets. A greater reliance on local food sources to reduce transportation could similarly require changes in consumption patterns as well as the adoption of urban gardening on a large scale. Perhaps a greater challenge still is the influence of large transnational chemical, petroleum, seed, and food companies who would see agroecology as counter to their economic interests along with government policies that favor industrial agriculture via subsidies and other incentives (Altieri and Nicholls 2005). Ultimately, to bring about a successful transition to agroecology in the global North would require both changes in government policies and changes in basic assumptions about food production, and indeed in the way we relate to food itself.

The promise of agroecology, however, should not be underestimated despite these challenges. Consider, for example, the permaculture project of Geoff Lawton who began working on five hectares of flat desert land near the Dead Sea in Jordan. On land with minimal rainfall, high salinity, and temperatures reaching up to 50 C – and using only simple methods like digging ditches on contour, composting, cover crops, nitrogen-fixing trees, limited micro-irrigation, and the gradual expansion to fruit trees and other crops – this severely-degraded land was turned into a fertile garden producing olives, figs, vegetables, dates, tilapia, chickens, and other farm animals within a single year while only using 20% of the water consumed by the neighboring “conventional” farms based on industrial methods (Bates 2010). To achieve such results with minimal economic resources under some of the most difficult conditions on the planet illustrates the potential of agroecology to address many of the Earth’s most pressing ecological challenges.

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