Biodiverse agriculture for a changing climate

Introduction

This paper is about biodiverse agroecology. The experiences of small-scale food providers are combined with those of researchers undertaking field scale trials and laboratory studies to offer an important alternative to the current dominant paradigm in food production. While food price volatilities and environmental degradation illustrate the failings of high input agriculture, this paper presents evidence demonstrating that agroecological approaches address both the causes and effects of climate change while offering environmentally and socially sustainable access to food. The challenge to food production presented by climate change is framed in terms of the need for resilience, adaptive capacity and the mitigation of greenhouse gas emissions in food production systems. This framing establishes the structure for the main body of the paper, in which studies of agroecology are reviewed to provide evidence derived from controlled experiments and agricultural practice. This review demonstrates that techniques common to biodiverse agroecological approaches bring multiple benefits, simultaneously building resilience in ecosystems and farming communities, while reducing greenhouse gas emissions from food production and drawing carbon from the atmosphere. The paper commences with a discussion of the challenges that climate change brings to food production and of the fundamental importance of biodiversity in agricultural ecosystems. It concludes by examining the power structures that support high input, industrialised agriculture despite its long term consequences for food and the environment, and recommends institutional and policy reforms to return control over agricultural biodiversity to food providing communities while supporting their ability to implement locally appropriate agroecological approaches.

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Agroecosystems: life support, if we allow it

Ultimately, human survival depends on the exploitation of agroecosystems for food, fuel and fibre. They are the ecosystems in which naturally occurring plants and animals have been replaced by deliberately selected crop plants and livestock animals. Their continuing productivity is a foundation stone of society, yet much of modern agricultural policy fails to recognise the need to support ecosystems while we satisfy our needs. Straightforwardly, if production is to be sustained, so must agroecosystems. However, whilst natural ecosystems are formed by the growth and decay of a wide diversity of plant and animal species, agroecosystems are focused around key species of use to humans. Crop production or livestock rearing, for example, typically require the transformation of ecosystems to ones containing pasture and domestic animals or crops. A significant volume of the biomass may also be removed from the ecosystem when the product is harvested. From an ecological perspective, agriculture can often be an extractive process that creates less diverse ecosystems than their natural counterparts.

The loss of biodiversity in agroecosystems can bring devastating consequences. While every ecosystem changes as time passes, in naturally occurring environments the diversity of ecosystem biota interact to create an approximately stable or equilibrium condition. This self-regulating condition is known homeostasis. Disturbances from outside the ecosystem are compensated for by responses in the different components of the ecosystem, be they producers (such as crops and weeds), consumers (animals), decomposers (soil fungi and bacteria) or the non-living elements (decomposed soil humus). Achieving homeostasis requires a large number of different species: without this, the ecosystem starts to deteriorate in response to any external variation. For this reason, simplified, human constructed agroecosystems may be unable to maintain their structure. Deterioration sets in, seen in processes such as the accelerated loss of resilience and diversity and the erosion, salinisation or decline in the fertility of soils.[1]

Current conventional industrial agriculture tends to simplify agricultural systems and reduces diversity. Agricultural methods and practices are made increasingly similar the world over to enable industrial scale production of similar products. Monocultures of single varieties of plants are grown over vast fields and prairies, in ways that facilitate mechanised planting, weed control, chemical spraying and harvesting. Similar seeds, livestock breeds, aquatic organisms, inputs and machines are supplied globally by an ever decreasing number of corporations. Diversity is the enemy of these large scale processes: diversity creates a complex landscape that prevents the homogenisation of methods and the uniformity of product demanded by the commodity supply chain. This simplification and the associated deterioration of the agroecosystems is compensated for through the introduction of chemical inputs - fertilisers, pesticides and herbicides and the increasing using of antibiotics in livestock. Thus, fossil fuel dependent industrial processes are required to provide agricultural inputs and sustain productivity. Yet while yields may be supported in the short term, these highly simplified agroecosystems cannot achieve homeostasis and remains in long term decline.

This paper is concerned with a different approach. Biodiverse agroecological methods fundamentally contrast with conventional industrial agriculture. Whilst industrial methods have become the dominant paradigm in only in the last 100 years, for centuries farming has relied on working with nature, mimicking natural ecology rather than trying to dominate it. Maintaining

[1] Egziabher, T.B.G (2002) 'The Human Individual and Community in the Conservation and Sustainable Use of Biological Resources', Darwin Lecture. Egziabher's discussion of homeostasis relies on Heywood, V. H., and R. T. Watson (1995) 'Global Biodiversity Assessment', UNEP and Cambridge University Press.

biodiverse ecosystems is key to agroecology and, as will be shown, is essential to meeting the new pressures that will be placed on agroecosystems as the effects of climate change take hold.

The challenges of climate change

The impact of greenhouse gas emissions on the global climate is now beyond doubt: the earth's temperature will rise throughout the coming century.[2] As time passes the emerging science continues to suggest that the changes may be more profound and with us sooner than first thought.[3] However, the precise implications remain unclear: predictions of rainfall rates, the likely frequency of extreme weather events, and regional changes in weather patterns cannot be made with certainty. Agriculture is challenged by this reality on two fronts.

First, global agriculture is a major contributor to greenhouse gas emissions.[4] The IPCC conclude that agriculture accounts for 10-12% of all anthropogenic greenhouse gases, including around 47% of methane and 58% of nitrous oxide.[5] While carbon dioxide is the main greenhouse gas currently in the atmosphere, small changes to methane and nitrous oxide can have a major impact, as they carry a 'greenhouse warming potential' (GWP) 72 and 289 times that of carbon dioxide, respectively.[6] The emissions attributable to agriculture are hard to measure and estimates vary. The World Resources Institute (WRI) suggest that agriculture comprises 15% of the total, as indicated in Figure 1. According to WRI's calculations, methane and nitrous oxide comprise more than 90 per cent of these emissions, and respectively half and three quarters of the global totals. Importantly for climate change mitigation, Figure 1 also identifies the activities responsible, with soil management and the digestive processes of livestock dominating. Note, however, that this is not full lifecycle analysis, so excludes the carbon embedded in agricultural machinery or inputs (fertiliser manufacture, for example, is a fossil fuel intensive process). This is a significant issue when comparing agricultural systems: organic agriculture, for example, in which no chemical inputs are applied, has a very different energy profile to industrial agriculture when the full costs of production are accounted for. This difference is explored in more detail in the following section. A further missing component is the impact of land use change, principally due to the clearance of forests to create pasture or crop land.[7] Estimates for the total emissions resulting from land use change vary between 15 and 18 percent of total global anthropogenic carbon dioxide.[8] Land use

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[2] IPCC (2007) 'Summary for Policymakers' in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[3] Hare, B. (2008) The science of climate change, Breaking the Climate Deadlock Briefing Paper, The Climate Group.

[4] Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the three main anthropogenic greenhouse gases. IPCC (2007) *ibid.*

[5] 2005 figures. Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko (2007) 'Agriculture' in *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, s8.3.

[6] Calculated over a 20 year time horizon. The global mean radiative forcing (a comparison of the strength of different human and natural agents in causing climate change) of each of the gasses for the period 1750-2005 is 1.66 (carbon dioxide) 0.48 (methane) 0.16 (nitrous oxide). See Table 2.12 and 2.14 in Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[7] Forestry Commission 'The international challenge: deforestation' http://www.forestry.gov.uk/forestry/infd-6vjhlf

[8] Bruinsma, J. (ed) (2003) 'World Agriculture: Towards 2015/2030. An FAO Perspective' FAO, Rome p334; Baumert, K.A., T. Herzog, J. Pershing (2005) 'Navigating the Numbers: Greenhouse Gas Data and International Climate Policy', World Resources Institute p91; Forestry Commission *ibid.*

change is dominated by industrial agriculture's desire for pasture for livestock, for crops including those such as soybean used as feed for cattle in industrial systems across the world, and increasingly for large scale biofuel production.[9] A significant component is the direct result of the transition from traditional resource-driven to demand-driven livestock production, and in particular towards a model of intensive, grain-fed livestock: the FAO estimate that livestock related land use change accounts for 9 percent of global anthropogenic emissions.[10] As a report for the Food Climate Research Network notes in relation to soybean production in the Amazon region, intensive livestock rearing can be the catalyst for an unsustainable chain reaction of land clearing[11]:

> soybean cultivation not only makes use of land in its own right, but is also an important 'push' factor for deforestation by other industries. In other words, although soy production may not always take place directly on virgin rainforest, it takes land away from other uses, such as smallholder cultivation and cattle rearing, pushing these enterprises into the rainforest. As a highly profitable industry, it also provides income to purchase land for other purposes, including logging.

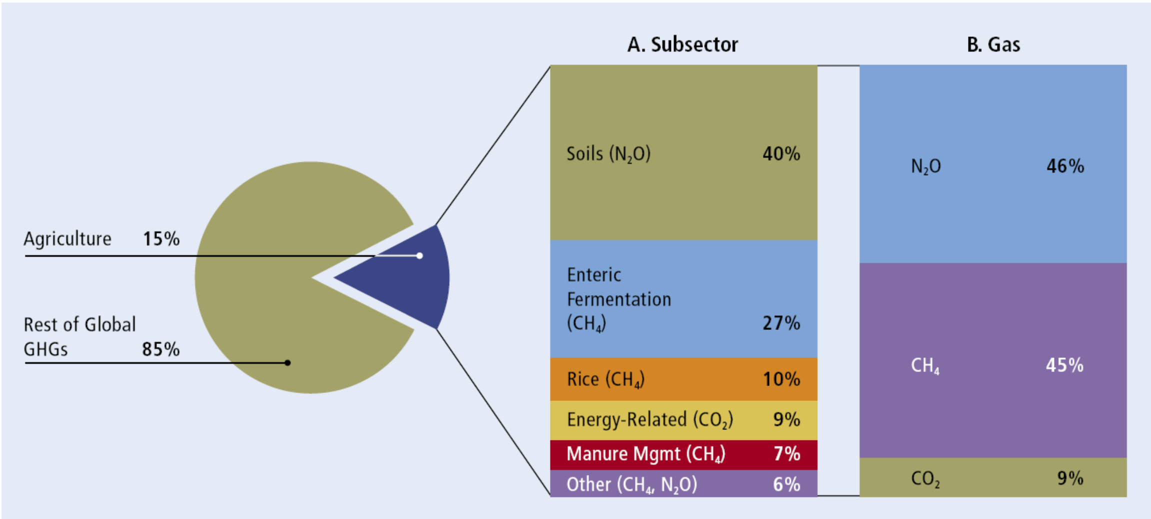

Figure 1[12]: Greenhouse gases (GHGs) from agriculture, where the per cent figures reflect the greenhouse warming potential of each gas.

Land use change cannot be excluded from an account of agricultural emissions as it underpins modern production. This makes agriculture responsible for more than 30% of total global greenhouse gas emissions. Mitigation of climate change demands a swift transition to methods of production that reduce emissions across all sectors of the economy, and there is an urgent need for agriculture to play its part. The good news is that agriculture and food production has huge potential to have a positive impact on global climate change. Greenhouse gases are emitted at all stages: the manufacture and operation of agricultural machinery and fishing gear, the production, transportation and application of agricultural inputs such as fertilizers, the by-products of growing processes, the 'food miles' that result from a globalised supply chain - and so on. Each link in the chain offers opportunities for efficiencies or transformation. The transition from fossil fuelled industrial production to ecologically-based agriculture focussed on supplying local needs is one

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[9] Baumert (2005) *op cit.* p91; Garnett, T. (2008) 'Cooking up a storm Food, greenhouse gas emissions and our changing climate' Food Climate Research Network p27
[10] FAO (2006) 'Livestock's Long Shadow: Environmental issues and options' FAO, Rome p112
[11] Garnett (2008) *ibid.* p27
[12] Baumert (2005) *op cit.* Figure 15.1. Reproduced with permission from the publisher.

such transformation. As the FAO note, 'most of the negative impacts from agriculture on the environment can be reduced or prevented by an appropriate mix of policies and technological changes'.[13] Importantly, many agricultural practices significantly alter the carbon content of soils, releasing stored carbon into the atmosphere as soils degrade. Yet agriculture could instead lock greater amounts of carbon into soil through regenerative practices such as those employed in agroecological approaches. Thus, as will be shown in more detail below, agroecology has the potential not only to reduce current levels of greenhouse gas emissions, but also to facilitate carbon capture, commonly referred to as sequestration.

However, the current levels of greenhouse gases in the atmosphere mean that even with the most ambitious mitigation strategies climate change will still bring impacts over the next century. Climate change therefore presents a second challenge, due to the impact of environmental change on agriculture. The intimate relationship between food production and weather makes climate change a potential threat to the lives and livelihoods of billions worldwide, including 370 million of the world's poorest who survive in environments that are already resource poor. The need for adaptation is therefore unavoidable. Yet unlike mitigation, adaptation is highly context specific: climate change will bring different challenges in different places, and the nature of the impacts will in part be dependant on the local natural and physical environment. While the particular impacts may vary, two broad categories can be identified. First, climate change brings *discrete hazards* such as flash flooding, droughts or storms. These phenomena develop rapidly and have the potential to damage or destroy crops, livestock and infrastructure. Yet climate change also brings slower, incremental changes to the average conditions, such as warmer winters, wetter summers, earlier seasonal changes or rising sea levels. These *continuous hazards* may have a profound effect on agriculture, altering the location, timing and rate of growth of plant, animal and fish species, the spread of diseases, and the availability of coastal land. But for each category of hazard the particular impact will be felt as a consequence of climate change in combination with the current condition of the environment.[14] Heavy rains, for example, may either wash away degraded top soil, or be absorbed and stored within a healthy soil structure, so that water is available to support plant growth during dry periods.

Adaptation is the process through which communities adjust to the impacts of climate change. Rather than being purely reactive, adaptation can be forward looking, aided by forecasting information and climate predictions. However, effective adaptation requires an appreciation of the uncertainty that is inherent in climate change predictions. Climate models are relied on to provide information on long-term trends. While they are able to establish with high confidence that global average temperatures will continue to increase (not least because of the levels of greenhouse gases currently in the atmosphere), more detailed changes, such as the impact of warming on wet and dry seasons, remain unclear. Climate models are only approximations of reality, offering an incomplete representation of the full complexity of the Earth's systems. Uncertainty – meaning that more than one plausible future can be asserted – is unavoidable.[15] Even for a fixed rate of future emissions there is uncertainty as to the exact impact on temperature. While the highest emission scenario in the IPCC's Fourth Assessment Report produces a most likely average temperature increase of 4ºC by the end of the 21st century, it is also possible that the increase

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[13] Bruinsma (2003) *op cit.*
[14] Ensor, J. and Berger, R. (2009) 'Understanding Climate Change Adaptation. Lessons from Community-Based Approaches' Practical Action Publishing, Rugby, UK pp13-15.
[15] Ensor and Berger (2009) *ibid*, pp6-11.

might be as high as 6.4ºC or as low as 2.4ºC.[16] Currently, the impact of uncertainty can be seen most clearly in the failure of climate models to provide good agreement at the regional scale, and in particular on future levels of precipitation. In East Africa, for example, the impact of climate change on rainfall is unclear. Climate models fail to agree as to whether precipitation will increase or decrease in any season, and uncertainty peaks during the summer when as many models project an increase as a decrease.[17]

Climate change, then, provides a particular challenge: we know that change is coming, but our ability to foresee that change depends on a number of factors. How far into the future we look, what region we are in, whether a local or national prediction is needed, whether we are concerned with temperature, precipitation or extreme events all have an impact on the degree of confidence with which predictions can be made. A meaningful approach to adaptation must address this challenge by ensuring that altered livelihood strategies do not only bring benefit if climate change plays out as predicted. Optimising agricultural, aquacultural or pastoral strategies to a particular climate future risks maladaptation and will always be a mistake as long as uncertainty remains in climate projections. Rather, adaptation needs to take account of uncertainty by ensuring that livelihoods - and therefore also agroecosystems - retain and enhance the ability to ride out or respond to unexpected events. Efforts to reduce current vulnerability may form part of an adaptation strategy, but should be employed in combination with measures to increase resilience and build adaptive capacity. Here, adaptive capacity is understood as an individual or community's ability to change in response to climate changes, while resilience refers to the ability to absorb or cope with the unexpected. [18]

Table 1 summarises these three components of adaptation.[19] The emphasis that is placed on each component will depend on the particular circumstances. For example, areas in which rising sea levels are inundating land or changing the salinity of waterways will demand immediate action to reduce vulnerability to sea level rise. However, such a clear identification of vulnerability to climate change will usually be restricted to phenomena that are imminent or already occurring - changes predicted further into the future are subject to increasing uncertainty. As the real possibility of unforeseen hazards emerges, or where, for example, projections of greater rainfall become as likely as those of drought, adaptation actions need to focus increasingly on resilience and adaptive capacity. Temperature increases, glacial retreat and sea level rise remain the most predictable elements of climate change, yet even here the rate of change is open to question, subject to both future greenhouse gas emissions and regional variation. Moreover, all climate predictions are by definition an expression of the average conditions over a 20-30 year period, meaning that regular departures from the overall average will be the norm. Resilience against variation and the unexpected, and the capacity to adapt to a changing world are therefore cornerstones of adaptation.

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[16] Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A., Raper, S.C.B., Watterson, I.G., Weaver A.J. and Zhao, Z.-C. (2007) 'Global climate projections', in S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 748–845, Cambridge University Press, Cambridge, UK: p. 749.
[17] Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R.K., Kwon, W.-T., Laprise, R., Magaña Rueda, V., Mearns, L., Menéndez, C.G., Räisänen, J., Rinke, A., Sarr, A. and Whetton, P. (2007) 'Regional climate projections', in S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 848–940, Cambridge University Press, Cambridge, UK: p854.
[18] Ensor and Berger (2008) *op cit* pp 17-25
[19] Ensor and Berger (2009) *ibid* pp 26-33

Approach	Comments
Vulnerability reduction	• Vulnerability to climate change is assessed in reference to a particular hazard, for example vulnerability to flooding, and considers underlying human and environmental factors • Vulnerability reduction targets a particular hazard, and should aim to meet short term needs as well as addressing potential climate change
Strengthening resilience	• Defined as the ability to absorb shocks or ride out changes • Reduces vulnerability to a wide range of hazards • Underpinned by agricultural biodiversity • Local input into decision making supports resilience by reducing the chance of inappropriate interventions
Building adaptive capacity	• Defined as the ability to shape, create or respond to change • Strengthens resilience and reduces vulnerability to a wide range of hazards • Amount, diversity and distribution of assets facilitates alternative strategies • Requires information plus the capacity and opportunity to learn, experiment, innovate and make decisions

Table 1: Approaches to adaptation. Different circumstances will demand a different blend of approaches.

Resilience is often associated with coping during and following discrete hazards, but it is also the case that resilient ecosystems and diverse livelihoods are better able to adjust to slowly changing conditions. For example, healthy soils retain moisture and are thus better able to cope with a drying climate, and diverse ecosystems are better placed to adapt to the emergence of new pests or an increase in pest numbers under new climate conditions. Similarly, a livelihood predicated around species diversity is well placed to make gradual adjustments in crop or species selection strategy based on observed changes in yields and quality. However, continuous hazards in particular may be best addressed through adaptive capacity, which encompasses the ability of individuals or communities to make changes to their livelihoods or livelihood strategies in response to changing conditions. This creative and innovative component of adaptation is a central feature of agroecological practice.

Biodiverse agroecology: meeting the challenge

Agroecology responds to the challenges set out above: the need to foster sustainable productive agricultural environments, reduce emissions associated with farming, capitalise on sequestration potential, build resilience in farming practices and foster the adaptive capacity of communities. Table 2 links Pretty's principles for sustainability in agriculture to these challenges, summarising the multiple benefits of systems of food production based in agroecology. Two different classes of resilience are identified: the resilience of agroecosystems, achieved by fostering homeostasis, and livelihood resilience, which is achieved through a reduced dependency on external inputs (which harbour uncertainties such as price volatility) or a diversification of produce (preserving yields in the face of climate, pest or disease variability). As adaptive capacity and resilience both reduce vulnerability to a wide range of climate change hazards, vulnerability reduction can be achieved through all of the practices in Table 2, depending on the context. For example, existing vulnerability to rainfall variability may be reduced through the regeneration of soils (yielding agroecosystem resilience). These relationships are explored in more detail in the following sections.

Principles of agricultural sustainability (Pretty, 2006)[20]	Relationship to the challenges of agriculture and climate change
integrate biological and ecological processes such as nutrient cycling, nitrogen fixation, soil regeneration, allelopathy, competition, predation and parasitism into food production processes	• Resilient agroecosystems • resilient livelihoods (increased variety of produce)
minimise the use of those non-renewable inputs that cause harm to the environment or to the health of farmers and consumers	• resilient agroecosystems • mitigation • resilient livelihoods (reduced dependency)
make productive use of the knowledge and skills of farmers, so improving their self-reliance and substituting human capital for costly external inputs	• resilient livelihoods (reduced dependency) • adaptive capacity (self-reliance and local knowledge)
make productive use of people's collective capacities to work together to solve common agricultural and natural resource problems, such as for pest, watershed, irrigation, forest and credit management.	• Resilient agroecosystems • adaptive capacity (knowledge networks, experimentation and innovation)

Table 2: Agroecology and the challenges facing agriculture.

Agroecology encompasses a range of agriculture systems that employ an understanding of environmental systems to both draw on and replenish natural resources. For Pretty, 'sustainable agriculture' refers to 'systems … that aim to make the best use of environmental goods and services whilst not damaging these assets',[21] while Altieri refers to agroecology as the development of agroecosystems in which the interactions and synergies between the different components sponsor fertility, productivity and protection.[22] The focus in each case is on the entire ecological system so as to generate environments that are productive and natural resource conserving, while also socially sustainable: culturally sensitive, socially just and economically viable.[23] In Europe and the US agroecological systems have emerged that are referred to as biodynamic, organic and biological: despite differences of emphasis the common feature is 'to stress the essential link between farming and nature, and to promote respect for natural equilibria'.[24]

At the heart of agroecology is agricultural biodiversity. Agricultural biodiversity describes the subset of overall biodiversity that has come about through the creative efforts of farmers, fishers

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[20] Pretty, J. (2006) 'Agroecological Approaches to Agricultural Development' Background Paper for the World Development Report 2008
[21] Pretty, J. (2006) *ibid.*
[22] Altieri, M.A. and Nicholls C. I. (2005) 'Agroecology and the Search for a Truly Sustainable Agriculture' UNEP, Mexico
[23] Altieri, M.A. (2007) 'Agroecology: The Science of a Sustainable and Resilient Agriculture for the XXI Century' Proceedings of Tropentag 2007: International Research on Food Security, Natural Resource Management and Rural Development http://www.tropentag.de/2007/proceedings/node5.html
[24] FAO (2006) *op cit.* footnote 17

and herders over many centuries. Agricultural biodiversity includes all the living organisms that make up an agroecosystem, not just those elements that are harvested. Agroecology thus is both based upon and contributes to agricultural biodiversity: it is founded in the ecological necessity of biodiversity for healthy, productive and resilient environments, and as a process seeks to ensure that agriculture fosters biodiversity[25] and is itself biodiverse. Agricultural biodiversity is the cornerstone of productive, sustainable agriculture, provides important opportunities for climate change mitigation, and enables adaptation in food, fuel and fibre production. The following sections examine first the importance of agricultural biodiversity, then how biodiverse agroecology contributes to resilience, adaptive capacity and mitigation. Throughout, the efficacy of agroecology is demonstrated through both the results of long term scientific tests as well as cases studies of agroecology in practice.

The fundamental importance of agricultural biodiversity

"we cannot forget that biodiversity conservation is part of the solution to climate change."
Ahmed Djoghlaf, Executive Secretary of the Convention on Biological Diversity [26]

Agricultural biodiversity can be understood as the totality of the elements that create an agroecosystem. It comprises not only harvested elements - the genetic diversity inherent in breeds and varieties and between species - but also those components that are essential to maintaining the agroecosystem. These non-harvested elements include those that support food, fuel, fibre and medicine provision (including soil micro-biota, predators and pollinators), and those that support the agroecosystem (including wider agricultural, pastoral, forest and aquatic ecosystems).[27]

The variety and variability of harvested animals and plants includes both wild and domesticated breeds and species. Both contribute to agricultural biodiversity and, together with non harvested elements, generate synergies that help support broader ecosystem services such as air and water purification, fixing and recycling of nutrients, control of local microclimate, regulation of local hydrological processes, and detoxification of noxious chemicals. [28] Trees in and around fields, for example, help protect soil structure and also provide habitats for birds which, in turn, control pest populations.[29] In this way each component of an agroecosystem may offer multiple functions in support of a range of services including - but by no means limited to - food production and security. In many parts of the world these complex systems are managed by communities whose livelihoods and food supply have depended on sustainable production for generations. As the Food and Agriculture Organisation (FAO) points out, 'local knowledge and culture can therefore be considered as integral parts of [agricultural biodiversity], because it is the human activity of agriculture that shapes and conserves this biodiversity'.[30] Small holder and traditional biodiverse farms are examples of the embodiment of this knowledge. They assemble key organisms that, in

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[25] For example, 'organic farms are known to be better for wildlife than conventional, chemical-dependent farms. In a five year study across Britain, environmental scientists found that, compared with conventional farms, organic farms contained 85 per cent more plant species, one-third more bats, 17 per cent more spiders and 5 per cent more birds.' Harvey, G. (2008) 'The carbon fields: How our countryside can save Britain', Grass Roots, Bridgwater.
[26] Ahmed Djoghlaf, Executive Secretary of the Convention on Biological Diversity (CBD), addressing the ninth National Conference on Science, Policy and the Environment, organized by the US National Council for Science and Environment.
[27] FAO (1999) 'Sustaining agricultural biodiversity and agro-ecosystem functions' Report of the International Technical Workshop, 2 - 4 December 1998, FAO Headquarters, Rome, Italy
http://www.fao.org/WAICENT/FAOINFO/SUSTDEV/EPdirect/EPre0080.htm
[28] Altieri, M.A. (1999) The ecological role of biodiversity in agroecosystems Agriculture, Ecosystems and Environment 74 pp19–31
[29] Swedish Society for Nature Conservation (2008) Ecological in Ethiopia – Farming with nature increases profitability and reduces vulnerability, Stockholm
[30] FAO (2004) What is agrobiodiversity? http://www.fao.org/docrep/007/y5609e/y5609e01.htm

combination, promote and enhance those ecosystem services that are important to the performance of the agroecosystems. While a huge variety of these farms exist across the world, they share common features, as outlined in Box 1.

Box 1: Common elements characterising biodiverse farms[31]

- They combine species and structural diversity in time and space through both vertical and horizontal organization of crops.
- The higher biodiversity of plants, microbes, and animals inherent to these systems supports production of crops and stock and mediates a reasonable degree of biological recycling of nutrients.
- They exploit the full range of micro-environments, which differ in soil, water, temperature, altitude, slope, and fertility within a field or region.
- They maintain cycles of materials and wastes through effective recycling practices.
- They rely on biological interdependencies that provide some level of biological pest suppression.
- They rely on local resources plus human and animal energy, using little modern technology.
- They rely on local varieties of crops and incorporate wild plants and animals. Production is usually for local consumption.

The productivity enhancing, purifying, regulating and recycling functions provided to agroecosystems by biodiversity occur as a result of improved nutrient use and energy capture among the different biological elements. However, these enhanced functions occur only when a threshold of niche utilisation is reached. In natural ecosystems the variation within and between species allows them to occupy different ecological niches, such as plants growing to differing heights and with a variety of leaf structures to make use of available light. The importance of biodiversity is in providing a critical number of complementary species that are able maximise the exploitation of available niches[32], enhancing productivity, enabling homeostasis and preventing ecosystem decline. [33] A reduction in biodiversity through the simplification of agroecosystems reduces niche utilisation and therefore brings losses in fertility and an increased risk of exposure to new pest and disease variants. This loss of internal regulation increases progressively under agricultural intensification, creating an 'artificial ecosystem that requires constant human intervention'. [34] From this perspective, agricultural monocultures become the ecological worst case scenario, in which

> only one niche is used, and all the individuals of the crop or animal species compete absolutely for that same niche while there remain other niches fully or partly unoccupied because species that could use them are not present. Therefore … though intensive inputs may make agricultural production in a given season high, sustained high productivity over years is not possible. [35]

[31] Altieri, M.A. and P. Koohafkan (2008) Enduring farms: Climate change, smallholders and traditional farming communities, Third World Network
[32] Finke D., and W. Snyder (2008) Niche partitioning increases resource exploitation by diverse communities, Science, Sept. 12, 2008.
[33] Egziabher (2002) *op cit.* Egziabher's discussion of homeostasis relies on Heywood, V. H., and R. T. Watson (1995) Global Biodiversity Assessment, UNEP and Cambridge University Press.
[34] Altieri (1999) *op cit*
[35] Egziabher (2002) *op cit*

Box 2: Biodiversity in traditional coffee cultivation

Coffee is cultivated across 11 million hectares (ha) of land within the world's richest centers of terrestrial biodiversity. In tropical America, coffee is traditionally grown [by small scale farmers] under a diverse canopy of overstory shade trees, which enhances the quality of the coffee farm as a conservation matrix and supports a broad spectrum of pollinators that increase fruit set per bush. Unlike sun coffee monocultures, shade coffee also sustains a diverse array of vertebrates, including bats and migratory birds, which provide farmers with many ecological services, such as insect predation, and may also conserve seed dispersal processes necessary for native tree re-establishment.[36]

Improving the ability of agroecosystems to self regulate is of central importance to resilience to climate change, and returned to in more detail below. However, the aim is not to achieve homeostasis through agricultural biodiversity, but to improve the ability of the system to self regulate; that is, to move closer to homeostasis. Agroecological methods then seek further synergies, making use of the available biodiversity to promote regeneration and arrest declines in the agroecosystem (for example, through the spreading of green waste). Unchecked, the decline of agroecosystems is inevitable. However, by integrating context specific and responsive agroecological practices (requiring skills and knowledge that are often locally or communally held) decline can be arrested and regeneration becomes an aspect of farming, fishing or herding practice. This approach is in stark contrast to the large scale introduction of inorganic fertilizers, which provide short term compensation for declines in yields but not regeneration - and therefore not resilience. Research into the benefits of agricultural biodiversity in farming demonstrates that[37]:

1. Higher diversity (genetic, taxonomic, structural, resource) within the cropping system leads to higher diversity in associated biota.
2. Increased biodiversity leads to more effective pest control and pollination.
3. Increased biodiversity leads to tighter nutrient cycling.

This regulating and regenerating function of agricultural biodiversity is a key component of resilience and therefore an important element in adaptation to climate change. However, agricultural biodiversity also contributes to resilience through the different genetic traits in breeds (for example, resistance to particular pathogens) and to adaptive capacity by providing the foundation for future genetic variation (through breeding or variety selection) to meet as yet unknown challenges.

Climate change adaptation: Resilience

'Modern [industrial] agroecosystems have weak resilience … transitions towards sustainability need to focus on structures and functions that improve resilience.'
Jules Pretty (2006)[38]

Resilience to climate change in agricultural systems comprises overlapping elements: agroecosystem resilience (persistence and sustainability of yield from the land or sea in face of a changing climate) and livelihood resilience (achieved through livelihood strategy diversification,

[36] Jha, S. and C.W. Dick (2008) Shade coffee farms promote genetic diversity of native trees, Current Biology, 18 (24) pp1126-1128
[37] Power, A.G., (1999) Linking ecological sustainability and world food needs. Environment Development and Sustainability 1, pp185–196.
[38] Pretty (2006) *op cit.*

such as by introducing fish into rice paddies, or planting a wider variety of crop species). These strongly overlap and will completely do so in those cases where crop or species diversity improves niche utilisation and hence ecosystem resilience. Resilience is also improved through removing dependence on external inputs, decoupling agricultural practice from volatility and changes in other markets, whilst retaining assets on-farm through a reduced need to spend capital.

Box 3: Agroecological approaches that build resilience[39]

• **Complex systems:** In traditional agroecosystems the prevalence of complex and diversified cropping systems is of key importance to the stability of peasant farming systems, allowing crops to reach acceptable productivity levels in the midst of environmentally stressful conditions. In general, traditional agroecosystems are less vulnerable to catastrophic loss because they grow a wide range of crops and varieties in various spatial and temporal arrangements.

• **Use of local genetic diversity**: In most cases, farmers maintain diversity as insurance against future environmental change or to meet social and economic needs. …The existence of genetic diversity has special significance for the maintenance and enhancement of productivity of small farming systems, as diversity also provides security to farmers against diseases, especially pathogens that may be enhanced by climate change. By mixing crop varieties, farmers can delay the onset of diseases by reducing the spread of disease-carrying spores, and by modifying environmental conditions so that they are less favourable to the spread of certain pathogens.

• **Soil organic matter enhancement**: Throughout the world, small farmers use practices such as crop rotation, composting, green manures and cover crops, agroforestry, etc., all practices that increase biomass production and therefore build active organic matter. Soil management systems that lead to maintenance of soil organic matter levels are essential to the sustained productivity of agricultural systems in areas frequently affected by droughts.

• **Multiple cropping or polyculture systems**: Studies suggest that more diverse plant communities are more resistant to disturbance and more resilient to environmental perturbations. Intercropping, which breaks down the monoculture structure, can provide pest control benefits, weed control advantages, reduced wind erosion, and improved water infiltration.

• **Agroforestry systems and mulching**: Many farmers grow crops in agroforestry designs and shade tree cover to protect crop plants against extremes in the microclimate and soil moisture fluctuation. Farmers influence the microclimate by retaining and planting trees, which reduce temperature, wind velocity, evaporation and direct exposure to sunlight and intercept hail and rain. … it is internationally recognized that agroforestry systems contribute simultaneously to buffering farmers against climate variability and changing climates, and to reducing atmospheric loads of greenhouse gases because of their high potential for sequestering carbon.

• **Home gardening:** Home gardening is a term to describe the cultivation of small plots used to grow food either adjacent or close to the habitation. They are fertilized with household wastes and are rich in plant species diversity, usually maintaining 30 to 100 species. This practice provides diversification of crop species and is of economic importance because of its food and nutritional (balanced diet) and medicinal value to the household. The farmer obtains food products, firewood, medicinal plants and spices, and some cash income all year round. These self-sustaining systems are ecologically and economically very efficient.

Agroecological methods have multiple benefits for resilience to climate change. The ability to withstand shocks and stresses is enhanced through practices that are themselves diverse and which separately and taken together reduce risks, enrich natural resources and build synergies between different farm species and activities. Altieri and Koohafkan's review of traditional and

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[39] Adapted from: Altieri and Koohafkan (2008) *op cit* and: Altieri, M.A. (2002) 'Agroecology: the science of natural resource management for poor farmers in marginal environments', Agriculture, Ecosystems and Environment 1971 pp1–24

small scale agroecological farming provides examples of common practices and methods that build resilience, summarized in Box 3.

Other methods include traditional aquaculture, in which diverse domestic breeds are conserved in situ, utilising different ecological niches to enable optimum use of resources in a breeding pool. [40] As with the polyculture systems outlined in Box 3, different species are combined using an understanding of the species, local environment and ecosystem energy flows to produce multiple harvests and consistent yields that are less susceptible to environmental change. Altieri and Koohafkan highlight the role of local knowledge in polycultures, noting how 'indigenous knowledge of management of the fragile and variable environment, local genotypes of food crops, intercropping, and agroforestry systems' enables resilience to climate variability and its corollary, conservation of biodiversity.[41] For farmers, strategies commonly include guarding against reduced rainfall by planting vegetable crops as an insurance against crop failure.[42] Diversity in management strategy is thus employed alongside agricultural biodiversity to enable resilience: the integration of a wide range of crop and livestock types allows livelihoods to be maintained in the face of pathogen infestation, variable rainfall and fluctuations in market prices. The FAO point out that companion crops that grow in infertile or eroded soils can have a significant role in maintaining livelihoods in harsh environments, being a valuable source of food in their own right, a marketable crop, or a source of fodder for livestock varieties that will eat degraded vegetation. [43]

Box 4: Overcoming low rainfall and environmental degradation in Senegal[44]

In Sahelian countries, the major constraints to food production are related to lack of moisture and soils most of which are sandy and low in organic matter. Where they are heavier and better in quality, they are subject to intensive use and so exposed to erosion by water and wind. In Senegal, soil erosion and degradation threaten large areas of agricultural land. Since 1987, the Rodale Institute Regenerative Agriculture Research Center (RARC) has worked closely with farmers associations and government researchers to improve the quality of soils in Senegal by using agroecological methods.

The RARC works with about 2 000 farmers in 59 groups to improve the soil quality, integrate stall-fed livestock into crop systems, add legumes and green manures, improve the use of manures and rock phosphate, incorporate water harvesting systems, and develop effective composting systems. The result has been a 75-195 percent improvement in millet yields-from 330 to 600-1 000 kg/ha, and in groundnut yields from 340 to 600-900 kg/ha. Yields are also less variable year on year, with consequent improvements in household food security. As Amadou Diop has put it: "crop yields are ultimately uncoupled from annual rainfall amounts. Droughts, while having a negative effect on yields, do not result in total crop failure".

Diversity in livestock and fish species and breeds is as important as in crop varieties when coping with the impacts of climate change. Fish stocks become increasingly vulnerable when modern fishing fleets target particular high value species: at low levels [once overfished] populations are vulnerable to environmental change, robbed of the genetic diversity that underpins the ability of the population to respond. [45] As the FAO note, 'the maintenance and enhancement, where

[40] ITDG (1996) Fisherfolk safeguarding Aquatic Diversity through their Fishing Techniques, ITDG, Rugby, UK.
[41] Altieri and Koohafkan (2008) *op cit.*
[42] Altieri and Koohafkan (2008) *ibid.*
[43] FAO (2004) *op cit.*
[44] FAO (2002) Land and Agriculture: From UNCED, Rio de Janeiro 1992 to WSSD, Johannesburg 2002. FAO: Rome. ftp://ftp.fao.org/docrep/fao/006/y3951e/y3951e00.pdf
[45] Martínez i Prat, A.-R. (1995) 'Fishing Out Aquatic Diversity', Grain, July 1995

possible, of the resource base and of biodiversity' is crucial to achieving the sustainable contribution of fish to food security.[46] Indigenous breeds of livestock are known for their ability to withstand particular diseases and environments - for example, the Red Masai sheep is resistant or less prone to intestinal worms while the Kuri cattle, found on the shores of Lake Chad, are resistant to insect bites.[47] As environments in some regions become harsher, the loss of breeds that are able to exploit poor quality vegetation may also damage the ability of societies to persist.[48] These and many other traits found in indigenous breeds will become increasingly important as climate change alters the environment and the pattern of pathogen spread between and within countries. Their protection, along with the local knowledge that is critical to their management and breeding, is therefore ever more important.

As climate change brings increasing variability in rainfall frequency and amount, integrated agroecological techniques in which 'crop yields are ultimately uncoupled from annual rainfall amounts', such as those illustrated by smallholding groundnut farmers in Senegal (Box 4), will have huge significance in supporting climate change resilience. The improvement and protection of soils in particular is crucial in enabling agroecosystems to remain productive in the face of variable and extreme weather. Surveys carried out following the landfall of Hurricane Mitch in Central America found that farmers practicing agroecology experienced lower economic losses. Their land was found to have 20 - 40 per cent more topsoil, greater levels of moisture and less erosion.[49] The soils in Nicaragua, Honduras and Guatemala with high levels of organic matter had the capacity to retain larger quantities of moisture. Linked to locally appropriate land management practices such as terracing, a resilient agroecosystem resulted that was better able to withstand extreme weather events, absorbing heavy rains and high winds.

Box 5: Literature review of scientific evidence on organic farming[50]

- Soil erosion was significantly reduced in the organic production systems compared with the conventional production systems, thus conserving nitrogen, phosphorus, and potassium.
- Water resources were conserved in the organic production systems compared with the conventional production systems.
- Corn and soybean organic farming system-yields during drought years were 30 percent and 50 percent higher than the conventional corn and soybean-yields, respectively.
- Soil organic matter in the organic farming systems was 54 percent higher than in the conventional farming systems.

Long term scientific studies have established the importance of soil quality to resilience, demonstrating that higher levels of soil organic matter - the non-living decomposed and partially decomposed plant and animal tissues that are found in soils - conserve the soil itself and, critically, water resources within the soil.[51] However, soil composition is not static. Soil organic matter and the biodiversity of organisms within the soil in agroecosystems vary, meaning that the approach to agriculture is critical in maintaining or diminishing the productivity and resilience of the agroecosystem. A side by side comparison of organic and conventional farms that has run

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[46] FAO (1996) 'Safeguarding fish supplies: key policy issues and measures' International Conference on the Sustainable Contribution of Fisheries to Food Security, FAO, Rome.
[47] Smallstock in Development, Domestic Animal Diversity, http://www.smallstock.info/issues/diversity.htm#contrib
[48] Smallstock in Development, Domestic Animal Diversity, *ibid.*
[49] Altieri (2002) *op cit.*
[50] Pimentel, D. (2006) 'Impacts of Organic Farming on the Efficiency of Energy Use in Agriculture', An Organic Center State of Science Review
[51] Pimentel, D., Hepperly, P., Hanson, J., Douds, D., and Seidel, R. (2005) 'Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems', Bioscience, 55(7) pp573-582

continuously since 1948 demonstrates the impact of farming practice. It found that organic methods, in which crop rotations, manuring, organic fertilizers and biological pest controls are employed in place of chemical inputs, reduce soil erosion and maintain productivity over the long term. The study found that the organically farmed soils had 'significantly higher levels of organic carbon' concluding that organic farmers 'can, and generally do, achieve higher organic matter levels in their soils than do conventional farmers'. [52] Moisture contents were 'significantly higher' in the organically farmed soils, while 'the amount of productive topsoil was dramatically less on the conventionally farmed soil'.[53] A similar study, based on a 22 year continuous field scale trial, found that 'high levels of soil organic matter helped conserve soil and water resources and proved beneficial during drought years'[54]:

> the organic crop systems performed significantly better in 4 out of 5 years of moderate drought. In the severe drought year of 1999, three out of the four crop comparisons resulted in significantly better yields in the organic systems than the conventional. [55]

A 21 year long Swiss study comparing organic and conventional farm systems demonstrated that soil quality and microbial biomass activity are both increased by the use of manure compost in place of chemical inputs.[56] In particular, soil components[57] that play a crucial role in nutrient acquisition and soil fertility are known to be maintained under organic farming methods but severely depressed in conventional industrial agriculture, reducing soil fertility.[58] The scientific literature also provides evidence that soils with high organic matter and biodiversity render crops less susceptible to pest attack and infection by disease causing organisms, due to the presence of beneficial organisms and microbes within the food web supported by the soil.[59] This ability to cope with pests and diseases will form an important element of resilience as their distribution changes in response to the modification of regional and local temperature and moisture profiles by climate change. As Pimentel and colleagues point out, 'abundant biomass both above and below the ground (soil organic matter) also increases biodiversity, which helps in the biological control of pests and increases crop pollination by insects.' [60] Recent research in China illustrates the significance of above ground biodiversity, finding that farmers who grew four different varieties of rice 'suffered 44 per cent less blast incidence and exhibited 89 per cent greater yield than homogeneous fields without the need to use fungicides.'[61] Alteri's review of literature suggests that agroecological practices that improve soils reduce the incidence of plant diseases (whereas applications of nitrogen fertilizer can create nutritional imbalances, and render crops susceptible to diseases) and control weeds. On pest control, he summarises:

> The more diverse the agroecosystems and the longer this diversity remains undisturbed, the more internal links develop to promote greater insect stability. Any changes on the levels of plant diversity in such systems can lead to disruptions of natural pest control mechanisms,

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[52] Reganold, J. P., L.F. Elliott, Y.L. Unger (1987) 'Long term effects of conventional and organic farming on soil erosion', Nature 330(26) pp370-372
[53] Reganold (1987) *ibid.*
[54] Pimentel *et al* (2005) *op cit.*
[55] Lotter, D.W., R. Seidel, and W. Liebhardt (2003) 'The performance of organic and conventional cropping systems in an extreme climate year', American Journal of Alternative Agriculture 18(2) pp1-9
[56] Fließbach, A., H.-R. Oberholzer, L. Gunst and P. Mäder (2006) 'Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming', Agriculture, Ecosystems and Environment, 118 pp273-284.
[57] Arbuscular mycorrhizal fungi (AMF)
[58] Oehl, F., E. Sieverding, P. Mäder, D. Dubois, K. Ineichen, T. Boller, A. Wiemken (2004) 'Impact of long-term conventional and organic farming on the diversity of arbuscular mycorrhizal fungi', Oecologia 138 pp574–583
[59] Altieri (2002) *op cit.*
[60] Pimentel *et al* (2005) *op ct.*
[61] Altieri (2002) *op cit.*

potentially making farmers more dependent on pesticides. Specialised insect pest species usually exhibit higher abundance in monoculture than in diversified crop systems.[62]

Climate change adaptation: Adaptive capacity

Adaptive capacity refers to the ability of individuals or communities to actively engage in processes of change. It is the capacity to respond to anticipated and experienced climate change, enabling adjustments or transformations in lifestyles or livelihoods that reduce vulnerability to climate hazards, increase resilience, or capitalise on opportunities. Where resilience is the capacity to absorb or cope with shocks and stresses, adaptive capacity is defined by overlapping resources and abilities that can be employed to respond to and create changes. While the particular components of adaptive capacity will be context dependant, three common characteristics can be identified. First, access to information on the anticipated effects of climate change (in the short, medium and long term) is necessary to inform decision making, including the uncertainty that is inherent in climate modelling. Second, the opportunity and ability to learn, experiment, innovate and make decisions in response to climate change information or experience underpins adaptive capacity. Finally, the amount and diversity of assets available to an individual or community define the alternative strategies that can be pursued in adapting to climate change.[63] For food producers, agricultural biodiversity is an asset of fundamental importance, but needs to be married with the creativity and innovation that is necessary to capitalise on biodiversity to meet new challenges.

Agricultural biodiversity provides the raw materials for meeting the challenges of climate change. As a recent report into agroecological practices in Ethiopia notes, diversity is[64]

> the foundation for plant and animal breeding and an insurance for the future. We know that climate and the environment will in all probability change at an increasing pace and it is therefore important to maintain a diversity of plants and animals with different environmental requirements that can perform the same functions under new conditions.

The ability to meet unforeseen challenges - and opportunities - depends on maintaining the rich mix of characteristics that is found in breeds and varieties worldwide. Declining diversity, powered by industrial agriculture's quest for homogenisation and ever higher yields, has serious consequences for the future, as important, resilience-providing traits in crops and livestock disappear in favour of varieties and breeds that are able to maximise efficiency and profit in the short term.[65] Yet utilising diversity also requires harnessing the adaptive capacity that is to be found in those communities that practice agroecology worldwide. Agroecology encourages and requires farmers, fishers and herders to be responsive to their environment, engendering flexibility and experimentation in breeding and management practices. It is this ability to experiment and innovate in order to maximise the productive capacity of the available resources that underpins adaptive capacity. Methods for coping with harsh environments exist within different communities, and tend to be 'knowledge-intensive rather than input-intensive', creatively applying agroecological principles to a particular context.[66] Altieri and Koohafkan, for example, describe how 'indigenous knowledge of management of the fragile and variable environment [and] local genotypes' has

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[62] Altieri (2002) *ibid.*
[63] Ensor and Berger (2008) *op cit.* pp 18-25.
[64] Swedish Society for Nature Conservation (2008) *op cit.*
[65] Smallstock in Development, Domestic Animal Diversity *op cit.*
[66] Altieri (2002) *op cit.*

enabled the cultivation of drought tolerant varieties of particular crop species,[67] while, more generally

> Thousands of examples of the application of agroecology are at work throughout the developing world, where yields for crops that the poor rely on most—rice, beans, maize, cassava, potatoes, barley—have been increased several-fold, relying on local biodiversity, family labor and new and traditional agroecological knowledge.[68]

The combination of responsive management strategies and technologies with agricultural biodiversity is witnessed in 'millions of hectares under traditional agriculture in the form of raised fields, terraces, polycultures, agroforestry systems'. Altieri goes on to note that '[t]hese microcosms of traditional agriculture offer promising models for other areas as they promote biodiversity, thrive without agrochemicals, and sustain year-round yields.'[69] Indigenous knowledge, then, is as significant to adaptive capacity as the biodiversity that it works with.

Box 5: Supporting adaptive capacity in Sri Lanka[70]

Small scale rice farmers in coastal Sri Lanka are facing increasing salinity following temperature increases and sea level rise. To combat falling yields, local farmer groups conducted participatory variety selection to determine the acceptability of 10 different traditional rice varieties under the saline conditions. Variety selection was conducted by the farmers, in their own fields, during the 2005 planting season, building on local knowledge of valuable plant traits. Support was provided by Practical Action during the selection process to help farmers to develop their skills in experimentation and decision-making. Those testing traditional varieties shared their findings with farmers from adjacent villages that were facing similar problems. This process stimulated a discussion between farmers on variety selection, increasing the knowledge of neighbouring farmers on climate change issues, and enabling the farmer groups to become change agents at the community level.

These characteristics define adaptive capacity in terms of access to the skills, information and resources that are available at the community level. As such, a crucial element in adaptive capacity will be the broader policy environment, which ideally will support knowledge and resource distribution and sharing between communities and stakeholders. Creativity, innovation and experimentation are inherent in agroecological methods as employed by farmers, fishers and herders worldwide. The promotion of adaptive capacity requires mechanisms to support the sharing of this existing knowledge and for on-farm, community-based experimentation as environmental challenges shift across regions and continents in a changing climate. Institutional support is also necessary for climate information dissemination, as climate change science and predictions will be beyond the reach of many communities. It is the responsibility of national governments to assimilate and communicate short- and long-term weather and climate change information, and to identify and facilitate the filling of gaps in knowledge where they exist. Moreover, these tasks should be grounded in the livelihood context of those farmers, fishers and herders who are most vulnerable to climate change: information should be targeted at these groups in a form and with content that is appropriate to their needs.[71]

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[67] Altieri and Koohafkan (2008) *op cit*

[68] Holt-Gimenez, E., M.A. Altieri and P. Rosset (2006) 'Ten Reasons Why the Rockefeller and the Bill and Melinda Gates Foundations' Alliance for Another Green Revolution Will Not Solve the Problems of Poverty and Hunger in Sub-Saharan Africa' Food First Policy Brief No.12: October 2006

[69] Altieri (2002) *op cit.*

[70] Ensor and Berger (2009) *op cit* pp87-100.

[71] Ensor and Berger (2009) *ibid* p20.

Climate change mitigation

Data from nearly three decades of research trials indicate that wide-scale implementation of established, scientifically researched and proven practical farming methods will change agriculture from a global warming contributor to a global warming inhibitor, from a problem to a solution.
LaSalle and Hepperly, Rodale Institute[72]

As Figure 1 illustrates, the principal contribution of agriculture practice to global warming is through the emission of nitrous oxide and methane, generated from soils and the digestive processes of ruminant livestock. However, as noted above, this is not the complete story, as greenhouse gas emissions emerge during the production of agricultural inputs such as machinery and chemical products. The Haber-Bosch process is used in 97% nitrogen fertiliser production and is both energy intensive (releasing carbon dioxide stored in fossil fuels) and leads to the generation of nitrous oxide as a by-product. The extremely high pressures demanded by the process account for roughly one per cent of the world's annual energy usage.[73] The most significant omission, however, is land use change, which is typically assessed separately in national greenhouse gas inventories, yet is predominantly driven by agriculture. Land use change leads to the production of carbon dioxide through the burning of above-ground biomass and through soil carbon losses due to ploughing and the conversion of pasture, savannah and forest to tilled agriculture.[74]

Evidence from research focused on the energy inputs used in different methods of production illustrate the potential for climate change mitigation through the adoption of agroecological methods. In industrial corn production, the most significant energy input is in the production of nitrogen fertiliser, followed by the energy required for chemical herbicide production.[75] These findings are reflected in side-by-side assessments of organic and industrial production. Studies examined as part of a 2006 review of scientific evidence revealed:

- Fossil energy inputs in organic corn production were 31 per cent lower than conventional corn production, and the energy inputs for organic soybean production were 17 per cent lower than conventional soybean production.
- Organic corn farming systems collected 180 per cent more solar energy than the conventional corn farming system, principally via cover crops, contributing to the improved energy efficiency of the organic systems.
- Organic grass-fed beef required 50 per cent less fossil energy than the conventional grain-fed beef system.[76]

As discussed, agroecological methods can reduce the need for fossil fuel intensive chemical inputs. Pesticides can be replaced by integrated pest management techniques including avoidance of monocultures and improvements in soil quality. Fertiliser dependence can similarly be avoided through a focus on agricultural biodiversity; in particular, rotations that include leguminous crops provide an effective supply of soil nitrogen. Cover crops provide temporary vegetation between successive crops and act as green manure, bringing nitrogen to the soil at the same time as suppressing weeds, retaining moisture in the soil and improving fertility. Catch crops provide a

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[72] LaSalle, T.J. and P. Hepperly (2008) 'Regenerative Organic Farming: A Solution to Global Warming', Rodale Institute
[73] FAO (2006) *op cit.* p86
[74] Forestry Commission *op cit.*; Garnett (2008) *op cit.* p20; Baumert *et al* (2005) *op cit.* p91.
[75] LaSalle and Hepperly (2008) *op cit.*
[76] Pimentel (2006) *op cit.*; see also: Pimentel *et al* (2005) *op cit.*

similar function, but also extract nitrogen unused by previous crops, preventing its release as nitrous oxide and allowing its reintroduction to the soil as green manure.[77]

Ecosystem management approach	Net GWP
Annual crops (corn-soybean-wheat rotation)	
Conventional tillage	114
No till	14
Low input with legume cover	63
Organic with legume cover	41
Perennial crops	
Alfalfa	-20
Poplar	-105

Table 3 Relative greenhouse warming potential for different management systems, based on an eight year US research study. Negative figures indicate sequestration potential.[78]

Table 3 summarises the results of a 9 year research trial examining the emissions associated with different agricultural management systems. The net greenhouse warming potential[79] (GWP) of each system reflects the effects of carbon storage in soils, the different inputs applied, and the flux of different gases absorbed and released during the rotation. The dramatic difference between conventional and low input and organic systems demonstrates the effectiveness of agroecological approaches for mitigation. The ability of these systems to retain carbon in the soils as soil organic matter also demonstrates the sequestration potential of agroecology: here, rather than avoiding emissions, carbon is taken from the atmosphere and locked into the soil as soil organic matter. The difference between till and no till systems is most profound in this regard: the very low GWP of the no till system principally results from soil carbon accumulation (although no till and conservation tillage also generally reduce machine usage for ploughing and thus fossil fuel inputs[80]). The conventionally tilled system, on the other hand, builds *no* soil carbon to offset the emissions generated from nitrous oxide release (accounting for around 50% of GWP), energy consumption in fertiliser production (25%), and carbon dioxide release in lime production (25%). In the low input and organic systems fertiliser and lime production emissions are lower, and carbon is sequestered in the soil, yielding much lower net GWPs.[81] Untested in this study was the impact of organic and no till techniques in combination: these figures suggest a potential for significant sequestration and the approach is currently the subject of a major new research trial at the US Rodale Institute.[82] Table 3 also demonstrates the sequestration potential of alfalfa and poplar trees, perennial crops that fix substantial quantities of carbon in the soil. In this study, the

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77 Smith *et al* (2007) *op cit.*
78 Robertson *et al* (2000) *op cit.*
79 A normalised unit allowing the expression or comparison of the global warming impact of different gases in combination.
80 FAO (2006) *op cit.* p117; the same source defines conservation tillage as is any tillage and planting system in which 30 percent, or more, of the crop residue remains on the soil surface after planting'; note that the benefits are lost if conventional tillage is subsequently adopted.
81 Robertson, G.P., A.P. Eldor, R.R. Harwood (2000) 'Greenhouse Gases in Intensive Agriculture: Contributions of Individual Gases to the Radiative Forcing of the Atmosphere', Science 15 September 2000: Vol. 289. no. 5486, pp. 1922 - 1925. GWP measured in grams of carbon dioxide equivalents per square meter per year.
82 Rodale Institute 'Organic no-till leads to updating of Farming Systems Trial' http://www.rodaleinstitute.org/20080529/gw1

alfalfa crop received lime inputs and released greater quantities of nitrous oxide than the poplars, resulting in lower overall net sequestration. [83]

In each case examined in Table 3, sequestration results from a balance between building carbon into soils, the negative effects of the production of inputs and the release of nitrous oxide. Agroecological approaches have dual benefits, eliminating or substantially reducing chemical inputs, while building soil carbon in the form of soil organic matter. As noted in relation to resilience (above), research results demonstrate that agroecological practices routinely build soil organic matter.[84] Significantly, results from the Rodale Institute suggest that conventional agriculture achieves the opposite, releasing carbon from soils into the atmosphere as a consequence of soluble nitrogen fertiliser application stimulating rapid and complete decay of organic matter. [85]

The sequestration of carbon in soils offers huge potential for climate change mitigation. The IPCC's Fourth Assessment Report draws attention to the potential of agroecological practices for sequestration, noting that catch and cover crops planted between successive crops or between rows of trees or vines add carbon to the soil, while:

> Improved agronomic practices that increase yields and generate higher inputs of carbon residue can lead to increased soil carbon storage. Examples of such practices include: using improved crop varieties; extending crop rotations, notably those with perennial crops that allocate more carbon below ground; and avoiding or reducing use of bare (unplanted) fallow. [86]

The FAO draw attention to practices such as integrated pest management, double-cropping, and crop rotations including green manure and cover crops in support of intensification, and highlight the benefit of integrating such methods with low or no till agriculture.[87] Significant benefits can be gained in dryland areas in particular, where the historic loss of carbon from soils through desertification offers great potential for sequestration. Importantly, the soil quality improvement achieved through returning carbon to these soils also revives social and economic opportunities for those living in degraded areas.[88]

Improved pasture management is required on much of the world's grasslands, 71 per cent of which are degraded. Tree planting, species selection and fertilisation (including from livestock) can help to restore pastureland and reverse declines in biodiversity in areas that in total form the largest human land use.[89] While livestock are responsible for significant methane emissions through enteric fermentation and at current and projected levels also present challenges to water and biodiversity, livestock production at environmentally sustainable rates offer multiple benefits[90]

> by contributing to soil carbon sequestration and by making use of otherwise unproductive land (avoiding the need to plough alternative land). Livestock's ability to consume crop residues and by-products that are inedible to humans is resource efficient and leads to

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[83] Robertson *et al* (2000) *ibid.*
[84] Fließbach *et al* (2006) *op cit.*; Pimentel *et al* (2005) *op cit.*; Reganold *et al* (1987) *op cit.*
[85] LaSalle and Hepperly (2008) *op cit.*
[86] Smith *et al* (2007) *op cit.*
[87] FAO (2006) *op cit.* pp116-117
[88] FAO (2006) *ibd.* p118
[89] FAO (2006) *ibd.* p118
[90] Garnett (2008) *op cit.*

GHG avoidance. Manure can improve soil quality and reduces the need for synthetic fertilisers. There will, moreover, be an environmental cost to producing substitute goods and services if we did not have livestock from which to obtain them.

Sustainable production would, however, necessitate a switch away from feeding high protein feeds, remotely produced at an industrial scale (a system which drives land use change, demand fossil fuels for transport and reduce livestock diversity), in favour of local feed sources and breeds.[91]

Overall, the IPCC's Fourth Assessment Report estimates the technical mitigation potential of agriculture to be up to 6,000 mega tonnes of carbon dioxide equivalents per year, of which 89% (up to 5,340 mega tonnes) is from soil carbon sequestration via improved crop and grazing land management and the restoration of degraded soils and lands.[92] In 2005, global emissions totalled 51,000 mega tonnes of carbon dioxide equivalents[93], suggesting that soils have the potential to absorb up to around 10 per cent of current annual anthropogenic greenhouse gasses. While the total absorption capacity of soils is ultimately limited, current research suggests in the region of 25 to 100 years of remaining sequestration potential.[94]

The multiple benefits of biodiverse agroecology

In an era that is set to be dominated by climate change, it is hugely significant that the introduction of agroecological approaches offers benefits to both adaptation and mitigation. Yet a further advantage also arises from the application of agroecological approaches. Yield increases frequently result due to the combination of[95]

- Organic matter accumulation and nutrient cycling
- Increased soil biological activity
- Natural control mechanisms (disease suppression, biocontrol of insects, weed interference)
- Resource conservation and regeneration (including soil, water and germplasm)
- Enhanced agricultural biodiversity and synergies between components.

Diverse systems benefit from the efficient use of resources such a light, water and nutrients, and reduced susceptibility to pests and disease, contributing to yield improvements that have been particularly significant for small holder farmers and those in marginal environments. As Altieri notes in reference to the introduction of agroecological approaches in developing countries,

> Increases in production of 50–100% are fairly common with most alternative production methods. In some of these systems, yields for crops that the poor rely on most - rice, beans, maize, cassava, potatoes, barley - have been increased by several-fold, relying on labour and know-how more than on expensive purchased inputs[96]

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[91] Forestry Commission 'The international challenge: deforestation' http://www.forestry.gov.uk/forestry/infd-6vjhlf; FAO (2006) *op cit.* p112
[92] Smith *et al* (2007) *op cit.* p515; potential based on assumed 2030 B1 emissions scenario
[93] Smith *et al* (2007) *ibid.* p499
[94] Smith *et al* (2007) *ibid.* p514; FAO (2006) *op cit.* p116
[95] Altieri (2002) *op cit.*
[96] Altieri (2002) *ibid.*

Similarly, a 2008 UNEP-UNCTAD study concluded:

> All case studies which focused on food production in this research where data have been reported have shown increases in per hectare productivity of food crops, which challenges the popular myth that organic agriculture cannot increase agricultural productivity.[97]

Reporting on the results of maize and soybean trails the FAO observe that 'organic systems can achieve yields comparable to conventional intensive systems [that are dependant on inorganic fertilisers and pesticides], while also improving long term soil fertility and drought resistance'.[98] The Rodale Institute's 22 year trial comparing organic and industrial methods similarly find that corn or soybean yields are the same under both systems, 'except in drought years, when regenerative systems yielded about 30 per cent more corn than the petroleum-based system.' [99] Some results from Northern research have suggested yield decreases for agroecological approaches compared with well established industrial agriculture. However, even when yields fall, the overall result is less clear cut. A Swiss research centre, for example, reported a 20 per cent reduction in yield, 'although input of fertilizer and energy was reduced by 34 to 53 per cent and pesticide input by 97 per cent' leading the researchers to conclude that organic approaches 'are a realistic alternative to conventional farming systems'.[100] A study in the US running since 1948 provided yields of 8% lower within the trial, but 13 per cent higher than on an adjacent conventional farm. Moreover, the loss of topsoil in the industrial system was profound (16cm lost from an initial total of 60cm), leading the researchers to conclude that 'at some point the increasing yield reduction from erosion may exceed the diminishing yield increase due to technical progress.'[101] A simple focus of crop yields per hectare is also misleading: agroecological approaches in particular demand a focus on the output of the whole farm, including livestock that are an integral part of the agroecology. Raising fish in rice paddies, growing crops with trees or including goats or poultry are all common practices and all contribute to the total farm output beyond crop yields. [102] Other advantages that accrue to agroecological approaches include lower variance in crop yields and labour needs. On farm labour is an average of 15 per cent higher and is more evenly distributed through the year, offering realistic full time employment in place of the demand for seasonal workers. [103]

The alternative to agroecological approaches, as the experiences in Box 6 illustrate, is to persist with short term, industrial agriculture that is unsustainable, vulnerable to climate change and a significant source of greenhouse gas emissions.

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[97] UNEP-UNCTAD Capacity-building Task Force on Trade, Environment and Development (2008) Organic Agriculture and Food Security in Africa, Geneva and New York
[98] FAO (2006) *op cit.* p117
[99] LaSalle and Hepperly (2008) *op cit.*
[100] Mäder, P., A. Fließbach, D. Dubois, L. Gunst, P. Fried, U. Niggli 'Soil Fertility and Biodiversity in Organic Farming', Science, 31 May 2002: Vol. 296. no. 5573, pp1694 - 1697
[101] Reganold *et al* (1987) *op cit.*
[102] Altieri (2002) *op cit.*
[103] Pimentel *et al (*2005) *op cit.*

Box 6: Contrasting approaches to agricultural development[104]

In India, industrial agriculture locks farmers into spirals of decline
Only a few decades ago, farmers in India grew 30,000 different varieties of rice, which were adapted to local conditions. Since the green revolution, these have been replaced by a few high-yielding rice varieties that are often grown in monoculture. This is leading to cropping systems with increased susceptibility to diseases, pests and climate change. To achieve profitability and continuing high yields there is often a need for a range of fossil fuel-consuming and environmentally damaging cultivation inputs such as poorly managed irrigation, pesticides and artificial fertilisers – items which poor farmers seldom can afford.

In Ethiopia, agroecology improves lives, livelihoods and agricultural biodiversity
In Northern Ethiopia, experts together with farmers have devised a farming system that is based more on biological diversity – particularly the rich knowledge and agricultural biodiversity of the farmers – than on fossil fuel, in order to provide a long-term secure food supply and ecologically sustainable agriculture. The project, which is primarily directed at small farmers with around one hectare of cultivated land, has resulted in higher yields, higher groundwater levels, better soil fertility, increased household income and stronger livelihood opportunities for women.

Implementing biodiverse agroecology

Barriers to biodiversity

Local, diverse food production systems are under threat. One quarter of the world's biomass is now traded internationally, all of it controlled by a handful of multinational corporations.[105] Knowledge, skills and agricultural biodiversity are being eroded, seriously endangering our capacity to produce food sustainably and meet the challenges of climate change. According to data from the UK Agricultural Biodiversity Coalition[106]

- More than 90 per cent of crop varieties have disappeared from farmers' fields;
- Half of the breeds of many domestic animals have been lost;
- All the world's 17 main fishing grounds are now being fished at or above their sustainable limits, with many fish populations effectively becoming extinct.

Since the 1960s there has been international recognition of the loss of agricultural biodiversity as a serious problem.[107] Erosion of genetic diversity has been precipitated by increasing variety replacement, in which local indigenous crops and livestock breeds have been displaced. These practices undermine agricultural biodiversity, degrading the capacity of agroecosystems to meet the demands of food, fuel and fibre production. Worse, this is occurring against a backdrop of climate change, which itself poses a significant threat to genetic diversity: the IPCC estimate that between 10 and 30 per cent of species worldwide will be committed to extinction under a temperature rise of only 1.2 to 2.0 degrees above pre industrial levels (rising to 20 to 50 per cent for 2.6 to 3.3

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[104] Swedish Society for Nature Conservation (2008) *op cit.*
[105] ETC Group (2008) 'Who Owns Nature? Corporate Power and the Final Frontier in the Commodification of Life' Communiqué Issue 100.
[106] UK Agricultural Biodiversity Coalition http://ukabc.org/
[107] For example, Otto Frankel and Erna Bennett (1970) 'Genetic Resources in Plants: Their Exploration and Conservation', FAO, Rome.

degrees).[108] The principal underlying causes of current losses include:[109]

- The rapid expansion of industrial agriculture, intensive livestock production, industrial fisheries and aquaculture. These approaches cultivate relatively few crop varieties in monocultures, rear a limited number of domestic animal breeds, or fish for, or cultivate, few aquatic species.
- Globalisation of the food system and marketing, and the extension of industrial patenting and other intellectual property systems to living organisms, which have led to the widespread cultivation and rearing of fewer varieties and breeds for a more uniform, less diverse but more competitive global market.

These forces are antithetical to biodiverse agroecology. As Altieri concludes:[110]

> powerful economic and institutional interests have backed research and development for the conventional agro-industrial approach, while research and development for agroecology and sustainable approaches has been largely ignored or even ostracized.

In short, 'the balance of forces are stacked largely in favour of the dominant corporate model of agriculture.' [111] Increasingly deregulated international trade has contributed to the concentration of power and influence into the hands fewer and fewer companies: ten companies now control more than two-thirds of global proprietary seed sales; ten control almost 90 per cent of agrochemical sales worldwide; and ten have three-quarters of biotechnology industry revenue. Six of the leaders in seeds are also leaders in pesticides and biotech.[112] This powerful alignment has capitalised on and supports policies promoting private sector involvement in technology development, enabling multinational corporations to scale up agrochemical usage.[113] Similarly, trade liberalisation has favoured industrial production, marginalising smallholders who are poorly placed to meet the volumes and standards demanded by global food buyers and retailers.[114] Subsidies continue to support energy inputs to farming,[115] while European and US policies have opened developing country markets by dismantling barriers to international trade.[116]

Since the 1990s new global rules have emerged in several different negotiating fora, including in relation to trade and the rapid expansion of intellectual property law to cover living organisms.[117] These new rules form the framework within which food production takes place, yet are the consequence of 'unequal and sometimes coercive bargaining relationships in which the strong undermine the weak'.[118] The institutions that mediate the governance of food security and

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[108] Fischlin, A., G.F. Midgley, J.T. Price, R. Leemans, B. Gopal, C. Turley, M.D.A. Rounsevell, O.P. Dube, J. Tarazona, A.A. Velichko (2007) 'Ecosystems, their properties, goods, and services' in: *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, 211-272. Table 4.1

[109] UK Agricultural Biodiversity Coalition *op cit.*

[110] Altieri (2002) *op cit.*

[111] Romeo Quijano, Pesticide Action Network (Philippines), quoted in Scoones, I. (2008) 'Global Engagements with Global Assessments: The Case of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD)', IDS Working Paper 313.

[112] ETC Group (2008) *op cit.*

[113] Altieri and Nicholls (2005) *op cit.*

[114] De Schutter, O. (2008) 'Building resilience: a human rights framework for world food and nutrition security' Report of the Special Rapporteur on the right to food. Human Rights Council Ninth Session A/HRC/9/23

[115] Bruinsma (2003) *op cit.* pp369-379

[116] ETC Group (2008) *op cit.*

[117] Tansey, G. and T. Rajotte (eds) (2009) Future control of food, Earthscan p1.

[118] Tansey, G. (2009) 'Global rules, local needs' in Tansey, G. and Rajotte, T. (eds) Future control of food, Earthscan p213.

biodiversity issues routinely bypass procedural fairness, allowing strong states and large transnational corporations to dominate through their ability to participate in multiple protracted negotiations and to draw on expertise.[119] Discussions of power, control, risks and benefits in agriculture are muted, and agroecological approaches, which have little to offer corporate profit, fail to gain traction. Nowhere is this clearer than in the rapid extension of the concept of intellectual property (IP). Tansey outlines the fundamental contradiction between agroecology and the privatization of biology:[120]

> there is a basic tension between IP and biodiversity that those in favour of IP refuse to discuss. IP owners do best (in terms of profit) if they have a global standard or product that is protected globally by high IP standards. Yet innovation in food and agriculture does best if it can draw on a rich biodiversity, a biodiversity that depends on fragile variables such as traditional knowledge, local farming systems and free exchange of materials. By building a property rights system that rewards standardisation and homogeneity, we almost certainly risk affecting those variables that underpin our systems of biodiversity.

Thus, 'the one vision of the future that is not being facilitated by the way IP rules are developing and affecting the direction of research and development is the ecological approach'.[121] The net result is environmental degradation (seen in biodiversity loss, agroecosystem collapse, depletion of fundamental resources, and climate change), and hunger driven by a globally inequitable food system. Olivier De Schutter, the UN Special Rapporteur on the Right to Food, refers to 30 years of policies supporting industrial agriculture that culminated in the 2006-2008 food crisis, including the dismantling of public support schemes, rushed and mismanaged trade liberalization, and the powerless position of developing country producers in the food production and distribution chain.[122] Industrial agriculture's focus on tradable commodities for the international market render it incapable of feeding hungry people.[123] The FAO report that developing countries have shifted from food producing to food importing countries as trade liberalisation has taken hold: in the 1960s developing countries produced an agricultural trade surplus of $7 billion per year, yet by 2001 this had turned into a deficit of more that $11 billion. The challenge, then, 'is not simply to increase production' but to adopt 'structural measures, leading to a profound reform of the global food system.'[124] Institutional reform that ameliorates the democratic deficit in decision making and values sustainable food ahead of profitable commodities is urgently required if agricultural biodiversity is to be preserved and enhanced and climate change adaptation and mitigation are to be achieved.

Recommendations

> *Compared to expensive, experimental, high-technology projects, global transition to biologically based farming can be achieved without new technology or expensive investment.*
> *LaSalle and Heppely, Rodale Institute*[125]

To cope with climate change and to avoid environmental collapse, the recent global review on the future of agriculture, the International Assessment of Agricultural Knowledge, Science and

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[119] Tansey, G. (2009) *ibid.*
[120] Tansey, G. (2009) *ibid.* p216.
[121] Tansey, G. (2009) *ibid.* p216.
[122] De Schutter (2008) *op cit.*
[123] ETC Group (2008) *op cit.*
[124] De Schutter (2008) *op cit.*
[125] LaSalle and Hepperly (2008) *op cit.*

Technology for Development (IAASTD), found that research and policy attention should be paid to biodiverse agricultural practices. The review highlighted the need for investment and public research in low-input and organic systems, biological substitutes for agrochemicals, site-specific cultivars, local seed systems and reduced dependency on fossil fuels.[126] As De Schutter points out, the search for sustainable food production is not one that can rely on technologies devised away from their site of application - and as such may be one that is not as attractive to private interests as the industrial approach that generates agricultural commodities.[127] The alternative, as IAASTD states, is to refocus on the knowledge and ingenuity of peasant food producers:[128]

> When Agricultural Knowledge, Science and Technology is developed and used creatively with active participation among various stakeholders across multiple scales, the misuse of natural capital can be reversed… A powerful tool for meeting development and sustainability goals resides in empowering farmers to innovatively manage soils, water, biological resources, pests, disease vectors, genetic diversity, and conserve natural resources in a culturally appropriate manner.

Voice and democratic space are therefore crucial to the implementation of biodiverse agroecology. Equally, effective adaptation and mitigation require the empowerment of local institutions to support food producers to develop and share agroecological knowledge, and to enable producers to contribute to climate change discussions and policy. Small scale food producers are increasingly calling for the right to work with indigenous knowledge and to engage with external innovation and markets as the basis for the sustainable production of nutritious food. Globally, this call has been in form of the 'food sovereignty' policy framework: as the Prime Minister of Nepal summarised, 're-establishing and guaranteeing the farmers' inalienable right to choose – food sovereignty – is an essential part of social justice and empowerment … Only empowered citizens, aware of their rights and choices, can overcome deprivation and marginalisation.'[129]

Food sovereignty offers an alternative to globalised industrial agriculture, placing food providers and consumers, rather than corporate agribusiness, at the heart of decision making. It seeks to return control over all aspects of agricultural biodiversity to local food providers, building on their knowledge and skills to develop localised, biodiverse food production systems.[130] And as the food sovereignty movement recognise, the development of knowledge, skills and institutions in support of agroecology are also essential components of climate change adaptation and mitigation.[131]

Policy, research and investment efforts in support of biodiverse agroecology and climate change mitigation and adaptation therefore should involve: [132]

- Implementing laws, policies and practices to promote food sovereignty and support small-scale producers and localised biodiverse, agroecological food production
- Investing in infrastructure, creating equitable market opportunities and ensuring security of

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[126] See the summary at footnote 10 in De Schutter (2008) *op cit*, and: IAASTD (2009) Summary for Decision Makers of the Global Report, Island Press, Washington, DC.
[127] De Schutter (2008) *op cit.*
[128] IAASTD (2008) *op cit.*
[129] European Voice (2008) Development through choice by Pushpa Kamal Dahal 07.11.2008 / 16:11 CET
[130] Windfuhr, M. and J. Jonsén (2005) 'Food Sovereignty: Towards democracy in localized food systems' ITDG Publishing, Rugby.
[131] Nyéléni 2007 Forum for Food Sovereignty Synthesis Report http://www.nyeleni.org/spip.php?article334
[132] Drawing on Altieri (2002) *op cit.*; and: FAO Committee on Agriculture (2009) 'Agriculture and environmental challenges of the twenty-first century: A strategic approach for the FAO', Twenty First Session COAG /2009/03

tenure and rights of access in poor and marginal areas

- Changing priorities in research and development towards practices and technologies that promote biodiverse agroecology and farmer to farmer information sharing
- Promote participatory technology development, farmer centred research and extension workers linking policy makers, research and small scale producers
- Changing attitudes and philosophies of decision makers, scientists and others to support biodiverse agroecology
- Removing subsidies for and regulating the influence of corporations that dominate the agricultural input sector
- Challenging existing laws and regulatory frameworks that prevent small-scale farmers and communities from developing, saving, exchanging and selling seeds, livestock breeds and fish species
- Empower local institutions to manage agricultural biodiversity, strengthen community capacity to access genetic resources, monitor threats to genetic diversity and promote in situ and on farm genetic resources to guarantee the dynamic evolution of genetic diversity to changing climatic conditions.