Agroecology: Adaptation and Mitigation Potential and Policies for Climate Change

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Definition

The chapter lays out the reasoning and evidence for transition in both industrial and developing countries toward agricultures and food systems based on agroecological principles, in order to develop the resilience and mitigation potential of farming under climate change. Agroecology is defined and illustrated by means of three examples with proven potential to bring about transformational change: "push-pull" approaches to crop protection, weed control, and soil fertility management; agroforestry; and perennial crops. Some of the key barriers to wider, faster adoption of agroecological options are noted. Novel funding and action arrangements, regional food movements, and policy-led changes are identified as three powerful drivers of agroecological responses to climate change.

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The Need for Transformational Change

The percentage of global investments directed to agriculture dropped from 16 % to 4 % between 1980 and 2010, according to World Bank data. Nonetheless, food price shocks, animal disease outbreaks, contamination of traded food stuffs, the mounting evidence of the actual and potential harmful environmental impacts of farming, and climate change disruptions to production have prompted numerous countries in the last decade to commission parliamentary and scientific studies of the future of agriculture and food (including Australia, the USA, France, Germany, Ireland, the UK, China). Regional bodies (e.g., in sub-Saharan Africa and the EU) have commissioned similar studies, as have intergovernmental consortia (e.g., IAASTD) and United Nation agencies (e.g., UNEP, FAO, IFAD, UNCTAD, WTO, IFAD). These have been accompanied by innumerable specialist policy, economic and scientific studies, as well as by statistical, scenario, and modelling exercises. The weight of the evidence indicates that food and farming are on the wrong pathway.

However, the evidence has not given rise to consensus about what to do. Fundamentally this is because neither "scientific methods of inquiry" nor the "evidential facts" speak for themselves. They do not give rise to uncontested choices about what should be done. Questions of what should be done, by whom, and how are inflected by differing political, commercial, and livelihood interests, divergent contexts entangled in both local and global histories, distinctive food cultures, and ethical values.

Deciding what to do, moreover, requires a capacity to understand the interconnections among an exceptionally wide range of diverse information, experience, practices, disciplines, risks, and highly specialized sciences. This provides ample scope not only for informed dissent but also for divergent political choices concerning what the preferred alternatives are.

A few areas of consensus nonetheless have emerged:

- The United Nations Development Programme's 2013 Human Development Report sets out the considerable, sustained, and in many countries accelerating progress made over the last two decades for the vast majority of the world's people in terms of education, health, and income. The progress is not accidental; it is directly and indirectly related to government policies and public investments.
- Production of adequate amounts of affordable, nutritious food is a necessary but not sufficient condition for easing hunger. Whether increased agricultural production contributes to the easing of poverty and hunger, or not, depends on where, by whom, and the way in which the effort is made. If yield and output were the only measures, there is more than enough primary food grown and traded to feed current populations. Primary yield has risen to historically unprecedented levels across all major food and fodder categories, and aggregate surplus has been sustained at rates considerably higher than population growth. However, the commonly posed question "can we feed the 9 billion people?" forecast to be alive by mid-century is the wrong question because the answer can only be: *it all depends on the choices that are made* (Tomlinson 2013).

For instance, feeding protein crops (such as wheat, maize, and an estimated 90 % of the global soy harvest) to intensively reared animals and poultry converts relatively cheap-to-produce food that people can eat into expensive meat products but generates a larger greenhouse gas footprint, creates significant and costly pollution, requires costly and intensive animal health management (giving rise to new risks of animal welfare, human and animal health), and consumes unsustainable amounts of water that people need for drinking. The question is rather *how much of what, for whom, where, how, and with what consequences?*

- The effort to sustain the rate of increase in yield, and small farmers' livelihoods, has given rise to second-order problems of unprecedented magnitude that are on the brink of escaping individual and societal management.

The second-order problems are interdependent and coevolving across multiple spatial and temporal scales. Thus agriculture cannot adapt in an ordered fashion to climate change, nor can the mitigation potential of agriculture be realized, by means of simple technology substitutions alone (The Royal Society 2009). The following points highlight these problems and lay the basis for the illustrations of agroecological transitions that follow:

- Agri-food systems make significant contributions to greenhouse gas emissions as the aggregate effect of the choices made in the development of and technologies used in agriculture and food systems. Agricultural activities are estimated to account for some 15 % of global greenhouse gas emissions (methane, nitrous oxide, carbon dioxide), chiefly as a result of land use and soil management practices, followed by methane from livestock, wetland rice production, and manure management and by land clearing and biomass burning. Carbon-rich grasslands and forests in temperate zones have been replaced over time by annual crops that have much lower capacity to sequester carbon. The technical potential for carbon sequestration in the agricultures of the EU 27 in 2007 has been estimated at about 16 MT carbon dioxide equivalent/year, representing about 37 % of all emissions in the EU; the achievable potential, without permanent management changes to farming systems, is probably much lower and in any case would make only a small global impact.
- Mass degradation of landscapes and soils, and desertification, tied to monocropping, mechanized total tillage, deforestation, and land competition.
- Global-scale destruction of hydrological systems, tied to irrigation technology, fossil fuel and fertilizer subsidies, agrochemical pest control, and salination of soils. Farming practices in poor countries are only part of the problem. A recent study in the USA of water conditions at 2,000 sites sampled in 2008 and 2009 found poor conditions at more than half of the sites, with nutrient pollution from agriculture as the major cause: 40 % of rivers and streams rated poor because of high phosphorus levels and 28 % as poor for excessive nitrates (Tesoriero et al. 2013).
- Loss of agro-biodiversity and locally controlled seed systems, tied to the rise of corporate power and biotechnology and the intrusion of private intellectual property rights into agri-food systems.

- Wide-scale impairment and death by neurotoxins used in agrochemicals. Highly toxic pesticides kill more people globally than wars and homicides combined.
- Malnutrition, leading to undernourishment for around 1bn people and to overweight and obesity for more than 1.4 bn people. Both are tied to the production, marketing, and consumption of insufficient and/or inappropriate foods and foods deficient in micronutrients, giving rise to labor and cognitive impairments and other health problems that are irreversible over the short term and on scales that no private or public health system can afford to treat.
- Extended trade and food chains of increasing complexity that can no longer be sufficiently regulated to prevent fraud or give warning of emergent risks.

The task is not to meet the current and upcoming challenges by intensifying what are clearly the wrong things to be doing but to move as rapidly as possible toward alternatives. Agroecology, although an imprecise term, provides the necessary frame for thinking about developing and bringing into being alternative ways forward in agricultural production. It has both scientific and practice dimensions that incorporate the multidisciplinary study and management of the interactions among plants, animals, insects, people, and natural resources, within agricultural and food systems and farming landscapes. By bringing ecological principles to bear, its practitioners pursue the normative goal of harmonizing productivity, stability, sustainability, and equitability.

The remainder of this chapter first provides three examples framed by agroecology from the production side, either that already have more than local significance or that offer the prospect of radical transformations of a helpful kind. The examples have been chosen because, taken together, they open up prospects for radical agroecological transformations of agriculture and farm landscapes. They also allow some of the key barriers to the necessary transitions to be brought into view. The chapter concludes by further pinpointing three emerging drivers of transitions, where significantly increased effort, investment, and creative problem-solving seem necessary and possible.

Push-Pull Approaches to Crop Protection

Beginning in 1993, scientists at *icipe* (International Centre of Insect Physiology and Ecology, based in Nairobi), KARI (the Kenya Agricultural Research Institute), other national partners and nongovernment organizations, and Rothamsted Research (UK) have developed a "push-pull" technology that simultaneously addresses the major constraints to cereal-based farming in sub-Saharan Africa (SSA). Maize, sorghum, millets, and rice are the main cereal crops grown for both food and cash by millions of smallholders throughout SSA. Average yields are less than 2 t a hectare, largely because of a host of biotic constraints that include insect pests (notably, stem borers) and the parasitic week *Striga*, as well as land degradation and poor soil fertility. Poor harvests mean low incomes and the constant risk of food shortages for households and high cereal import bills for national governments. Management practices based on purchase of insecticides and fertilizers have proven too costly for the majority of smallholders and, where used, in practice have caused unacceptable environmental and human health problems.

The principles of push-pull are simple. The cereals are intercropped with a plant such as *desmodium* that repels the insect pests away from the crop. Other plants, such as Napier grass, are planted around the border to attract the pests out of the crop and pull in predator insects. The *desmodium* fixes nitrogen in the soil and also first stimulates the germination of *Striga* seeds but then inhibits their growth (Midega et al. 2013). Typical yields in smallholder farming systems in Kenya for cereals grown with and without push-pull are up to 4 t/ha compared to 1.5–2.5 t/ha, respectively, for maize; 2.4 and 1.9 t/ha, respectively, for sorghum; and 4 and 2.1 t/ha, respectively, for finger millet. The intercrop and border grasses provide high-quality animal fodder. The companion plant species are perennial and help conserve soil moisture and improve soil health. Through propagation of the grasses, and by harvesting *desmodium* seeds, some farmers and communities are earning additional income through sales to other farmers. Ongoing field studies and monitoring effort allows scientists to identify and respond to emergent problems (such as Napier stunt disease).

Farmers themselves are making notable contributions to push-pull. They helped initially to identify suitable varieties of the companion plants. Recently they have helped identify and test drought-tolerant *desmodium* varieties that allow the technology to spread into drier areas and together with the scientists have begun to incorporate other crops (such as beans). From its initial focus in eastern Africa, push-pull is spreading rapidly to other parts of SSA, through farmer-to-farmer sharing and training (assisted by innovative use of modern communication technologies), farmer field schools, and more conventional extension methods. Today, over 35,000 farmers are using push-pull; the target is one million by 2020.

For a habitat management strategy, the number of adopters is impressive, yet the numbers are insignificant compared to the potential. The missing element is a social mechanism of sufficient power and reach to drive adoption forward. With an increasing number of countries no longer investing in the delivery of advice and extension support through public services, some expect market actors and commercial companies to step in. A few have. The Western Seed Company Ltd, one of the main private seed producers in East Africa, is selling commercial quantities of *desmodium* seed, produced through a network of contracts with individual farmers and farmer groups. However, push-pull does not offer significant opportunities for product marketing nor can it be protected by the kinds of exclusive intellectual property rights that would attract the dominant international corporations. Indeed, insofar as it is effective and becomes widespread, it can be viewed as a potentially damaging competitor to the insecticide and fertilizer sales of the corporate leaders. Many researchers thus consider the lack of development of economic and organizational models that could make such solutions as push-pull a mainstream practice, the more significant barrier to sustainable agriculture and food systems than the technology alone (Renwick et al. 2012).

Agroforestry

Forests are estimated to store up to 40 % of terrestrial carbon. Although temperate regions are slowly restoring forest cover, the replacement of forests by annual crops and other uses throughout the world has increased greenhouse gas emissions and led to significant and largely detrimental changes in soil condition and capacity, in hydrological cycles and flood management, and in biodiversity. Deforestation also threatens the loss of forest-based products that support the livelihoods of some 1.5 bn people. Agroforestry is an elastic term that encompasses multiple pathways to the reversal of these trends (Leakey 2012). Agroforestry's carbon sequestration contribution and potential is substantial. Within the European Union, agroforestry stands out very clearly as the measure with the highest potential for mitigation (Aertsens et al. 2012). In a comparison of the contribution to climate change mitigation of five types of organic agricultural systems in countries as diverse as the Netherlands and Egypt, an organic cocoa-based agroforestry system in Indonesia performed best of all, sequestering 11 t carbon/hectare/year. Examples of agroforestry include the sustainable exploitation of the products of the extensive natural *damar* forests in Indonesia and the domestication and modern management of species little known outside the areas where they are locally known and used (such as *Garcinia Kola*, whose fruits, nuts, exudates, bark, and gum are used throughout West and Central Africa in a variety of hygiene, medical, and household uses).

Tree species that capture atmospheric nitrogen and fix it in the soil are key elements in new designs for "evergreen agricultures" in sub-Saharan Africa (Garrity 2009; Badege et al. 2013). *Gliricidia* in trials with smallholder farmers in Zambia, Malawi, and an increasing number of neighboring countries, for example, has brought record maize yields, doubling the harvest obtained from use of commercial fertilizers and increasing sevenfold the yield obtained when maize is grown without any fertilizer. Over a quarter of a million households in Malawi alone have adopted the practice of intercropping with *Gliricidia* and nitrogen-fixing shrubs.

Faidherbia albida is an acacia species that can last for up to 75–100 years. It not only fixes nitrogen but sheds its leaves during the early rainy season, thus increasing its compatibility with food crops. It has been incorporated into food cropping systems by farmers in many of the drier regions of Africa, including Senegal, Mali, Burkina Faso, Niger, Chad, Sudan, and Ethiopia; Malawi and Tanzania in southern Africa; and parts of northern Ghana, Nigeria, and Cameroon. Agronomists and farmers are working together throughout these areas to develop and test improved systems for establishment, pruning, and intercropping and that incorporate faster-growing nitrogen-fixing species to provide fertility in the 3–5 years it takes for *Faidherbia albida* to provide significant benefits. The effects on the environment, soils, water regimes, insect life, and other forms of biodiversity are also being monitored.

Development of agroforestry systems is expanding the range of cereals and other food crops, as well as food and nonfood products that enter modern markets. This is an important consideration under climate change given that the world's commercial food supply currently rests on five crops (maize, rice, wheat, soy, and potatoes) that face significant yield losses under predicted changes to temperature and rainfall.

Agroforestry developments linked to product development and marketing lend themselves to wider adoption of geographic indications, as well as community-owned plant variety rights and territorial-based rights, as forms of protected but widely shared intellectual rights. These share the intention and potential to conserve agroecological functioning, sustain favored landscape features, and provide a worthwhile return.

Perennial Cereals and Other Crops

Perennial grains, legumes, and oil seeds, combined with sustainable practices and novel farming systems, offer the prospect of ending the numerous conflicts between increasing food production and safeguarding ecological well-being. Some 5–10,000 years' ago, our ancestors collected and selected seed from perennials for the development of annual cropping systems. Annuals have ephemeral, typically low-density root systems, with a lower capacity than perennials to nurture microbial life systems in soils and to optimize the use of nutrients and water. Some traditional and modern farming systems rely on techniques such as zero tillage to compensate for the weaknesses in annual cropping. It is estimated that currently about 100 million hectares are managed worldwide under minimum or zero tillage, mostly in the USA, Brazil, Argentina, Australia, Canada, and Paraguay in the areas of industrial commodity production. The practice can reduce erosion and improve soil structure in the top layers of the soil significantly. It has been hailed as an agroecological success story, but in industrial farming over a large scale, it requires increased use of toxic and polluting chemical inputs and leaves the lower soil levels unimproved. Organic farming methods for their part do not include use of toxic pesticides and may improve soil fertility but do not avoid the soil erosion and water problems consequent on tillage. Perennials grown for food, fodder, and grazing could avoid the consequences of basing the world's food systems on annuals and resolve emergent problems such as salinity while increasing drought tolerance, soil health and fertility, and opportunities for carbon sequestration.

Research groups and networks based in the USA, the UK, Sweden, China, and Australia, and in an increasing number of other countries, are at various stages of investigating, developing, and trialing perennial varieties of wheat, wheat grasses, rice, barley, sunflower, sorghum, and other crops. In the effort to recover perenniality from the precursors to today's crop varieties, new disease resistance traits are being identified that open the way to further innovative pathways to disease management. Some prototype varieties (e.g., of rice) are already in field trials as mono-crops, others are emerging as dual-purpose crops for grazing and grain production or for use in intercropping systems that include a perennial grain and a nitrogen-fixing legume and, as in the push-pull system, plants that employ secondary metabolites that protect against parasitic weeds such as *Striga*. Further ahead lies the prospect of multi-species mixes that provide additional resilience in the face of climate change.

Many of the advances in the understanding of perenniality could not have been gained without the tools and insights of the advanced genetic sciences. Varietal development of perennials is likely to emerge both from conventional breeding effort and genetic modification. With respect to current commercial GM crops, ownership of the associated techniques and genetic material is controlled by a handful of companies and protected by a range of exclusionary intellectual property rights (Renwick et al. 2012). Insofar as perennial crops are either vegetatively propagated or (in the case of grains, for instance) seed based, can strong private sector participation be expected to drive the uptake of perennials? Over time the transition to perennial systems seems likely to diminish the need for sales of chemical inputs and, once perennial systems are established, also of seeds themselves. Alternative intellectual property rights in the form for instance of contracts, open-source strategies, and public ownership of patents are under consideration, in order to put in place the kinds of rights that simultaneously encourage the spread of perennial crops while meeting the diverse needs of each country.

The Potential for Faster, Stronger Effort

A question that emerges throughout this chapter is what might be the drivers of a systemic turn toward agroecology. As noted already, market-based actors clearly will play a part. In addition to participating in rolling out field-based options, pioneer companies already are developing so-called closed-loop systems, for instance, those for urban-based insect farming in which the insects feed off the wastes from supermarkets and provide high-quality proteins, vitamins, and minerals for poultry, fish, and some other types of livestock production. Other companies are developing greenhouse-based closed systems that combine, for example, tomato and *tilapia* production; make much more efficient use of water, heat, and space; rely on biological pest and disease management; reduce greenhouse gas emissions; do not release pollutants to the environment; allow comprehensive traceability and regulation of food safety; and bring production much closer to centers of high population density. However, the considerable vested interests in business as usual, as well as institutional inertia, offer formidable barriers to rapid and widespread change. Three dynamic sectors nonetheless are driving faster, wider transitions.

Mobilization of New Funding and Action Modalities

Instances here include the group of American Foundations that have formed the New Venture Fund to amplify agroecological solutions in both industrial and developing countries. The Global Biodiversity Foundation, a not for profit based in the USA and UK, is negotiating bio-cultural community protocols with indigenous peoples and local communities throughout the world, to make an inventory of and protect and develop the livelihood potential of biodiversity within "community conserved areas." The Caribbean Community Climate Change Centres, established in 2002 by regional governments, are coordinating and supporting collaboration among ministries, research agencies, farmers' organizations, local governments, and civil society groups in bringing about systemic change in farming and food systems throughout the Caribbean. The Future Earth program, established in 2012, aims at developing the required knowledge for responding to global environmental change and supporting transformation toward global sustainability. One of its actions is centered on food systems, and one of its approaches includes transdisciplinarity to address problems, that is, including all actors in the research process.

Regional food movements are emerging that create new opportunities for valuing and rewarding local seed security and conservation, bring new income opportunities for landscape and catchment management, create shorter value chains between producers and consumers, give value to foods of high nutritional and cultural importance, and create new opportunities for democratic decision-making about the balance among social justice, inclusive development, and economic growth. The Alliance for Food Sovereignty, for instance, has self-organized among eight nongovernment organizations and numerous civil society and consumer organizations, to develop regional food systems across the four states of Maharashtra, Orissa, Tamil Nadu, and Madhya Pradesh in India. In Ecuador the "canastas" movement is providing comparable evidence of citizens' capacity to develop new kinds of commercial and cultural relationships in the market transactions among producers, processors, and consumers. Initiatives that are achieving impact at scale are to be found also in industrial countries. For example, under the combined leadership of civil society groups, farmers' organizations, the research community, and the Södertälje local government in the Järna/Södertälje area of Sweden, a sustainable food society is emerging, based on agroecological principles, a commitment to 100 % advanced organic production within 10 years, and scientific understanding of landscape ecology. Other regions around the Baltic Sea in ten countries, supported by the EU, have embarked on similar transitions (www.beras.eu). Locally grown, tasty and wholesome food has become more widely available, at a price even low-income consumers can afford. A national supermarket chain is supporting the transition. Soil and water conditions are improving, and biodiversity is recovering its variety and abundance. New enterprises have been established in seasonal horticulture, distribution, retailing, catering, and tourism.

Policy-Driven Change

Policy-led innovation also can be a powerful driver of the transitions illustrated in this chapter. The Food and Agriculture Organization's Mitigation of Climate Change on Agriculture program documents many of these (www.fao.org).

Policy innovation may emerge in unexpected contexts. For instance, the Law for the Orientation of Agriculture (LoA) became law in Mali in September 2006. In China the Circular Economy Law was adopted at the 4th Meeting of the Standing Committee of the 11th National People's Congress on August 29, 2008. The Organic Law on Food Sovereignty received final presidential approval in Ecuador in May 2009. All three open up new spaces for the public at large and diverse interests to participate in the interpretation and implementation of the provisions.

The LoA, Mali, asserts the principle of food sovereignty. It gives priority to the modernization of family farming, to the domestic and regional food and commodity trade, and to the social equity and environmental sustainability of technology choices and service provisions. The law evolved out of multi-stakeholder nationwide consultations, from village to national level. A series of citizens' juries, culminating at the national level (February 2010), proposed and deliberated a series of options for how to translate the law into practice. The Circular Economy Law, China, "is formulated for the purposes of promoting the development of the circular economy, improving resource utilisation efficiency, protecting and improving the environment and realising sustainable development" (Art. 1). It sets out for every sector, including agriculture, forestry, and food, the generic measures required for "reducing, reusing and recycling activities conducted in the process of production, circulation and consumption" (Art. 2). Articles 10 and 11 give citizens the right to report "acts of wasting resources and damaging the environment," "to propose their opinions and suggestions," and "encourages agencies, societies and other social organisations to engage in the publicity, technical promotion and consultancy service of circular economy so as to promote the development of circular economy [sic]." The Food Sovereignty law, Ecuador, gives preference to the development of culturally appropriate food products and conversion to agroecological practices in farming and requires land to service its environmental and social functions (generating employment, distributing income equitably, conserving and utilizing biodiversity productively). The law institutionalizes a National Conference on Food Sovereignty with eight statutory members (including representatives for women, indigenous groups, and peasant movements), responsible for deliberating implementation, new proposals, research, and the merits of various options for translating the law into practice.

Conclusions

Agroecology's contribution to climate change mitigation and adaptation is no longer of purely theoretical interest. It has become a powerful organizing principle around which national and local government policy-makers, farmers, citizens, actors in commercial food chains, and scientists have begun to bring a more sustainable future into being. Many practical and scientific questions remain, but the outlines of transformational ways of thinking about and practicing farming and food systems under climate change are already being created.

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