Building Resilience in East African Agriculture in Response to Climate Change

GREENPEACE

Contents

For more information contact: iafrica@greenpeace.org

Kirsten Thompson[a], Frank Chidawanyika[b], Iza Kruszewska[c] and Reyes Tirado[a]

[a] Greenpeace Research Laboratories, University of Exeter, Devon, UK

[b] School of Animal, Plant and Environmental Sciences, University of the Witwatersrand, Johannesburg, South Africa.

[c] Greenpeace International, Ottho Heldringstraat 5, 1066 AZ Amsterdam, The Netherlands.

Citation suggestion: Thompson K, Chidawanyika F, Kruszewska I, Tirado R. (2015). Building resilience in East African agriculture in response to climate change. Greenpeace Research Laboratories Technical Report: 05-2015.

Commissioned by: Greenpeace Africa

Designed by: Kaitoma Creatives

Cover photo: © Greenpeace/Cheryl-Samantha Owen. Kenya, East Africa. 2015.

Published: July 2015 by Greenpeace Africa

Report number: Greenpeace Research Laboratories Technical Report: 05-2015

Greenpeace Africa: 10A and 10B Clamart House, Clamart Road, Richmond, Johannesburg, 2092, South Africa, www.greenpeaceafrica.org

1. Executive Summary

The climate in East Africa is changing, as it is throughout the world. The timing and duration of the rainy seasons have altered, becoming highly unpredictable. Profound climate shocks, such as floods and droughts, are already evident (Cook & Vizy, 2012). Arid and semi-arid regions are predicted to increase over the next century and temperatures will rise (IPCC, 2014). However, the effects of climate change in East Africa are, and will continue to be, highly spatially variable. As a result of this variability, biological communities (biomes) will be altered with widespread range-shifts in animals and plants.

The majority of agriculture is rain-fed and climate change has already proved to have a profound effect on farmers' ability to grow food. Modelling predicts that the number of days suitable for growing food will decline dramatically in some regions, and shifting biomes will make crop yield changes spatially patchy. However, there are a number of practical strategies that farmers can use to build intrinsic resilience within agricultural systems. Resilience is the ability to withstand climate shocks and in the long-term adapt to a changing environment. Resilience-thinking focuses on reducing risks by increasing the adaptive capacity of people and the agriculture ecosystems on which they depend. This will enable farmers to meet current and future food needs whilst coping with uncertainty and change (Adger, 2003).

In this report we provide a detailed review of current literature that discusses, and tests, practical ways in which farmers in East Africa can build resilience to climate change into agricultural systems. Greenpeace considers these practices as part of ecological farming and we provide detailed case studies in an accompanying report (*Building Environmental Resilience: A Snapshot of Farmers Adapting to Climate Change in Kenya*). Taken together, these two reports focus on positive steps that farmers, businesses and policy-makers can take to enhance long-term resilience in the context of climate change. These ecological farming strategies fundamentally build on four key elements within agricultural systems: soil, water, diversity and communities.

Healthy soils underpin healthy food, and agricultural yields (Amundsen et al., 2015). African soil is geologically very old, and extremely weathered. Natural tropical ecosystems involve a nutrient cycle that relies on a critical relationship between forest and micro-fungi. When these forests are removed, nutrients leach quickly from the soil, leaving it highly vulnerable to even more leaching and erosion. With the organic content and physical structure of the soils destroyed, the ability for rain to permeate, and water to be retained, declines. Ecological agriculture focuses on returning nutrients to the soils through practices such as agroforestry, intercropping with nitrogen fixing crops, animal manure, and green manure. Minimum tillage ensures that the physical structure of the soil is retained. Soils that are not left bare but are covered, using cover crops or mulching with residues, have protection from erosion and leaching (Garrity et al., 2010). All these soil-focused strategies also serve to increase water penetration and retention, making more water available for crops. Traditional methods of soil conservation, particularly terracing on sloped land, also serve to increase water retention.

Crop yields are constrained by the availability of water in East Africa (Lobell and Gourdji, 2012). To build resilience to fluctuations in rainfall, farmers focus on strategies that will harvest water that can be stored in the long-term to cover periods of drought. Macro-catchments include community dams, with localised drip feed irrigation directly to crop plants, with no water wastage. In communities where these projects are not possible, many farmers aim to collect water in smaller-scale micro-catchments that are lined water pans, or tanks. The main limitation in farmers adopting these water catchment strategies is the financial investment it takes to acquire liners that prevent seepage of stored water. Another way of harvesting available water is through certain planting strategies, where crops are planted in pits and mulched so that water evaporation rates are minimised, and plant water uptake is maximised.

On-farm diversity assists farmers in spreading risk across time, and space, building redundancy into agricultural systems and leading to long-term resilience (Martin & Magne 2015). Drought resilient crop varieties and livestock breeds increase the likelihood of returns for farmers during unpredictable periods of rainfall. Retaining indigenous practices, and seeds, also serves to provide a mosaic of crops and varieties giving dietary diversity that is location-specific (Cernansky, 2015). Temporal diversity – by adjusting sowing and planting times – staggers harvests so that if one crop fails, the farmer can rely on food from another. Physical diversity of plants can be used successfully in pest protection in the push-pull system, avoiding the need for costly external inputs.

Community learning, and participatory research, builds individual farmer knowledge that can then spread throughout the region. Farmer field schools provide training in ecological farming approaches that are location-specific, and ensure that communities are working together to ensure the best price for their harvests. Access to global information technology means that farmers, and communities, can directly participate in learning, climate warnings, marketing and advocacy.

This review provides the scientific rationale for the adaptive practices that are being used successfully in the field (Table 1) (examples of which are listed in Thompson et al. (2015)). The way forward must include investment in multiple elements that will improve soil health, water resources, diversity and communities. The adoption of adaptive practices is a transition process for farmers and is more likely to take hold with education and continued support that minimises individual risk.

To ensure food and nutritional security in the long-term, it is vital that resilience building be farmer-focused with climate adaptation, and mitigation, that is highly context-specific with constant learning and evaluation to ensure its long-term success.

2. Introduction: Climate change and East African agriculture

Climate change already has, and will further, result in environmental perturbations that increase the vulnerability of agricultural systems of Africa. Further changes are predicted to occur earlier than in other areas of the world and hence adaptation is urgent (UNEP, 2015). Models predict rising temperatures and changes to the duration of rainy seasons with more erratic conditions for growing crops throughout the region. These changes will dramatically impact on the ability to grow food (IPCC, 2014). The IPCC states with 'high confidence' that crop productivity will be reduced as a result of heat and drought stress associated with climate change. This will have strong adverse effects on regional, national and household livelihoods. There is also a strong likelihood of increased pests and disease, and damage to physical infrastructure of the food system. Water resources are already under significant strain through overexploitation and degradation and, with increased demand, drought stress is likely to be exacerbated (IPCC, 2014).

Near-surface air temperatures in East Africa have already increased by over 0.5°C in the last century, with the minimum temperatures rising more rapidly than the maximum (Funk et al., 2008; IPCC, 2014) (Fig. 1A). Projected trends for East Africa also show increased warming. In the whole of Ethiopia, for example, several climate projections show a rise in temperature in all four seasons. This is likely to increase the frequency of heat waves that in turn, will increase evaporation rates (Conway & Schipper, 2011; IPCC AR5, 2014). The number of days warmer, by more than 2 °C, when compared with the 1981-2000 average in the equatorial part of Eastern Africa, is projected to climb in these projections.

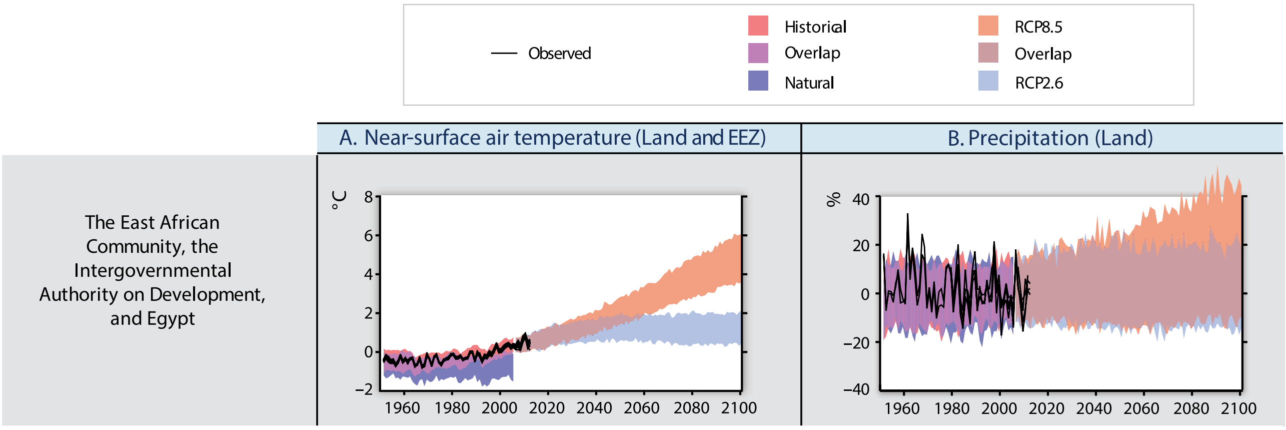

Figure 1. Trends and projected increases in near surface air temperature and precipitation in the East African Community and future projections using the lowest and highest global warming scenarios, RCP2.6 and RCP8.5 respectively (IPCC, 2014). A) Past, current and projected increases in near surface temperatures, B) Past, current and projected percentage increases in precipitation.

Observed and projected figures for precipitation in East Africa indicate variable changes at both spatial and temporal scales due to location-specific physical processes (Fig 1B) (Heshion & Moore 2011, IPCC, 2014). One such physical feature is the rapid warming of the Indian Ocean that has resulted in the decrease in rainfall and increased frequency of drought spells in the months of March to June in East Africa (Williams & Funk 2011; Lyon & Dewitt, 2012; Williams et al., 2012). Particular surface-pressure gradients draw moist air towards East Africa and changes in these gradients in the regions of Sudan, southern coast of the Mediterranean Sea and the Indian Ocean are thought to have contributed to changes in precipitation in East Africa (Williams et al., 2012; IPCC 2014).

Overall, it is predicted that the short rainy season (of the autumn) will extend as the Indian Ocean warms, but the traditionally longer rainy season (of the spring) will diminish, resulting in the rain being concentrated into bursts that may result in flooding (Cook & Vizy, 2012). Under a scenario where mean temperatures have increased by 2ºC by the 2040s, heat extremes are predicted to become more frequent during the summer and the hyper-arid and arid regions of East Africa will grow by 3% (IPCC, 2014). Under these scenarios, shifts in the distribution of biomes are predicted with 'high confidence' in East Africa and this is likely to have severe impacts on farming, people and wildlife due to disease and species extinction.

2.1 Food production in a changing climate

According to Cook & Vizy (2012), large decreases in the number of growing season days (GSDs) are predicted over most of East Africa during 2041-60 (Fig. 2). Predictions show that GSDs will be virtually eliminated over much of Ethiopia and Somalia, with reductions of 10 – 40 % throughout Tanzania, and more than this over Southern Kenya (40 – 60 %).

African agriculture relies on rain-fed farming systems and the observed and projected climatic changes, within and across different seasons, make food production systems of Africa highly vulnerable (Lobell et al., 2011; Berg et al., 2013; IPCC, 2014). Predictions state that there will be strong regional variability in the degree of losses with aggregated yields in maize-based cultivation across sub-Saharan Africa (SSA) forecasted to decrease by over 22% (Schlenker & Lobell, 2010). In East Africa yield changes are likely to be spatially patched with reductions in low lying areas of East Africa (traditional maize-growing areas) (IPCC, 2014). Conversely, at higher elevations (1700m above sea level, e.g., highlands of East Africa) temperature rises are projected to improve the yields of maize (Thornton et al., 2009). Whilst there may be a shift of cereal cultivation to these highlands, the low-lying areas where these cereal crops have been historically grown are likely to become unsuitable growing areas.

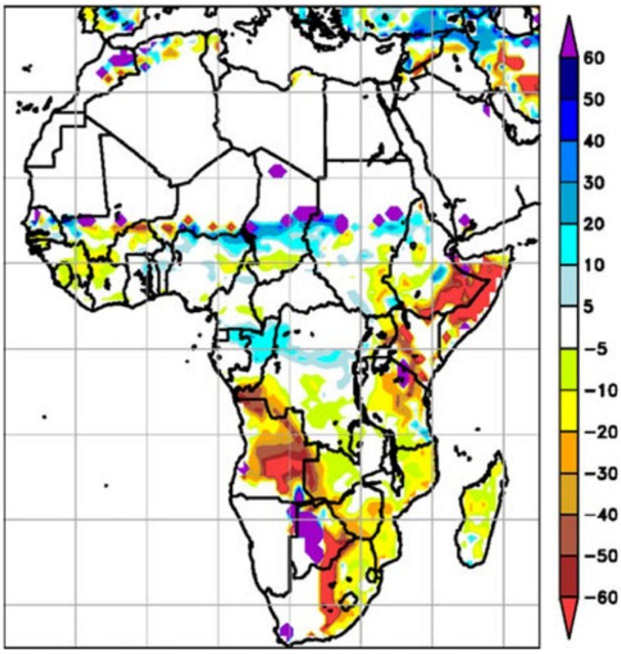

Figure 2. Percentage change in growing season days (GSDs) for 2041-2060 predicted using a regional climate model at a 90 km resolution. Expressed as a percent change from the number of days in the mean value at each grid point. Based on Cook & Vizy (2012).

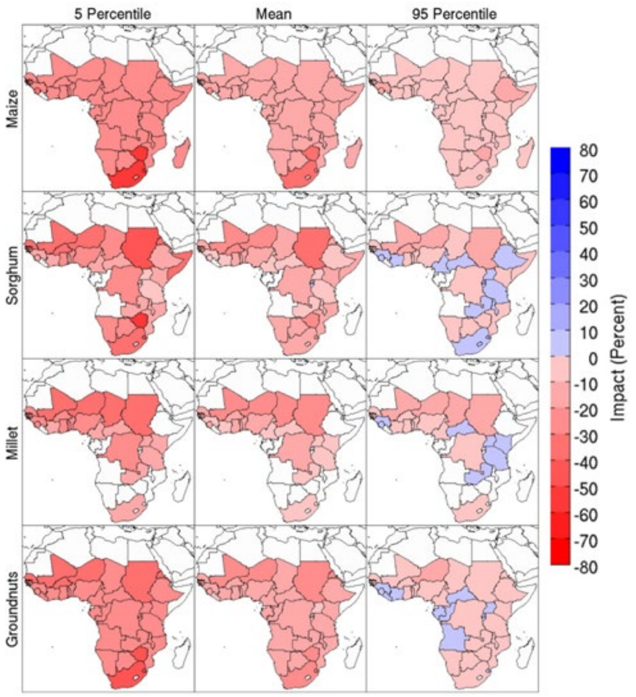

Figure 3. Distribution of impacts from climate change throughout East Africa by country (percentage of yield change for four types of crops – maize, sorghum, millet and groundnuts). Each row represents one crop. Mean impacts are shown (middle column) and the five and 95 percentiles (left and right column respectively) give the lower and higher likelihoods. Based on Schlenker and Lobell (2010).

Certain crops are likely to be more suited to temperature fluctuations. Beans are a major source of protein in East African communities and are projected to experience yield reductions in 50-70% of areas between the 2030s and 2050s under projected higher greenhouse gas emission scenarios (Thornton et al., 2011; Jarvis et al., 2012). However, predicted models for the yield potential of groundnuts, or peanuts, are inconsistent. Tingem and Rivington (2009) predict an increase in yields whereas both Lobell et al. (2008) and Schlenker and Lobell (2010) suggest yields will decline (Fig. 3). Yields of sorghum and millet are also predicted to decline at a broad scale throughout the region, though to a lesser degree in comparison to maize crops, and at the 95% percentile, they are actually predicted to increase. Rosenthal et al. (2012) suggest that yields of cassava may increase due to elevated atmospheric CO^2, however, modelling by Schlenker and Lobell (2010) indicate a likely 8% decline, though with less confidence than found in other crop yield declines. For bananas and plantains, an important source of carbohydrate in East Africa, projections indicate yield declines in the lowland areas (Ramirez et al., 2011; IPCC 2014). There is also evidence to suggest that the nutritional content of certain staple crops is likely to be altered under future climate change conditions (particularly elevated CO2 conditions) (Myers et al., 2014). Differences in yield predictions for crops not only highlights both the current uncertainty surrounding such projections using analytical modelling but also the spatial variability in the impacts of climate change.

However, there is consensus in the scientific community that suitable growing conditions for different crops will shift throughout the East African region and this will have a significant impact on localised communities and their adaptive capacity. **The largest impacts on crop yields are predicted to occur in highly productive areas suggesting that systems using modern seed varieties and large amounts of fertiliser may be most susceptible to yield losses.** This is due to the predicted susceptibility to temperature increases in these areas (Schlenker & Lobell, 2010). Continued sole reliance on fertiliser inputs is likely to increase vulnerability to warming. Even though in the short term yields may increase, the benefits of climate adaptation are likely to grow at the same rate whilst building intrinsic resilience into food systems.

Apart from direct impacts on crop yields, the occurrence and population dynamics of certain pests, weeds and diseases will change. In East Africa, it is projected that climate change will result in the geographic range expansion of pests into the highlands that have lower average temperatures that previously limited pest colonisation. For example, commercial crops of the highlands such as the Arabica coffee in Kenya, Uganda, Rwanda, Ethiopia and Burundi will increasingly be threatened by pests, e.g. coffee berry borer (Jaramillo et al., 2011). Other potential pests that are likely to increase their geographic range include nematodes that attack the roots of bananas and plantains (Nicholls et al., 2008). However, there are critical gaps in our understanding of how crop pathogens will be affected by a changing climate (Luck et al., 2011). Whilst there may be a mixture of effects on the transmission of certain diseases, given the number of factors involved, it is likely that only large-scale modelling will provide some indication of how these will play out in the long-term.

Livestock productivity will also be impacted by climate change, both directly and indirectly. Direct effects of changing temperatures, humidity and other factors may influence growth rates and other performance factors such as milk production and reproduction (Rust & Rust, 2013). One of the most critical, but indirect, impacts of climate change results from changing feed resources for livestock. Rangelands are likely to become degraded and the composition of forage, or grass species available to animals will change (Freier et al., 2012). Drinking water will also become limited as a result of prolonged droughts (Solomon et al., 2007; Schilling et al., 2012). East African farmers are likely to resort to smaller livestock such as goats and sheep instead of cattle.

2.2 Small scale farming: The need for ecological farming

Small-scale farms (SSF) represent over 80% of farms in Africa. These farmers generally do not have the financial ability to buy expensive technologies and chemical fertilisers.[1] The Food and Agriculture Organisation (FAO) defines small-scale farms both in terms of farm size (less than 10 hectares and often less than 2 hectares) and also as those that are dependent on household members for the majority of the labour on the farm (Scoones & Thompson, 2011). Forty to 60% of the entire population of the continent resides in rural areas, where the majority of small-scale farmers (SSFs) live, and these farms underpin the livelihood of two-thirds of the poor (United Nations, 2014).

However, there is evidence that farm sizes are dropping (Jayne et al., 2010; Masters et al., 2013). Population densities per unit area continue to rise and this puts pressure on the availability of land for SSFs. In cases where land is available, competitive prices have only led to more land acquisition by both domestic and foreign investors with many farmers not being financially able to compete. The need for the protection of land rights for the most vulnerable has long been recognised (Godfray et al., 2010). However, even where formal governance of access to land is in place, government land regulations often conflict with customary laws of land tenure in Africa. The enactment of pro-poor land rights has therefore been difficult to implement.

2.3 Agrodiversity in East African small scale farms

Traditionally, small-scale farmers (SSFs) in East Africa cultivated a variety of crops and livestock breeds in their farms that, together with the wild species present in the landscape, created a high on-farm diversity (Enjalbert et al. 2011). Until recently, East African SSFs cultivated a variety of small grain cereals (e.g. sorghum, millet, Teff grass) together with legume oil-seed crops and vegetables. Small grain cereals were traditionally selected for resistance to adverse climatic or pest conditions, ensuring harvest in times of hardship (Clawson, 1985; Dicko et al., 2006). Currently, some of this diversity is still present, and is becoming increasingly recognised as a nutritious and resilient crop for farmers (Cernansky, 2015). However, the cultivation of maize as a staple food dominates much of the cultivated land by SSFs in many African countries, including Kenya (Nuss & Tanumihardjo, 2011). The history of maize in Africa is young, but due to its relatively high yield and low labour requirements it quickly became favoured over more traditional grains.

Livestock remains an integral part of African farming systems. Often a symbol of wealth in traditional farming systems, livestock ensures improved nutritional diversity and economic growth for farmers. In East Africa, mixed crop-livestock systems are widely practised. However, some societies such as the Masai of Kenya are pastoralists who are frequently nomadic in search of rangelands for their livestock. In particularly arid areas, nomadic pastoralism may be a more reliable means of food security than solely relying on cropping. Increased urbanisation and wealth has increased the demand for livestock and their products and in some cases this demand has put pressure on rangelands and water resources which has been a source of civil conflict in some communities of East Africa, e.g. northern Kenya (Thornton & Gerber, 2010; Schilling et al., 2012; Herrero & Thornton, 2013).

[1] http://www.fao.org/3/a-ar588e.pdf

2.4 The cost of poor soil health

The vitality of soils underpins the ability of agricultural land to retain water, provide ecosystem services, climate change abatement, and ultimately food security (Fig. 4). Soil security is a broad-scale concept that plays a central role in tackling all current global challenges (McBratney et al., 2014). Healthy soils retain, store and provide clean water in addition to the many other services required to sustain both human communities and ecosystems as a whole.

Figure 4. The relationship between soil security and other vital services. Based on McBratney et al. (2014).

Africa is very old in geological terms and soils across the continent are, therefore, deeply weathered (Jones et al., 2013). In tropical Africa, most soils are highly acidic with increased levels of iron and aluminium oxides (giving the red colour) and devoid of many essential nutrients such as phosphorus, potassium, calcium and magnesium, which have leached out over time. In natural ecosystems, nutrients are maintained within a delicate balance between the decay of leaf litter and *Mycorrhiza* spp. fungus. Clearing forest destroys this balance, making soils infertile within only a few years and, therefore, the role of nutrient management presents a significant challenge for farmers (Zingore et al., 2015). Hence, the critical factor in declining yields throughout East Africa is a combination of soil erosion, as a result of declining vegetative cover, and widespread continued degradation in soil health through poor nutrient management (Muchena et al., 2005 Vanlauwe & Giller, 2006; Ajayi et al., 2007; 2011; Vanlauwe et al., 2014). Nutrients removed with the harvested crops are often not replenished and consequently the organic matter (and biological activity) within the soil is reduced. In addition, the chemical properties of the soil are degraded through the loss of essential nutrients such as phosphorus, nitrogen, potassium and carbon (Woniala & Nyombi, 2014). Annual crops, (particularly cereals), without any rotations have led to continuous mining of the nutrients from soil. Crop residues are often burnt or fed to livestock resulting in minimal nutrient cycling and the organic matter in the soil is not replaced in the soil. Even though some farmers put manure back into the fields, manure application is generally restricted to plots that are near to homesteads resulting in fertility gradients that only improve productivity close to home (Zingore et al., 2012).

Because of limited land for farming, fallowing – that allows soil to recover and replenish nutrients – is rarely practiced by farmers in Africa. Previously recommended long-term fallows of up to 30 years are no longer feasible due to land shortages (Kwesiga et al., 2003). Tillage practices based on seasonal deep ploughing methods involve soil inversion that mobilises the soil and results in increased erosion and the leaching of nutrients. Soils become compacted through livestock grazing and this, in combination with associated nutrient losses, can severely impact soil health (Maitama et al., 2009). The ability of the soil to retain water is also reduced by both horticulture and livestock grazing as a result of its physical degradation, the loss of vegetative cover and increased exposure to the sun. Many areas suffer from changes in soil pH and widespread salinisation, particularly in irrigated regions. Overall, this drive to expand and intensify agriculture has led to siltation, degrading soil health, erosion, eutrophication, desertification, and accumulation of pollutants from agrochemicals with extensive biodiversity loss (Wasige et al., 2013).

2.5 Resilience-thinking and ecological agriculture

Resilience is the ability to withstand a drastic change in external conditions (for example the weather, pests, or market prices) – and recover from it quickly. It is the opposite of vulnerability. Resilience-thinking focuses on risk reduction by increasing the adaptive capacity of people and the agriculture ecosystems on which they depend, enabling farmers to meet current and future food needs while coping with uncertainty and change (Adger, 2003).

UN institutions and processes have long been highlighting the importance of strengthening resilience in order to support smallholder livelihoods and long-term food security under a changing climate and faced with volatile markets (FAO, UN High Level Task Force on the Global Food Crisis, UN Commission on Sustainable Development, UN Special Rapporteur on the Right to Food (United Nations, 2008, Commission on Sustainable Development, 2008; De Schutter, 2008; FAO, 2008)).

Embracing diversity – growing different crops at the field and landscape levels – is a proven and highly reliable way to make our agriculture resilient to increasingly unpredictable changes in the climate. Well-tended soil, rich in organic matter, is much better at holding water during droughts, and much less prone to erode during floods. Farmers can benefit in another way – if your farming is diverse, so is your stream of income – providing security in uncertain times.

A redesigned food system, as the one Greenpeace calls Ecological Farming, would provide large-scale carbon sinks and many other ways to reduce greenhouse gases in the atmosphere (climate mitigation). Nutrient cycling, biological nitrogen fixation, and soil regeneration would reduce carbon emissions. And while livestock plays a key role in agroecosystems, global animal production and consumption would be changed radically (while allowing for increased protein consumption in regions where they are currently too low, like some areas in Africa). All this makes Ecological Farming one of the most powerful tools we have in the fight against climate change.

Ecological Farming combines modern science and innovation with respect for nature and biodiversity. It ensures healthy farming and healthy food. It protects the soil, the water and the climate. It does not contaminate the environment with chemical inputs or use genetically engineered crops. And it places people and farmers – eaters and producers, rather than the corporations who control our food now – at its very heart.

Our current food and agriculture systems are badly prepared to adopt the required mitigation and adaptation strategies recommended by experts (Smith et al., 2013). Current cropping systems in conventional agriculture require stable climates and ideal conditions to suit the highly specialised crop cultivars that thrive in narrowly defined geographic and climatic ranges. They also depend on expensive chemical inputs that farmers often buy on credit, expecting to get a return high enough to pay it back with interest. Industrial farming systems often work with monocultures lacking seed genetic diversity, embedded in large expanses of land with little refuge for any kind of biodiversity. Biodiversity is key to multiple ecosystem services, including pest protection, pollination, nutrient cycling, water filtration, and climatic adaptation (Cardinale et al., 2012).

Increasing biophysical resilience, in terms of soil nutrients (e.g., carbon, phosphorus and nitrogen) and water availability, within agricultural systems is particularly relevant in East Africa where widespread soil degradation, erosion and desertification hinder food security and are likely to increase as a result of climate change. Ecological farming practices focus on building such biophysical resilience and are known to increase yields significantly by using a variety of low input methods that require no external inputs for farmers (Pretty et al., 2006). Research suggests that these ecological farming practices are key to increasing food security in vulnerable regions of the world, more so than technologies such as genetically engineered crops that increase dependency on generally expensive external inputs (Pretty et al., 2011; Jacobsen et al., 2013). In contrast, ecological farming takes advantage of existing ecosystem diversity, both in terms of species diversity and genetic diversity within species.

In this review we present a synthesis of information on the adaptive ecological farming practices that will build resilience into agricultural systems in East Africa, so as to both increase food security and biodiversity within the region. Whilst certain practices focus on strengthening biophysical resilience in order to grow food in times of environmental change, others serve to build networks within human communities so that they have access to knowledge and new innovation. We have grouped these practices into four key elements: SOIL, WATER, DIVERSITY and COMMUNITIES.

3. Key resilience elements: Soil, Water, Diversity and Communities

Building resilience into the agricultural systems of rural communities in East Africa requires fundamentally building and restoring the ability of ecosystems to buffer change. Three elements relate to the building of natural capital, in the form of fertile soils, increased water availability and investment in diversity. Building social capital requires community strengthening. We provide evidence of practical strategies used to build these four elements from the scientific literature.

Table 1. Key resilience elements and practical strategies required to build natural capital within rural farming communities.

Key Resilience Element	Practical farming strategies
SOILS: Improve soil fertility and build long-lasting soil health (with better use of locally available resources).	Legumes and agroforestry (e.g. cover crops, green manures, alley cropping) Manure, rotational grazing, and other options for nutrient management (e.g. composting, eco-sanitation) Soil (and water) conservation (e.g. contour cropping, terraces, minimum tillage, grass strips, silt-traps, raised beds, drainage systems and sub-soiling). Restoration of degraded land so that all of the farm is productive
WATER: Increase local water availability for cropping and improve crop water use.	Rainwater harvesting for storage (e.g. micro- and macro-catchments, ponds with liners, reservoirs) Increased water infiltration into the soil (and reduced evaporation) (e.g. planting pits, terracing, cover crops, mulching, micro-climates) Maximised plant water uptake (e.g. soil rich in organic matter, mulching, drip irrigation, drought resistant local crop varieties and livestock breeds)
DIVERSITY: Diversity across the system, from the seed to the plate, to ensure adaptive ability and increased nutrition and economic security	A variety of seeds, crops and livestock on each farm for genetic diversity Changes in the timing of planting, mixed cropping and rotational fallows to give temporal diversity throughout the farm Fish in rice paddies and fish ponds for alternative protein Agroforestry for habitat diversity, soil fertility and alternative incomes Integrated livestock (chickens, rabbits, ducks), beekeeping Kitchen gardens that use all available land to grow vegetables Habitat management for pest-predators with an increase in ecological pest-protection using mosaic habitats to improve biodiversity Drought resistant local crop varieties and livestock breeds High value crops and tree nurseries for income diversification
COMMUNITIES: Strengthen community support networks, access to information, training and finance so as to buffer change.	Strengthened community-based networks that can solve problems, access services and build resilience to climate shocks Farmer field schools and teacher farmers that will spread innovative practices Farmer participatory research and on-farm testing of drought resistant varieties Protection of indigenous knowledge and networks Information centres that link farmers and communities to education, knowledge and each other Equal education opportunities for women Technological innovations (e.g. social enterprises, real time market information, climate and weather forecasting) Community advocacy with the ability to negotiate with national and international organisations By combining harvests, communities can negotiate a better deal. Access to microfinance particularly for community groups (e.g. investing in food processing and storage, value addition and knowledge).

3.1 Soil

Ecological farming practices that build resilience target the improvement of biophysical and chemical properties of the soil that will conserve water and boost crop yields, particularly in consistently food insecure periods. Healthy soils underpin nutritional security and several knowledge-intensive strategies that include integrating trees and food legumes have been used to improve yields under environmental variability (Amundsen et al. 2015). Adaptive practices also focus on the restoration of degraded land and diversifying farm areas to provide microclimates that become highly productive.

3.1.1 Soil health: Nutrient enrichment and yield increases

It has long been known that forest management can maintain the physical integrity of soils by preventing erosion and nutrient loss as a result of leaching during the rainy seasons – this is also true of perennial fertiliser trees that can be integrated into agricultural systems (Buresh & Tian, 1997). These nitrogen fixing trees or 'fertiliser trees' can also play a key role in soil quality improvement that will boost agricultural yields.

Fertiliser trees are used in cropping systems that involve **rotational fallows, intercropping and biomass transfer.** Where there is sufficient land area to allow rotational or relay fallows, this involves planting dense legume trees in rotation with crops so that fertility is restored during the fallow periods (Chikowo et al., 2006; Place, 2012). In practice, rotational fallows are established by first inter-planting fast growing trees with crops until complete canopy cover. Thereafter, the cropping season is followed by a fallow period of 4-5 years where the trees may be used for fuelwood, dry season fodder production and apiculture (Jama et al., 2008; Kimaro et al., 2008). Fallow periods are then followed by a sequential cropping of 2-3 years or until yields are reduced (Nyadzi et al., 2006; Kimaro, 2008; Nezomba et al., 2010).

Intercropping systems involve tree hedgerows planted within crops in what is sometimes referred to as **alley cropping** (Nyadzi et al., 2006). However, the initial high labour demand can constitute a challenge for its adoption, in addition to the extended time period until the system delivers yield returns (Kiptot et al., 2014; Nezomba et al., 2010). Several tree species including *Faidherbia (Faidherbia albida), Gliricidia (Gliricidia sepium), Leucaena (Leucaena leucocephala)* and *Sesbania (Sesbania sesban)* have been demonstrated to fix nitrogen in the soil to as high as 100 kg N ha^{-1} at high tree density (Mafongoya et al., 2006a and 2006b; Akinnifesi et al., 2008 and 2010; Place, 2012). Akinniefesi et al. (2008) reported that coppicing trees such as *Gliricidia* in Zambia improved nitrogen content up to 60-75 kg N ha^{-1}. These coppiced woody legumes (mainly Acacia spp., Calliandra spp., *Flemingia* spp., *Gliricidia* and *Leucaena*) grow back when cut. In Uganda, *Mucuna* trees fixed nitrogen up to 170-350 kg N ha^{-1} (Sileshi et al., 2008). In some of these cases, the level of nitrogen fixation by these trees replaced the need for chemical nitrogen fertilisers (Akinnifesi et al., 2010).

Trees such as *Gliricidia* have been reported to pump important micronutrients such as phosphorous, magnesium, calcium and potassium from below the root layer up to the soil surface (Makumba et al., 2006). Apart from biological nitrogen fixation, these trees retrieve nitrogen from lower depths that are unreachable by crops and make it available to the upper soil layer in the form of leaf litter (Place, 2012). Forest management can influence precipitation and the hydrological lift of water between areas of the farm (Vose et al., 2011; Wei et al., 2011; Pagano, 2013). Trees (and cover crops) also create microclimates where water is more easily retained by the soil and this promotes the survival of functional soil biota, and therefore, soil health. Recent studies in Malawi have shown leguminous fertiliser trees have the capacity to increase the density of key macro- and microfauna that will further increase soil health (and therefore, yields) (Barrios et al., 2012; Place, 2012).

Fertiliser tree systems have been one of the major yield improving agroecological interventions in Southern and East Africa (Table 2) (Akinnifesi et al., 2010; Ajayi et al. 2011). Different species are used in particular contexts. For example, *Gliricidia* are successful as intercropping trees whilst *Sesbania* and *Tephrosia* are used in annual relay intercropping and sequential tree fallows (Akinnifesi et al., 2008; 2010; Mafongoya et al., 2006b). A meta-analysis of the results of 94 studies showed that for 67% of coppiced species yield increases for maize were doubled or, in some cases, tripled in comparison to unfertilised maize by the use of these coppiced woody legumes (Sileshi et al., 2008). Yields were also reported to be higher when the trees were used in rotational fallows as compared to relay intercrops (Sileshi et al., 2008). Whilst fallows might reduce crop yields when including the fallow period of time, the subsequent regeneration of the farm soils may compensate farmers for the low production in fallow years. The time period required to produce these yield increases is thought to be around two years after planting for maize grown alongside *Gliricidia*, though larger increases were noted after 10 years (Akinnifesi et al., 2010).

Table 2. Average maize yield and yield increase (tonnes ha^{-1}) with fertiliser trees relative to those continuously grown as maize mono-crops in East and Southern Africa. Note: yield increase is the yield difference between the treatment (T) plot and the unfertilised control (C) plot, which is farmers' de facto practice. Percentage increase (%I) was calculated as follows: %I = 100((T-C)/C). Source: Akinnifesi et al. (2010).

Species	Country	Number of sites	Maize yield in monoculture (t ha^{-1})	Maize yield increase with agroforestry (t ha^{-1})	Percentage Increase in yields with agroforestry
Gliricidia	Malawi	5	3.9	2.9	345.6
	Tanzania	2	2.3	0.8	55.8
	Zambia	4	2.8	1.8	349.7
Sesbania	Malawi	7	2.5	1.3	161.4
	Tanzania	2	1.2	0.7	171.4
	Zambia	9	3.2	2.2	480.0
	Zimbabwe	4	3.0	1.9	583.1
Tephrosia	Malawi	9	2.0	1.1	232.7
	Tanzania	2	2.0	0.9	80.1
	Zambia	8	1.7	0.8	198.4
	Zimbabwe	5	3.6	0.2	17.7

Legumes can also be **intercropped** with cereals for soil fertility improvement (Doré et al., 2011; Lupwayi et al., 2011). In addition to the fixation of nitrogen to improve soil health, there are also added nutritional benefits to legume cultivation for farmers ensuring an improved and diversified diet and income (Rusinamhodzi et al., 2012). These crops can be rapidly grown and serve to diversify diets and add protein in food insecure months. Several legume species successfully used in cereal intercrops (and rotations) include: common bean (*Phaseolus vulgaris*); cowpea (*Vigna uinguiculata*); pigeon pea (*Cajanus cajan*); soybean (*Glycine max*); groundnut (*Arachis hypogaea*) and Bambara groundnut (*Vigna subterranea*) (Giller et al., 2009; Baudron et al., 2012; Rusinamhodzi et al., 2011; 2012).

In most cases, incorporating herbaceous legumes for inter-cropping requires adjustments of planting patterns to maintain productivity and minimise competitive effects (Rusinamhodzi et al., 2012). For example, increased inter-row cereal spacing due to legume requirements can be compensated by planting up to three cereal seeds per planting station. Planting of the legume and cereal can even be temporally staggered to simultaneously minimise competition and the risk of climate variability within a season (Mucheru-Muna et al., 2010; Rusinamhodzi et al., 2012). Apart from cereals, grain legumes have also been successfully intercropped with cassava with observed improvements in yield and soil fertility (Pypers et al., 2011). In all examples, legume intercrops have shown great potential for improvement of soil fertility and crop productivity, particularly in areas troubled by intrinsically poor soils (Mucheru-Muna et al., 2010; Rusinamhodzi et al., 2011).

In central Kenya, an improved intercropping arrangement, known as the **MBILI** system is promoted as a way of increasing maize yields. MBILI is the *Kiswahili* word for two and also an acronym for Managing Beneficial Interactions in Legume Intercrops. In the improved system two, rather than one, legume rows are planted between two pairs of maize rows, and is sometimes described as the two-by-two method, rather than the one-by-one alternating method (Mucheru-Muna et al., 2010). Increased nitrogen fixation and subsequent improved yields when compared to the simple one-row intercropping method were attributed to an increase in light reaching the understory of the legumes and less underground competition for root space. The MBILI system appears to result in robust yield increases, both in fertile and infertile sites and in high and low rainfall conditions. Legumes such as groundnut and cowpea, as an alternative to beans, were found to be the preferred legume used for intercropping in different districts of Kenya. As the system requires more careful planting and weeding, farmers may benefit from an initial input of training and technical knowledge-building to ensure its success.

An economic analysis of maize-legume intercropping systems used in Kenya over seven seasons, that included the MBILI system, showed that not only did this system outperform other systems without an increase in labour costs, but it also effectively spread risk for the farmer (Mucheru-Muna et al., 2010). Seasons where maize yields were low, had high legume yields and vice versa. Under conditions where rainfall is unpredictable, critical periods for maize and legumes are at different times. Maize yields are most sensitive to drought during the grain filling time, whereas legumes are most sensitive when flowering and in the early pod-filling stage. Therefore, as these periods are at different times throughout the growing season, growing maize-legume intercropping is an **effective risk spreading strategy** for farmers during periods of unpredictable rainfall.

3.1.2 Soil health: The role of cattle manure

Livestock manure is an important component for management of soil fertility for SSFs. For East African small-scale farmers, livestock production systems are classified into three categories: pastoral, agro-pastoral and mixed farming systems (Cecchi et al., 2010). These classifications are based on their source of feed and the ratio of the income for the household that is derived from livestock or crops. Pastoral and agro-pastoral farmers graze livestock on natural vegetation or, in some cases, cut the fodder from natural rangelands to feed the livestock in enclosures. In mixed farming systems animals are exclusively kept in enclosures and fed on crop residues, and feeds such as concentrates. Manure collection within these systems is completed at variable efficiencies with some being more wasteful than others. Pastoral systems where animals are only enclosed at night lose more manure when compared to mixed farming systems where manure remains in the pen as livestock rarely leave the enclosure.

The **quality of manure** for soil fertility improvement depends on the livestock and the type of food that was consumed. For manure to be of good quality it should be free of sand, have anaerobically decomposed and contain nitrogen at above 1.8% (Rufino et al., 2006; Rusinamhodzi et al., 2013). Regular collection of manure and covering of manure piles will help reduce the nutrients lost from the manure and both fresh and composted manure constitute the best returns of nitrogen (16 kg ha^{-1} $season^{-1}$) and carbon (312 kg ha^{-1} $season^{-1}$) to the soil (Diogo et al., 2013; Castellanos-Navarrete et al., 2015). However, the highest levels of returns from manure were found on farms where animals are kept in covered stalls with a hard floor that are fed on Napier grass (*Pennisetum purpureum*) and maize residues. Nutrients are lost through tethering and off-farm grazing, and through gaseous losses and run-off from stalls. For poor farms with insufficient income to provide stalls and too little land to grow, Napier grass (leaving crop residues on the fields rather than feeding these to livestock) constitutes the cheapest source of nutrients for the following years' crops (Castellanos-Navarrete et al., 2015). Many farmers continue to feed these crop residues to livestock and it is clear that there is a need for further research into the most economical use of livestock manure so as to boost nutrient cycling within a small-scale farm.

In Zimbabwe, studies suggest that treating poor sandy soils with cattle manure collected from pens at an application rate of 20 t ha^{-1} yr^{-1} over 5 years will restore soil productivity (Rusinamhodzi et al., 2012; Tittonell, 2013). In more short-term studies, such as in north-eastern Zimbabwe, an application of 17 t ha^{-1} was effective in improving soil organic carbon, and phosphorous in a year. An application of relatively smaller quantities of 3 - 6 t ha^{-1} yr^{-1} over five years improved the fertility of the soils in another study in Zimbabwe (Grant, 1967). Where manure quantities may be limiting, micro-dosing or spot application of manure has been proven to raise crop productivity (Ncube et al., 2007).

There is also evidence from Zimbabwe that, apart from soil fertility, manure improves water retention and moisture conservation in soils. Rusinamhodzi et al (2013) showed an application of manure in the field improved rainfall infiltration from 21 to 31 mm ha^{-1}. In another study, Nyamangara et al. (2001) suggested that an annual application of 12.5 t ha^{-1} manure or 37.5 t ha^{-1} once in three years improved water retention capacity and structural stability of soil previously known to have low organic content.

Maize grain yield increases have been noted in Zimbabwe following manure application of 17 t ha^{-1} yr^{-1} with an improvement from 0.2 t ha^{-1} to 1.7 t ha^{-1} by the third year of cultivation (Zingore et al., 2007). Continued application of manure was shown to be important in maintaining this crop productivity. Other studies showed a comparative advantage in maize yields through applying cattle manure over mineral fertiliser, but only in the long-term, presumably as general soil health increases (Rusinamhodzi et al., 2013).

3.1.3 Soil and water: Soil cover, minimum tillage and terraces

Maintaining crop residues and cover crops will avoid soils being left bare and will directly protect the soil from erosion and runoff (Giller et al., 2009; Garitty et al., 2010). In maize-legume fields in Mozambique, where intercropping had been used for several years and soil cover was permanent, rain infiltration increased from 6 mm ha^{-1} to 22 mm ha^{-1} (Rusinamhodzi et al., 2012). The study attributed such marked improvement in water infiltration to this permanent soil cover.

In addition to cover crops, moisture conservation in soils can be achieved by **mulching** with crop residues and other dead plant material. In conservation farming programmes in sub-Saharan countries, including East Africa, mulching has been credited as the main activity that increases yield success for farming (Giller et al., 2009; Okeyo et al., 2014). As is the case for cover crops, mulch reduces soil erosion and evaporation whilst improving water infiltration and reducing maximum soil temperatures (Röcktrom et al., 2008; Giller et al., 2009). In general, the soil aggregate stability is also improved. Mulching is complementary to soil conservation methods such as **zero tillage** where the soils are disturbed as little as possible so as to conserve their physical structure.

Research in Ethiopia, Kenya, Tanzania and Zambia showed an increase in grain yield of both maize and Teff grass (where zero tillage systems were used compared to conventional tillage systems) through water harvesting and efficient rainfall use within the field (Röcktrom et al., 2008; Tittonell et al., 2012). In some cases, minimum or zero-tillage can reduce crop yields after its initial adoption, but over time the benefits to water infiltration ameliorate this loss, particularly when accompanied by mulching (Stevenson et al., 2014).

Terracing has been used as an indigenous method of soil and water conservation for several hundred years in SSA, e.g. Ethiopia (Engdawork & Bork 2014). These practices effectively increase water infiltration into the soil to near 100% whilst preventing erosion and creating a stable soil topography. Many of these practices benefit both the conservation of soil and the related infiltration and retention of water.

3.2 Water

Farming in East Africa is mostly rain-fed and often subject to the uncertainty of water availability. Sub-Saharan Africa suffers from serious food insecurity, but has less than 5% of agricultural land that is fed by irrigation systems. Ecological Farming can contribute to building food and agriculture systems with the inherent ability to cope with water limitations through using water more efficiently on the farm.

To secure global resilience, agriculture systems (in the words of one research group, The Stockholm Resilience Centre) need to *"invest in the untapped opportunities to use green water*[2] *in rain-fed agriculture as a key source of future productivity enhancement. There is a need for more innovative options for water interventions at the landscape scale, accounting for both green and blue water"* (Rockström and Karlberg, 2010). One of these innovations is distributed irrigation, with decentralised systems using low-cost solar irrigation pumps as a development priority in Sub-Saharan Africa (Burney et al., 2010).

Water is an essential element in increasing crop yields (Lobell et al., 2011; Lobell and Gourdji, 2012). Both the harvesting and the efficient use of water by the farmer and the plant, are critical. Future climate change projections show soil moisture to have a key role in moderating crop yields and this applies to rain-fed and irrigated agriculture systems.

Rain-fed agricultural systems are particularly vulnerable to climate change when precipitation is variable and unpredictable. Strategies to combat drought involve:

1) The collection of rainwater for storage, (e.g. rainwater harvesting, micro- and macro-catchments),

2) Techniques that increase the infiltration of water into the soil (and reduce evaporation), (e.g. terracing, cover crops, mulching) and,

3) Those that maximise plant water uptake (e.g. soil rich in organic matter, mulching, drip irrigation, drought resistant local crop varieties and livestock breeds, etc).

Climate change predictions show an increased likelihood of extreme weather events. More intense rainfall events may lead to flooding and water-logging of soils (Lobell and Gourdji, 2012). Increasing the organic content of soils with elevated rainwater penetration and retention, therefore decreasing the likelihood of erosion, and the resultant loss of nutrients.

Several water collection methods have been promoted both through micro-catchment scales (pits) and macro-catchment (ponds) (Karpouzoglou & Barron, 2014). Both macro- and micro-catchment techniques require investment by communities, or individual farmers, in terms of labour and time as well as start-up capital in larger scale projects.

3.2.1 Micro-catchments

Micro-catchment techniques involve a small area of 10-500 m^2, and are generally applied in areas where there is little or erratic rainfall. Methods that will increase water infiltration into the soil use **planting pits** (*zai* pits, half-moon *ngoro* pits), trenches, contouring (bunds made of stone/soil/vegetation) or terracing (*Fanya Juu* - Kiswahili for 'throw uphill') (Table 3) (Karpouzoglou & Barron, 2014). Planting pits are an indigenous farming method that has been in use for many years across Africa in particularly dry areas where there is particularly unpredictable rainfall (Biazin et al., 2012). Each region generally has a different term for the local planting pit used.

In *zai* pits (Burkina Faso), three to four grains of sorghum are planted in pits that are 60 x 60 cm apart. The *ngoro* system is used on steep sloping farms in Tanzania to hold pockets of soil and maintain moisture. Sometimes organic matter is added to the bottom of the pit or the pits are mulched. In Niger, the *tassa* system involves digging small planting holes 20 – 30 cm in diameter, and 20 – 25 cm in depth that are 1 m apart in each direction. Combining planting pits and stone lines, is sometimes a strategy used to rehabilitate degraded land and bring it back into cultivation. In semi-arid regions of Sudan where sand encroaches on fertile soil, seedlings are planted in shallow pits (5 – 15 cm deep and 10 – 30 cm wide) that are 40 – 70 cm apart (*Magun cultivation*) (Osman-Elasha et al. 2006).

Contours and **terraces** are formed from stones or earth and are generally around 0.50 – 0.75 m high, sometimes stabilised with grasses or shrubs, and are designed to trap water within agricultural slopes. Contour ridges can vary in size with the smallest being 1.5 m wide and 0.5 m deep. In many systems, pits are combined with contours or terraces, and mulching is used to reduce soil evaporation. In *Fanya Juu* a trench is dug and the soil is thrown up-slope to form an embankment. Vegetation barriers both reduce soil erosion and increase water infiltration. In Machakos, Kenya, hedgerows of yellow cassia (*Cassia siamea*) grown alongside a maize/cowpea rotation on 14% slopes, have been shown to increase infiltration by 30% in the dry season and 94 % in the wet season (Kiepe 1995).

Small-scale collection and storage of water harvested during the rainy seasons, is also an on-farm adaptation technique. Farmers often dig a small water pan on their farms although investment in plastic pan-liners is critical in avoiding seepage. Water is also commonly collected from rooftops into tanks for both domestic and agricultural

[2] Green water is the water stored in the soil, while blue water is the water in rivers, lakes, dams and groundwater wells. See more: http://www.stockholmresilience.org/21/research/research-news/4-26-2010-a-paler-shade-of-blue.html

use (Mati et al., 2006). However, care must be taken on the design of such water tanks so as to avoid the risk of disease transmission. In both community and domestic settings, without provision of specific (and relatively expensive) liners for the catchment ponds, farmers expend considerable energy in digging ponds for only temporary rewards as water will only store for a very brief period during wet seasons.

Table 3. Micro-catchment rainwater harvesting techniques used in SSA. Source: Biazin et al. (2012).

Type of micro-catchment	Description	Countries of application	References
Pitting (e.g. *zai*, *Ngoro*, tassa, trenches)	*Zai* pits: grid of pits dug across less impermeable areas. *Ngoro*: series of regular traditional pits, 1.5 m square by 0.1 – 0.5 m deep, where the crops are grown on ridges around pit. Trenches: pits are made along contour and can be with bund downslope that is either continuous or staggered to check velocity of runoff, conserve moisture and groundwater recharge.	Burkino Faso, Mali, Niger, Tanzania, Kenya, Somalia, Uganda, Ethiopia, Zimbabwe, South Africa.	Malley et al., 2004 Mupangwa et al., 2006 Reij et al., 1996
Contouring (stone/soil bunds, hedgerows etc)	Bunds: stone or earth banks 0.5 – 0.75 m high piled on a foundation built along a contour in a hill-slope. Sometimes stabilised with grasses or fodder plants. Hedgerows and vegetation strips: permanent strips of land within cropland plots that are either left for naturally established grasses and herbs, or alternatively planted with shrubs.	Kenya, Ethiopia, Tanzania, Burkina Faso, South Africa	Kiepe 1995 Spaan 2003
Terracing (*Fanya Juu* and hillside terraces)	Bunds with a ditch, built along a contour or on a gentle gradient. In *Fanya Juu* terraces the embankment is put in the upslope position.	Kenya, Ethiopia, Tanzania	Tengberg et al., 1998
Micro-basins (Negarims, half-moons, eye-brows)	Small basins of different shapes that are surrounded by low earth bunds, and runoff infiltrates the lowest point where plants are grown. Negarims (diamond), half-moons (semi-circular).	Ethiopia, Kenya, Tanzania, Uganda, Burkina Faso, Mali, Niger	Abdulkadir & Schultz 2005 Spaan 2003

3.2.2 Macro-catchments

Macro-catchment of rainwater involves creating reservoirs of up to 30 ha for capturing and storing rain, and run-off, either through sand- or earth-dams or stream diversions. Most macro-catchments are less than two hectares but in some cases the run-off can be collected from a catchment as large as 500 km^2 (Biazin et al. 2012). Rainwater can be collected from roads, natural slopes and then stored for later use in a variety of structures. The water is then used by the community for supplemental irrigation during times of drought, or for livestock and domestic consumption.

3.3 Diversity

Building greater diversity (variety, balance and redundancy) into agricultural systems enables farmers, and communities, to increase their adaptive capacity to perturbation events (Altieri & Nicholls 2013; Martin & Magne 2015). More diverse agrosystems have a range of traits and will therefore better suppress disease and pests in a changing climate (Lin et al., 2011). However, greater diversity on the farm also involves adapting planting strategies, livestock types and alternative incomes for times of crop failure.

On-farm functional habitat diversity provides benefits to farmers in terms of soil health, water retention, pest control and pollination services (Tscharntke 2012; Gemmill-Herren et al. 2014). This agro-diverse approach will in practical terms be realised in terms of gains in yields for farmers (Ponisio et al. 2015; Pretty et al. 2011). Bryan et al. (2013) surveyed households on the types of adaptive strategies currently employed by farmers in Kenya. The most common strategies included changing crop varieties (used by 33% of households), changing planting times (20% of households) and changing species (18% of households). However, there are many other strategies that have been shown to provide further adaptive capacity to SSFs.

3.3.1 On-farm diversification

Limited crop diversity has been reported to be a major driver of malnutrition as SSFs predominantly grow starchy foods (Frison et al., 2011; De Schutter, 2012). To counter this, farmers can plant, within one season, a variety of resilient crops with a diverse nutrient base, as opposed to monoculture of more sensitive crops. Rosset et al. (2011) showed that farmers using agroecological methods, and those with diversified crops (and incomes), both recovered more quickly from extreme weather events and lost fewer crops than monoculture farms. Crop diversity under agroecological systems ensures harvest security if major crops fail (Hassan & Nhemachena, 2008; Rurinda et al., 2014). **Mixed cropping**, or intercropping can spread risk for farmers in times of environmental change. Rusinamhodzi et al. (2012) showed that the cowpea harvest in a maize-cowpea intercrop succeeded despite total failure of maize due to drought.

Diversifying the types of crops grown in a small scale farm will ensure harvesting year round, particularly if these crops are short-maturing varieties, such as sweet potatoes or cassava that enable the cultivation of two crops per year. Indigenous, drought resilient crops will provide yields in growing conditions where other crops will fail. **Indigenous vegetables**, e.g. African nightshade, African eggplant, spider plant and amaranth are also a useful nutritional component to diets as well as, in some cases, crops that are more likely to thrive under local conditions (Pretty et al., 2011; Grubben et al. 2014; Luoh et al. 2014). Other traditionally grown vegetables, e.g. capsicum peppers, tomatoes, leaf cabbage will complement other crops grown and provide vital nutrients. **Indigenous fruits** (e.g. tamarind, wild mango) can also constitute an important component of diet during periods of drought, and can provide an additional form of income, though research is needed to take full advantage of these resources (Stadlmayr et al. 2013). On-farm diversification can also include the use of small patches of land for raised beds or **kitchen gardens** or the **rehabilitation of disused or degraded land** (Pretty et al., 2011).

Rotations serve to increase **temporal diversity** and suppress pests and increase production of various crops. Growing crops as **polycultures**, particularly with wild varieties, can give spatial diversity and a more complex agricultural system that is better able to cope with environmental stress. Crop **genetic diversity**, where mixed varieties of a species are grown together, is important in providing variants that are more resistant to disease and therefore give greater stability to the production of the crop (Zhu et al., 2000; Letourneau et al., 2011).

There is also some focus on conventional breeding programmes incorporating latest technology, e.g. marker assisted selection, to build a wider base of crop varieties suited for different regions. Conventional breeding of crop varieties that show **drought tolerance**, pest resistance and increased nutritional content often focus on those crops that have been neglected by large-scale breeding programmes such as cassava, plantains, sweet potatoes and teff. Improvements in these crops are sometimes developed in association with farmers that participate in breeding and testing of the new varieties (Pretty et al., 2006). Improvements in the sweet potato have resulted in 19 new orange-fleshed varieties with a range of specific attributes such as higher vitamin A content and increased yields even in a range of rainfall, planting times and soil conditions. Teff is an Ethiopian crop that has been the centre of much participatory varietal selection so as to improve yields and the number of varieties through farmers' cooperatives and seed grower associations. Improvements in yields have been noted even in the absence of fertiliser and few herbicides (Pretty et al., 2011).

A new cultivar of **pearl millet**, known as Okashana 1, was first developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and trialled in Namibia in the 1990s. This open-pollinated variety was found to be more resistant to drought and faster maturing than other local millet varieties and, therefore, was rapidly adopted by farmers throughout the country. However, it was found that most farmers did not buy seeds but saved seed from previous crops and therefore many farmers were cultivating their own variant of the original Okashana[-1] (Daisuke, 2005). Moreover, many farmers cultivated the new variety alongside older local varieties so as to take advantage of the characteristics of both cultivars in a multi-subsistence strategy. Since these trials, other varieties of millet and new sorghum varieties, such as

SV2, have been introduced throughout Africa in an attempt to boost yields in dryland areas. Low rates of adoption of **sorghum** varieties have initiated research into traditional seed systems throughout Africa that have revealed a strong social basis for continuing to use local varieties (Westingen et al., 2014). New research suggests that trials of certain conventionally bred **beans** may be more likely to withstand higher temperatures due to their greater pollen viability, and hence, pollination success, in these conditions. This ongoing work aims to select a number of varieties that can be added to the toolkit for resilience building.[3]

Changing sowing dates and **using sequential sowing** systems can be an important strategy in building agricultural resilience in that they increase temporal diversity in available crops. Multiple cropping systems allow for intensification in that the farmer grows several crops continuously and in sequence. There are also various other benefits from growing sequentially, such as nitrogen fixation and an increase in phosphorus as a result of previously growing deep rooted species (Waha et al., 2013). Both simulated and experimental data suggest that adjusting sowing dates of crops, such as maize and groundnuts, to the start of the main rainy season will increase yields, though in areas where temperature is the limiting factor yields can also decline (Waha et al., 2013). Where suitable temperatures and precipitation allow, sequential cropping systems produce the highest yields overall for farmers, as often the second crop may prove successful. Under changing climate conditions in mixed farming systems, where both the productivity of grassland pastures and crop yields are limited, the use of locally available plant diversity can build resilience amongst SSFs (Challinor et al., 2007; Morton, 2007).

[3] http://news.sciencemag.org/biology/2015/03/heat-beating-beans-resist-climate-change?rss=1

3.3.2 Livestock management

Livestock are an important component of the mixed farming system in Africa. Cattle, sheep and goats are used for meat, dairy products, draught power, manure production and as capital assets. Household surveys in Uganda, Kenya and Tanzania suggest that agro-pastoralists and farmers with mixed farming systems exclusively resort to livestock-based livelihoods in incidences of crop failure (Thornton et al., 2011; Vermeulen et al., 2012). However, livestock health and survival will be impacted upon by severe droughts. Larger species, such as cattle, are more severely affected and in some cases herd recovery can take up to 15 years (Lesnoff et al., 2012). Rangeland productivity is degraded with repeated droughts and climate change may also have significant impacts on the emergence and spread of livestock diseases (Thornton & Gerber, 2010).

Some farmers have adopted livestock-orientated strategies to cope with the effects of drought. The Sumburu, North Kenya, is a traditional cattle keeping area and farmers have adopted **camels** as a strategy to mitigate the effects of drought and disease. Other areas of East Africa use local **Zebu cattle** and climate change adaptation strategies include either increasing or decreasing herd sizes, depending on the ability of the farmer to afford buying new animals and absorbing the risk of cattle loss (Silverstri et al., 2012). In some cases farmers may diversify and **change livestock breeds** to more tolerant varieties or rely on smaller animals such as goats and chickens. In Nyando, Kenya, over half of households interviewed by Kristjanson et al. (2012) mentioned a reduction in the size of their herds over the previous decade and in Lushoto, 47% of households had introduced different breeds to their herds.

Locally developed goats in Kenya (such as Galla goats; an indigenous northern Kenyan breed), or **chickens** in Uganda, have improved resistance to disease. Farmers are also beginning to rear rabbits and guinea pigs for their own meat source and also to sell. Small livestock can be important sources of food and income for smallholders, particularly women and children, and some focus has been on improving management, particularly housing, feeding and parasite control so as to improve the health of these animals (Pretty et al., 2011). Most frequent management changes are the growing of fodder crops, particularly cut and carry crops that are then fed to stall kept cattle. However, the main barrier to these types of adaptation by farmers is the lack of savings (and credit) required to buy new breeds or species, and the absence of markets in which to find these animals. The demand for fodder crops can also be in conflict with land used to grow arable crops that will increase household food security.

3.3.3 Alternative incomes

Diversification of livelihoods can also provide farmers with alternative sources of income and, in the case of **fish farmed in ponds**, valuable protein during food insecure months (Beveridge et al., 2013). The addition of beehives onto farms provides a supplementary income from honey (Pretty et al., 2011). In some cases, at the interface of wildlife parks and agricultural land, **wildlife tourism** can also provide an additional income opportunity to farmers (Chaminuka et al. 2014). Renewable forest resources can also make an important contribution to the livelihood of those in many rural communities (Babulo et al. 2008).

Farmers have developed **novel innovations** in which to integrate fertiliser tree products with other livelihood requirements. For example, *Gliricidia* leaf products are now being used as fish feed for farmers who are practicing aquaculture. *Tephrosia* extracts are being used as bio-pesticides by farmers (Ajayi et al., 2005; 2007). These tree systems also provide an additional habitat for apiculture. Some farmers are now mounting beehives on the trees thereby creating additional areas for honey production. Above all, **coppicing** tree systems have also allowed farmers to meet the high demand for fuel wood, livestock fodder and building timber which is prevalent in the region (Jama et al., 2008; Franzel et al., 2014). Farmers can also sell their extra fuel wood (Quinion et al., 2010). Taken together, yield benefits to food crops and the other additional benefits of fertiliser trees have brought a number of direct economic benefits that have led to livelihood improvement in Africa. Consequently the adoption of agroforestry has been high in Southern and East Africa (Ajayi et al., 2011). For example in a five-year cycle, unfertilised maize produced a net profit of US$130 per hectare compared to US$269 and US$309 for maize grown with *Gliricidia* or *Sesbania* respectively. Using fertiliser trees also performed better with a benefit-to-cost ratio range of 2.77 - 3.13 in comparison to 2.65 for (subsidised) fertiliser fields, 1.77 in (non-subsidised) fertiliser fields and 2.01 in non-fertilised fields (Ajayi et al., 2011). Please also see the findings of a Greenpeace Africa study, Fostering Economic Resilience: The Financial Benefits of Ecological Farming in Kenya and Malawi.[4]

3.3.4 Pest protection and soil fertility management

Considering that the impact of crop pests is most likely to increase under climate change scenarios, agroecological pest control may be crucial in ensuring sustainably derived yields. The push-pull system is a particularly effective strategy that uses on-farm diversity to control parasitic weeds, improve soil fertility and control cereal pests (Khan et al., 2011; 2014). Plants in the *Desmodium* spp. are intercropped with cereals, whilst grasses such as Napier or *Brachiaria* cv. Mulato are planted in border rows surrounding the plot (Fig. 5). Stem-borers are attracted to the Napier grass (pull) whilst being repelled from the cereal crop by the intercropped *Desmodium* (push). Root exudates from the *Desmodium* also control the parasitic striga weed (or witchweed) by affecting germination efficiency. *Desmodium* also improves the soil fertility through nitrogen fixation. Both Napier grass and *Desmodium* provide high value fodder for livestock, therefore benefitting milk production and the nutrient content of manure (Zingore et al., 2007).

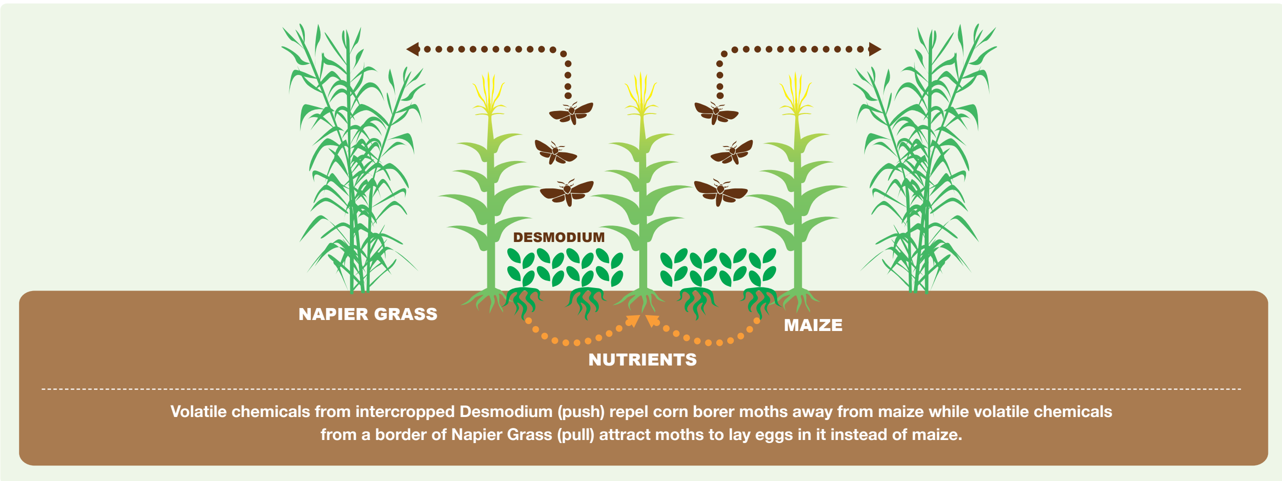

Figure 5. The push-pull pest management system showing intercropping of maize with *Desmodium* spp. legumes that repel (push-) and Napier grass that attracts (pulls) stem-borer. *Desmodium* also improves soil quality through nitrogen fixation and impedes striga weed. Source: Fostering Economic Resilience: The financial benefits of ecological farming in Kenya and Malawi. Greenpeace Africa.[6]

[4] http://www.greenpeace.org/africa/Global/africa/graphics/FoodForLife/Fostering%20Economic%20Resilience.pdf
[5] http://www.push-pull.net/
[6] Available at: www.greenpeaceafrica.org/financialbenefits

Taken together, the push-pull system requires little external input for small scale farmers yet provides multiple benefits and has been adopted by over 96,500 farmers in East Africa (Khan et al., 2011). Push-pull systems can also be modified to include food legumes with potentially similar effectiveness (Midega et al., 2014). Further, climate smart push-pull systems use drought tolerant varieties of pull (trap), and push crops, including a new pull crop *Brachiaria* hybrid Mulato.[5]

Other agroecological practices such as **crop rotations** are also a useful strategy in combating pests. Apart from being used as intercrops, rotations with other plants such as legumes can be important in combating pests and improving soil fertility. Life cycles of pests are biologically interrupted as farmland is made more temporally and structurally diverse (Lin et al., 2011).

Abuelmaali et al. (2013) suggest that the use of agricultural pesticides may be critical in conveying insecticide resistance in the malaria mosquito vector, particularly DDT and pyrethroids. In some cases, sustainable agricultural practices are heralded as an exemplar for management of malaria vectors in the context of widespread insecticide resistance (Thomas et al. 2012). Therefore the use of on-farm agrodiversity, and other sustainable methods to combat pest outbreaks, has further utility than solely protecting farmers from the economic and health risks of the pesticide use itself.

In addition to bio-insecticides derived from *Tephrosia* fertiliser trees, there are other indigenous ecological resources that can be used for crop protection such as naturally occurring biological control agents, e.g. parasitic wasps or endemic insect baculovirus (Grzywacz et al. 2014). In general, biological control is an understudied and under-exploited resource in the developing world and much of the focus has been placed on rice, maize and cotton growing rather than other key staple crops such as millet or fruits (Wyckhuys et al. 2013).

3.4 Community

The ability for communities to solve problems and build resilience to natural disasters and climate perturbations is greatly augmented by the formation of social and participatory groups. These groups can lead to action that will provide mutually beneficial outcomes. Groups that are formed for pest control, irrigation, forest management or marketing have been extremely successful in helping communities access training in and take on new adaptive strategies. This community involvement is seen as a critical prerequisite for adopting sustainable practices (Pretty et al. 2011). Group members are thought to have more confidence in investing in collective strategies and are less likely to engage in activities with negative outcomes that may degrade land or reduce market prices. Where group membership is strong in a community, other programmes such as seed sharing and storage systems to prevent post-harvest loss can also develop.

These community groups are also an important voice in collaborating with external organisations such as non-government organisations, research institutions and government departments. **Farmer participatory research**, on-farm testing of new varieties, and selection of new drought resistant cultivars all require a long process of dialogue, negotiation and reporting that is facilitated by the formation of social action groups within the community. Working together as a co-operative or producer group, farmers may be able to provide larger quantities of produce and negotiate a better deal.

3.4.1 Knowledge, learning and information

Improvement of farmer's knowledge and capacity to take on new innovations and adapt to change is critical to the success of these new practices. Farmers Field Schools (FFS) are a long established means of **improving training** in new techniques and giving support to farmers throughout the adaptation process. Each FFS has a training field that will be divided into two parts: one where management is decided by the group and may include new innovative practices, and the other with a conventional treatment regime that is a consensus of what farmers feel to be the 'usual' practice for their area (Settle & Hama Garba, 2011). Farmers make observations on growing stage and conditions of crop plants and trainers facilitate discussions on management of the crops. Special subjects such as pest control, life cycles and diseases, and 'insect zoos' are maintained so as to make direct observations on introduced pests, beneficial insects and interactions.

Davis et al. (2012) suggested that FFS are particularly important for increasing the production and income of women, low-literacy farmers and medium land size farmers, and it was noted that participation increased incomes by 61%. A questionnaire survey of 2,000 households suggested that FFS were most significant in building the capacity of communities to make decisions that ultimately lead to the uptake of agricultural innovations (Friis-Hansen & Duveskog, 2012). It was suggested that such knowledge centres be central to agricultural development programmes in empowering farmers rather than the technical solutions that are often the focus of such programmes.

Improving literacy and access to **information technology** and internet access are also an essential mechanism in delivering information and advice for contemporary farming. Many households in Africa possess mobile phones and in 2009 more than 50% of inhabitants were able to access climate forecasting to improve agricultural management for small-holders. Organisations such as the Arid Lands Information Network (ALIN) are also in the process of developing a network of knowledge, or *maarifa*,–centres that provide rural communities with internet access and training in computer skills. These centres also provide a focal point for other initiatives that focus on trading and marketing cooperatives that will aim to obtain best prices for farmers.

3.4.2 Access to infrastructure and finance

A study of the determinants of climate change adaptation by farmers in Tanzania suggests that one of the important factors in the uptake of new adaptive practices is the distance to the local market from the farm (Below et al., 2012). Where physical infrastructures, such as roads are poor, access to specialist veterinary and agricultural assistance and markets are difficult. Investment in **rural infrastructure** and an **education** system that provides **equal opportunities** for women were found to be the most useful means of improving adaptation of farmers to new farming techniques.

Microfinance and community banks are important in farmers' ability to take up new innovative practices where there might be a perceived increase in risk (Bryan et al., 2013; Pretty et al., 2011). Small family orientated farmers may often need very small amounts of money and applying for loans as a group may increase the chances of obtaining credit. Public sector and international support for larger projects, e.g. water macro-catchment development or drip-irrigation, can be influential in whether farmers change crop types (Bryan et al., 2013).

4. Conclusions

Climate change currently, impacts upon the ability of East African farmers to produce food and income for their families and this impact will only increase in time. Research on the negative impacts of a changing climate in Africa is robust and, therefore, the need for small-scale farmers to adapt their practices is well recognised and urgent. There are many strategies for adaptation and resilience theory provides a useful framework to describe agricultural system complexity so as to draw together a cohesive approach that will be practical and long lasting for farmers. In a severely food-insecure household, with only little resilience, relatively small changes in climatic conditions will create difficult times and thus long-term resilience is key in being able to cope with instability.

Successful strategies must include the investment in multiple elements that will improve soil security, water resources, diversity and communities (Table 5). Whilst there are many technological and innovative adaptations that may be useful in the future, the adoption of adaptive practices will be more likely with education and continued support to rural farmers. Techniques that require little or no external input, whilst strengthening community groups are thought to provide the best improvements for farmers.

Table 5. Examples of ecological agriculture practices (diversification and soil management) known to affect soil and water dynamics thus enhancing agroecosystem resilience. Based on Altieri & Nichols (2013).

	Soil organic build up	Nutrient cycling	>soil cover	Reduce ET	Runoff reduction	> water holding capacity	> infiltration	Microclimatc amelioration	Reduction soil compactation	Reduction soil erosion	> hydrological regulation	> water use efficiency	>mycorrhizal network
Diversification													
• Mixed or intercropping			✓	✓	✓			✓	✓	✓		✓	
• Agroforestry	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	
• Intensive sylvopastoral system	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
• Crop rotation	✓	✓	✓		✓		✓		✓	✓		✓	
• Local variety mixtures			✓									✓	
Soil Management													
• Cover cropping	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		
• Green manures	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓
• Mulching	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓	
• Compost applications	✓					✓							✓
• Conservation agricultura (organic -no till)			✓	✓	✓		✓		✓	✓		✓	
Soil Conservation													
• Contour farming					✓		✓		✓	✓	✓		
Grass strips/living barriers			✓		✓		✓				✓		
• Terracing					✓		✓				✓		
• Check dams along gullies					✓		✓				✓		

The ability of communities to adapt agricultural practices and build both biophysical and socio-economic resilience is critical. Both adaptation and climate change mitigation must be implemented within an integrated and coordinated framework from the community level to international organisations. Investment must be made to put into place means to up-scale the sustainable management of already dwindling resources to enable a positive future for rural African people.

The research that we present in this report suggests that building resilience using ecological farming is extremely context specific. A suite of successful strategies must consider local and domestic needs of different communities, and families, so that in all ways resilience building is maximised and takes spatial difference into account.

It is also necessary that the success of any resilience-building activity be measured and evaluated throughout the transition process. The FAO are now aiming to statistically measure the success for resilience building measures using the Resilience Index Measurement and Analysis (RIMA) model (FAO, 2014). This model attempts to evaluate a set of context-specific factors that will make a household resilient to food insecurity. These factors take into account income, assets, and access to food, technology, institutional help, social safety nets as well as particular aspects of climate change in that households' area. Evaluating resilience in this way is a step forward in assessing both knowledge and technical gaps in agricultural systems. Households and communities can then intrinsically deal with climate change themselves, diminishing the need for humanitarian intervention and empowering individuals.

Our climate is changing, and East Africa is one of the first regions to experience more unpredictable and uncertain weather. Those that depend on this weather for their livelihoods – farmers, farm workers and agricultural businesses – will find it increasingly challenging to grow food, in a region already designated as a hunger 'hotspot'. Fortunately, there are a number of resilience building practices that will increase farmers' capacity to adjust to climate change. These practices will help farmers and their communities cope with, and recover from, climate shocks whilst giving them the ability to further adapt in the long-term to changing weather patterns. Greenpeace, alongside a number of organisations, is working to promote ecological farming as a way of empowering farmers and communities to cope with climate change and build nutritional security in a time of profound change.

5. References

Abdulkadir A, Schultz R (2005) Water harvesting in a runoff-catchment agroforestry system in the drylands of Ethiopia. Agroforestry Systems 63: 291–298.

Abuelmaali S, Elaagip A, Basheer M, Frah E, Ahmed F, Eljah H, Seidahmed O, Weetman D, Hamid M (2013) Impacts of Agricultural Practices on Insecticide Resistance in the Malaria Vector Anopheles arabiensis in Khartoum State, Sudan. PLoS ONE 8: e80549.

Adger W (2003) Governing natural resources: institutional adaptation and resilience. In: Negotiating Environmental Change: New Perspectives from Social Science, F. Berkhout, et al. (eds.), Cheltenham: Edward Elgar. 193-208.

Ajayi O, Place F, Kwesiga F, Mafongoya P, Franzel S (2005) Impact of Fertilizer Tree Fallows in Eastern Zambia. 3RD EPMR External Programme and Management Review, World Agroforestry Centre.

Ajayi O, Akinnifesi F, Sileshi G, Chakeredza S (2007) Adoption of renewable soil fertility replenishment technologies in the southern African region: Lessons learnt and the way forward. Natural Resources Forum 31: 306-317.

Ajayi O, Place F, Akinnifesi F, Sileshi GW (2011) Agricultural success from Africa: the case of fertilizer tree systems in southern Africa (Malawi, Tanzania, Mozambique, Zambia and Zimbabwe). International Journal of Agricultural Sustainability 9: 129-136.

Akinnifesi F, Chirwa P, Ajayi O, Sileshi G, Matakala P, Kwesiga F, Harawa H, Makumba W (2008) Contributions of agroforestry research to livelihood of smallholder farmers in Southern Africa: Taking stock of the adaptation, adoption and impact of fertiliser tree options Agriculture Journal 3: 58-75.

Akinnifesi F, Ajayi O, Sileshi G, Chirwa P Chianu J (2010) Fertiliser trees for sustainable food security in the maize-based production systems of East and Southern Africa. Agronomy for Sustainable Development 30: 615-629.

Altieri M, Nicholls C (2013) The adaptation and mitigation potential of traditional agriculture in a changing climate. Climactic Change, Special Issue: Climate Change Mitigation and Adaptation with Local Communities and Indigenous Peoples. Eds.K Galloway McLean, A Ramos Castillo, E Castellanos, A Lynge. DOI: 10.1007/s10584-013-0909-y

Amundsen R, Berhe A, Hopmans J, Olson C, Sztein A, Sparks D (2015) Soil and human security in the 21st Century. Science 348: 1261071-6.

Babulo B, Muys B, Nega F, Tollens E, Nyssen J, Deckers J, Mathijs E (2008) Household livelihood strategies and forest dependence in the highlands of Tigray, Northern Ethiopia. Agricultural Systems 98: 147-155.

Barrios E, Sileshi G, Shepherd K, Sinclair F (2012) Agroforestry and soil health: linking trees, soil biota and ecosystem services. In: Wall, DH et al. (Eds.). Soil Ecology and Ecosystem Services. Oxford University Press, Oxford, UK. Pp. 315-330

Baudron F, Tittonell P, Corbeels M, Letourmy P, Giller K (2012) Comparative performance of conservation agriculture and current smallholder farming practises in semi-arid Zimbabwe. Field Crops Research 132: 117-128.

Below T, Mutabazi K, Kirschke D, Franke C, Sieber S, Siebert R, Tscherning K (2012) Can farmers' adaptation to climate change be explained by socio-economic household-level variables? Global Environmental Change, 22: 223-235.

Berg A, de Noblet-Ducoudré N, Sultan B, Lengaigne M, Guimberteau M (2013) Projections of climate change impacts on potential C4 crop productivity over tropical regions. Agricultural and Forest Meteorology 170: 89-102.

Beveridge M, Thilsted S, Phillips M, Metian M, Troell M, Hall S (2013) Meeting the food and nutritional needs of the poor: the role of fish and the opportunities and challenges emerging from the rise of aquaculture. Journal of Fish Biology 83: 1067-1084.

Biazin B, Sterk G, Temesgen M, Abdulkedir A, Stroosnijder L (2012) Rainwater harvesting and management in rain-fed agricultural systems in sub-Saharan Africa–A review. Physics and Chemistry of the Earth, Parts A/B/C 47: 139-151.

Boyd E, Cornforth R, Lamb P, Tarhule A, Lélé M, Brouder A (2013) Building resilience to face recurring environmental crisis in African Sahel Nature Climate Change 3: 631-637.

Brussaard L, Caron P, Campbell B, Lipper L, Mainka S, Rabbinge R, Babin D, Pulleman M (2010) Reconciling biodiversity conservation and food security: scientific challenges for a new agriculture. Current Opinion in Environmental Sustainability 2: 34-42.

Bryan E, Ringler C, Okoba B, Roncoli C, Silverstri S, Herrero M (2013) Adapting agriculture to climate change in Kenya: Household strategies and determinants. Journal of Environmental Management 114: 26-35.

Buresh R, Tian G (1997) Soil improvement by trees in sub-Saharan Africa. Agroforestry Systems 38: 51-76.

Burney J, Naylor R, Postel S (2013) The case for distributed irrigation as a development priority in sub-Saharan Africa. Proceedings of the National Academy of Sciences US 110: 12513-12517.

Cardinale B, Duffy J, Gonzalez A, Hooper D, Perrings C, Venail P, Narwani A, Mace G, Tilman D, Wardle D, Kinzig A, Daily G, Loreau M, Grace J, Larigauderie A, Srivastava D, Naeem S (2012) Biodiversity loss and its impact on humanity. Nature 486: 59-67.

Castellanos-Navarrete A, Tittonell P, Rufino M, Giller K (2015) Feeding, crop residue and manure management for integrated soil fertility management - A case study from Kenya. Agricultural Systems 135: 24-35.

Cecchi G, Wint W, Shaw A, Marletta A, Mattioli R, Robinson T (2010) Geographic distribution and environmental characterization of livestock production systems in Eastern Africa. Agriculture, Ecosystems and Environment 135: 98-110.

Cernansky R (2015) The rise of Africa's super vegetables. Nature 522: 146-148.

Challinor A, Wheeler T, Garfoth C, Craufurd P, Kassam A (2007) Assessing the vulnerability of food crop systems in Africa to climate change. Climatic Change 83: 381-399.

Chaminuka P, Udo H, Eilers K, van der Zijpp A (2014) Livelihood roles of cattle and prospects for alternative land uses at the wildlife/livestock interface in South Africa. Land Use Policy 38: 80-90.

Chikowo R, Mapfumo P, Leffelaar, PA, Giller KE, (2006) Integrating legume to improve N cycling on smallholder farms in sub-humid Zimbabwe: resource quality, biophysical and environmental limitations. Nutrient Cycling in Agroecosystems 76: 219–231.

Clawson DL (1985) Harvest security and intraspecific diversity in traditional tropical agriculture. Economic Botany 39: 56-67.

Conway D, Schipper EL (2011) Adaption to climate change in Africa: Challenges and opportunities identified from Ethiopia. Global Environmental Change 21:227-237.

Cook K, Vizy E (2012) Impact of climate change on mid-twenty-first century growing seasons in Africa. Climate Dynamics 39: 2937-2955.

Daisuke U (2005). Farmer's selection of local and improved pearl millet varieties in Ovamboland, Northern Namibia. African Study Monographs, Suppl. 30: 107-117.

Davis K, Nkonya E, Kato E, Mekonnen D, Odendo M, Miiro R, Nkuba, J (2012) Impact of farmer field schools on agricultural productivity and poverty in East Africa. World Development 40: 402-413.

De Schutter O (2008) Building Resilience: a human rights framework for world food and nutrition security. New York: United Nations.

De Schutter O (2012) Eco-farming addresses hunger, poverty & climate change. Pacific Ecologist (winter 2012).

Dicko M, Gruppen H, Traoré A, Voragen A, van Berkel W (2006) Review: sorghum grain as human food in Africa: relevance of starch content and amylase activities. African Journal of Biotechnology 5: 384-395.

Diogo V, Schlecht E, Buerkert A, Rufino M, van Wijk MT (2013) Increasing nutrient use efficiency through improved feeding and manure management in urban and peri-urban units of a West African city: A scenario analysis. Agricultural Systems 114: 64-72.

Doré T, Makowski D, Malézieux E, Munier-Jolain N, Tchamitchian, Tittonell P (2011) Facing up to the paradigm of ecological intensification in agronomy: Revisiting methods, concepts and knowledge. European Journal of Agronomy 34: 197-210.

Engdawork A, Bork H (2014) Long-term indigenous soil conservation technology in the Chencha area, Southern Ethiopia: Origin, characteristics and sustainability. AMBIO 43: 932-942.

Enjalbert J, Dawson JC, Paillard S, Rhone B, Rousselle Y, Thomaz M & Goldringer I (2011) Dynamic management of crop diversity: From an experimental approach to on-farm conservation. Comptes Rendus Biologies 334: 458-468.

FAO (2008) Declaration of the High-Level Conference on World Food Security: The challenges of Climate Change and Bioenergy. Rome: Food and Agricultural Organization; World Bank, 2008.

FAO (2014) Resilience Index Measurement and Analysis Model. Available from: http://www.fao.org/3/a-i4102e.pdf

Fischer J, Peterson G, Gardner T, Gordon L, Fazey I, Elmqvist T, Felton A, Folke C, Dovers S (2009) Integrating resilience thinking and optimisation for conservation. Trends in Ecology & Evolution, 24: 549-554.

Folke C, Carpenter S, Walker B, Scheffer M, Chapin T, Rockström J (2010). Resilience thinking: integrating resilience, adaptability and transformability. Ecology and Society 15: 20.

Franzel S, Carsan S, Lukuyu B, Sinja J, Wambugu C (2014) Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. Current Opinion in Environmental Sustainability 6: 98-103.

Friis-Hansen E, Duveskog D (2012) The empowerment route to well-being: An analysis of farmer field schools in East Africa. World Development 40: 414-427.

Freier K, Bruggemann R, Scheffran J, Finckh M, Schneider UA (2012) Assessing the predictability of future livelihood strategies of pastoralists in semi-arid Morocco under climate change. Technological Forecasting and Social Change 79: 371-382.

Frison E, Cherfas J, Hodgkin T (2011) Agricultural biodiversity is essential for a sustainable improvement in food and nutrition security. Sustainability 3: 238-253.

Funk C, Dettinger M, Michaelsen J, Verdin J, Brown M, Barlow M, Hoell A (2008) Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. Proceedings of the National Academy of Sciences US 105: 11081-11086.

Funk C, Husak G, Mahiny AS, Eilerts G, Verdin J, Rowland J (2013) Blending local scale information for developing agricultural resilience in Ethiopia. Earth Systems and Environmental Services: 165-175.

Garrity D, Akinnifesi F, Ajayi O, Weldesmayat S, Mowo J, Kalinganire A, Larwanou M, Bayala J (2010) Evergreen Agriculture: a robust approach to sustainable food security in Africa. Food Security 2: 197-214.

Giller K, Witter E, Corbeels, M, Tittonell P (2009) Conservation agriculture and smallholder farming in Africa: The heretics` view. Field Crops Research 114: 23-34.

Godfray H, Beddington J, Crute I, Haddad L, Lawrence D, Muir J, Pretty J, Robinson S, Thomas S, Toulmin C (2010) Food security: the challenge of feeding 9 billion people. Science 327(5967): 812-818.

Grant P (1967) The fertility of sandveld soils under continuous cultivation. I. The effect of manure and nitrogen on the nitrogen status of the soil. Rhodesia Zambia Malawi Journal of Agricultural Research 5: 71–79.

Grubben G, Klaver W, Nono-Womdim R, Everaarts A, Fondio L, Nugteren J, Corrado M (2014) Vegetables to combat the hidden hunger in Africa. Chronica Horticulturae 54: 25.

Grzywacz D, Stevenson P, Mushobozi W, Berlmain S, Wilson K (2014) The use of indigenous ecological resources for pest control in Africa. Food Security 6: 71-86.

Hassan R & Nhemachena C (2008) Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis. African Journal of Agricultural and Resource Economics 2: 83-104.

Herrero M, Thornton PK (2013) Livestock and global change: Emerging issues for sustainable food systems. Proceedings of the National Academy of Science USA 110: 20878-20881.

Hertel T, Ramankutty N, Baldos U (2014) Global market integration increases likelihood that a future African Green Revolution could increase crop land us and CO2 emissions. Proceedings of the National Academy of Science USA 111: 13799-13804.

IPCC (2014) Climate Change 2014: Impacts, Adaptation, and Vulnerability. Report from the Intergovernmental Panel of Climate Change. http://www.ipcc.ch/report/ar5/

Jacobsen S, Sørensen M, Pederson S, Weiner J (2013) Feeding the world: genetically modified crops versus agricultural biodiversity. Agronomy for Sustainable Development 33: 651-662.

Jama B, Mutengi J, Njui A (2008) Potential of improved fallows to increase household and regional fuelwood supply: evidence from western Kenya. Agroforestry Systems 73: 155-166.

Jaramillo J, Muchugu E, Vega F, Davis A, Borgemeister C, Chabi-Olaye, A (2011) Some like it hot: the influence and implications of climate change on coffee berry borer (Hypothenemus hampei) and coffee production in East Africa. PLoS One 6: e24528.

Jarvis A, Ramirez-Villegas J, Campo B, Navarro-Racines C (2012) Is cassava the answer to African climate change adaptation? Tropical Plant Biology 5: 9-29.

Jayne T, Mather D, Mghenyi E (2010) Principal challenges confronting smallholder agriculture in sub-Saharan Africa. World Development 38: 1384-1398.

Jones et al. (2013). Soil atlas of Africa. European Commission.

Karpouzoglou T, Barron J (2014) A global and regional perspective of rainwater harvesting in sub-Saharan Africa's rain-fed farming systems. Physics and Chemistry of the Earth, Parts A/B/C. http://dx.doi.org/10.1016/j.pce.2014.09.009

Khan Z, Midega C, Pittchar J, Picket J, Bruce T (2011) Push-pull technology: a conservation agriculture approach for integrated management of insect pests, weeds and soil health in Africa. Journal of Sustainable Agriculture 9: 162-170.

Khan Z, Midega C, Pittchar J, Murage A, Birkett M, Bruce T, Pickett J (2014) Achieving food security for one million sub-Saharan African poor through push-pull innovation by 2020. Philosophical Transactions of the Royal Society B 369: 20120284.

Kiepe P (1995). No runoff, no soil loss: soil and water conservation in hedgerow barrier systems. Doctoral thesis. Wageningen Agricultural University, The Netherlands, pp. 156.

Kimaro A, Timmer V, Chamshama S, Mugasha A, Kimaro D (2008) Differential response to tree fallows in rotational woodlot systems in semi-arid Tanzania: Post-fallow maize yield, nutrient uptake, and soil nutrients. Agriculture, Ecosystems and the Environment 125: 73-83.

Kiptot E, Franzel S, Degrande A (2014) Gender, agroforestry and food security in Africa. Current Opinion in Environmental Sustainability 6: 104-109.

Kristjanson P, Neufeldt H, Anja G, Mango J, Kyazze F, Desta S, Sayula G, Thiede B, Förch W, Thornton P, Coe R (2012) Are food insecure smallholder households making changes in their farming practices? Food Security 4: 381-397.

Kwesiga F, Akinnifesi F, Mafongoya P, McDermott M, Agumya (2003) Agroforestry research and development in southern Africa during the 1990s: Review and challenges ahead. Agroforestry Systems 59: 173-186.

Lesnoff M, Corniaux C, Hiernaux P (2012). Sensitivity analysis of the recovery dynamics of a cattle population following drought in the Sahel region. Ecological Modelling 232: 28-39.

Letourneau D et al., (2011) Does plant diversity benefit agroecosystems? A synthetic review. Ecological Applications 21: 9-21.

Lin B (2011) Resilience in agriculture through crop diversification: Adaptive management for environmental change. Biosciences 61: 183-193.

Lobell D, Burke M, Tebaldi, Mastrandrea M, Falcon W, Naylor R (2008) Prioritizing climate change adaptation needs for food security in 2030. Science 319: 607-610.

Lobell D, Schlenker W, Costa-Roberts J (2011) Climate trends and global crop production since 1980. Science 333: 616-620.

Lobell D, Bänziger M, Magorokosho C, Vivek B (2011) Nonlinear heat effects on African maize as evidenced by historical yield trials. Nature Climate Change 1: 42-45.

Lobell D, Gourdji S (2012). The influence of climate change on global productivity. Plant Physiology 160: 1686-1697.

Luoh J, Begg C, Symonds R, Ledesma D, Yang R (2014) Nutritional Yield of African Indigenous Vegetables in Water-Deficient and Water-Sufficient Conditions. Food and Nutrition Sciences 5: 812-822.

Luck J, Spackman M, Freeman A, Griffiths W, Finlay K, Chakraborty S (2011) Climate change and diseases of food crops. Plant Pathology 60: 113-121.

Lupwayi N, Kennedy A, Chirwa R (2011) Grain legume impacts on soil biological processes in sub-Saharan Africa. African Journal of Plant Sciences 5: 1-7.

Lyon B, DeWitt D (2012) A recent and abrupt decline in the East African long rains. Geophysical Research Letters 39. DOI: 10.1029/2011GL050337

Maitima J, Mugatha S, Reid R, Gachimbi L, Majule A, Lyaruu H, Pomery D, Mathai S, Mugisha S (2009) The linkages between land use change, land degradation and biodiversity across East Africa. African Journal of Environmental Science and Technology 3: 310-325.

Mafongoya P, Bationo A, Kihara J, Waswa B (2006a) Appropriate technologies to replenish soil fertility in Southern Africa. Nutrient Cycling in Agroecosystems 76: 137-151.

Mafongoya PL, Kuntashula E, Sileshi G (2006b) Managing soil fertility and nutrient cycles through fertilizer trees in southern Africa. In: Uphoff et al. (Eds) Biological Approaches to Sustainable Soil Systems, pp. 273-289. Taylor & Francis.

Makumba W, Janssen B, Oenema O, Akinnifesi FK, Mweta D, Kwesiga F (2006) The long-term effects of a Gliricidia–maize intercropping system in Southern Malawi, on Gliricidia and maize yields, and soil properties. Agriculture, Ecosystems and the Environment 116: 85-92.

Malley Z, Kayombo B, Willcocks T, Mtakwa P (2004) Ngoro: an indigenous, sustainable and profitable soil, water and nutrient conservation system in Tanzania for sloping land. Soil Tillage Research 77: 47–58.

Martin G, Magne M (2015) Agricultural diversity to increase adaptive capacity and reduce vulnerability of livestock systems against weather variability – A farm scale simulation study. Agriculture, Ecosystems and Environment 199: 301-311.

Masters W, Djurfeldt A, De Haan C, Hazell P, Jayne T, Jirström M, Reardon T (2013) Urbanization and farm size in Asia and Africa: Implications for food security and agricultural research. Global Food Security 2: 156-165.

McBratney A, Field D, Koch A (2014). The dimensions of soil security. Geoderma 213: 203-213.

Midega C, Salifu D, Bruce T, Pittchar J, Pickett J, Khan Z (2014) Cumulative effects and economic benefits of intercropping maize with food legumes on Striga hermonthica infestation. Field Crops Research 155: 144-152.

Morton J (2007) The impact of climate change on smallholder and subsistence agriculture. Proceedings of National Academy of Sciences US 104: 19680-19685.

Muchena F, Onduru D, Gachini G, De Jager A (2005) Turning the tides of soil degradation in Africa: capturing the reality and exploring opportunities. Land Use Policy 22: 23-31.

Mucheru-Muna M, Pypers P, Mugendi D, Kung`u J, Mugwe J, Merckx R, Vanlauwe B (2010) A staggered maize–legume intercrop arrangement robustly increases crop yields and economic returns in the highlands of Central Kenya. Field Crops Research 115: 132-139.

Müller, C, Cramer, W, Hare, W, Lotze-Campen H (2011) Climate risks for African agriculture. Proceedings of the National Academy of Sciences USA 108: 4313-4315.

Myers et al. (2014). Increasing CO2 threatens human nutrition. Nature 510: 139-142.

Ncube B, Dimes JP, Twomlow S, Mupangwa W, Giller KE (2007) Raising the productivity of smallholder farms under semi-arid conditions by use of small doses of manure and nitrogen: a case of participatory research. Nutrient Cycling in Agroecosystems 77: 53-67.

Nezomba H, Tauro TP, Mtambanengwe F, Mapfumo P (2010) Indigenous legume fallows (indifallows) as an alternative soil fertility resource in smallholder maize cropping systems. Field Crops Research 115: 149-157.

Nicholls T, Norgrove L, Masters G (2008) Innovative Solutions to New Invaders: Managing Agricultural Pests, Diseases and Weeds Under Climate Change. Agriculture in a Changing Climate. Paper prepared for presentation at Agriculture in a Changing Climate: The New International Research Frontier, Canberra, Australia.

Nuss E, Tanumihardjo S (2011) Quality protein maize for Africa: closing the protein inadequacy gap in vulnerable populations. Advances in Nutrition: An International Review Journal 2: 217-224.

Nyadzi G, Janssen B, Oenema O (2006) Analysis of the effects of rotational woodlots on the nutrition and yield of maize following trees in western Tanzania. Agriculture, Ecosystem and the Environment 116: 93-103.

Nyamangara J, Gotosa J, Mpofu S (2001) Cattle manure effects on structural stability and water retention capacity of a granitic sandy soil in Zimbabwe. Soil and Tillage Research 62:157-162.

Okeyo A, Muchera-Muna M, Mugwe J, Ngetich K, Mugendi D, Diels J, Shisanya C (2014) Deffects of selected soil and water conservation technologies on nutrient losses and maize yields in the central highlands of Kenya. Agricultural Water Management 137: 52-58.

Osman-Elasha B, Goutbi N, Spanger-Siegfried E, Dougherty B, Hanafi H, Zakieldeen S, Sanjak A, Atti H, Elhassan, H (2006) Adaptation strategies to increase human resilience against climate variability and change: lessons from the arid regions of Sudan. AIACC Working Paper No. 42.

Pagano M (2013) Plant and soil biota: crucial for mitigating climate change in forests. British Journal of Environment & Climate Change 3: 188-196.

Pickett J, Woodcock C, Midega C, Khan Z (2014) Push–pull farming systems. Current Opinion in Biotechnology 26: 125-132.

Place F, Ajayi O, Torquebiau E, Detlefsen G, Gauthier M, Buttoud G (2012) Improved policies for facilitating the adoption of agroforestry. In: Kaonga ML (Ed), Agroforestry for Biodiversity and Ecosystem Services - Science and Practice, pp.113-128. Intech Open publishers.

Ponisio L, M'Gonigle L, Mace K, Palomino J, de Valpine P, Kremen C (2015) Diversification practices reduce organicto conventional yield gap. Proceedings of the Royal Society B 282: 20141396.

Pretty J, Noble A, Dixon J, Hine J, Penning de Vries F, Morison J (2006) Resource-conserving agriculture increases yields in developing countries. Environmental Science & Technology 40: 1114-1119.

Pretty J, Toulmin C, Williams S (2011) Sustainable intensification in African agriculture. International Journal of Agricultural Sustainability 9:5-24.

Pypers P, Sanginga J-M, Kasereka B, Masamba W, Vanlauwe B (2011) Increased productivity through integrated soil fertility management in cassava–legume intercropping systems in the highlands of Sud-Kivu, DR Congo. Field Crops Research 120: 76-85.

Quinion A, Chirwa P, Akinnifesi F, Ajayi (2014) Do agroforestry technologies improve the livelihoods of the resource poor farmers? Evidence from Kasungu and Machinga districts of Malawi. Agroforestry Systems 80: 457-465.

Ramirez J, Jarvis A, Van den Bergh I, Staver C, Turner D (2011) Changing Climates: Effects on Growing Conditions for Banana and Plantain (Musa spp.) and Possible Responses (pp. 426-438). Wiley-Blackwell, Oxford, UK.

Reij C, Scoones I, Toulmin C (1996) Sustaining the Soil: Indigenous Soil and Water Conservation in Africa. Earthscan, London.

Rockström J, Kaumbutho J, Mwalley A, Nzabi M, Temesgen L, Mawenya J, Barron J, Mutua, Damgaard-Larsen S (2008) Conservation farming strategies in East and southern Africa: Yields and rain water productivity from on-farm action research, Soil Tillage Research 103: 23-32.

Rosenthal D, Slattery R, Miller R, Grennan A, Cavagnaro T, Fauquet C, Gleadow R, Ort D (2012) Cassave about-FACE: Greater than expected yield stimulations of cassava (Manihot esculenta) by future CO2 levels. Global Change Biology 18: 2661-2675.

Rosset PM, Machín-Sosa B, Roque-Jaime AM, Avila-Lozano DR (2011) The Campesino-to-Campesino Agroecology movement of ANAP in Cuba. Journal of Peasant Studies 38:161–191.

Rufino MC, Rowe EC, Delve RJ & Giller KE (2006) Nitrogen cycling efficiencies through resource-poor African crop–livestock systems. Agriculture Ecosystem and Environment 112: 261-282.

Rurinda J, Mapfumo P, van Wijk MT, Mtambanengwe F, Rufino MC, Chikowo R & Giller KE (2014) Comparative assessment of maize, finger millet and sorghum for household food security in the face of increasing climatic risk. European Journal of Agronomy 55: 29-41.

Rusinamhodzi L, Corbeels M, van Wijk MT, Rufino MC, Nyamangara J & Giller KE (2011) A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. Agronomy for Sustainable Development 31: 657-673.

Rusinamhodzi L, Corbeels M, Nyamangara J & Giller KE (2012) Maize-grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in central Mozambique. Field Crops Research 136: 12-22.

Rust J & Rust T (2013) Climate change and livestock production: A review with emphasis on Africa. South African Journal of Animal Science 43: 255-267.

Schlenker W & Lobell D (2010) Robust negative impacts of climate change on African agriculture. Environmental Research Letters 5. 014010.

Schilling J, Opiyo F, Scheffran J (2012) Raiding pastoral livelihoods: motives and effects of violent conflict in north-western Kenya. Pastoralism 2: 1-16.

Scoones I & Thompson J (2011) The politics of seed in Africa's green revolution: Alternative narratives and competing pathways. IDS Bulletin 42: 1-23.

Settle W, Hama Garba M (2011) The FAO integrated production and pest management programme in the Senegal and Niger River basins of francophone West Africa. International Journal of Agricultural Sustainability 9: 171–185.

Sileshi G, Akinnifesi FK, Ajayi OC, Place F (2008) Meta-analysis of maize yield response to planted fallow and green manure legumes in sub-Saharan Africa. Plant and Soil 307: 1-19.

Silvestri S, Bryan E, Ringler C, Herrero M, Okoba B (2012) Climate change perception and adaptation of agro-pastoral communities in Kenya. Regional Environmental Change 12: 791-802.

Sinclair K, Curtis A, Mendham E, Mitchell M (2014) Can resilience thinking provide useful insights for those examining efforts to transform contemporary agriculture? Agriculture and Human Values: 1-14.

Smith P et al. (2013) How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals? Global Change Biology, 19: 2285-2302.

Solomon T, Snyman H, Smit G (2007) Cattle-rangeland management practices and perceptions of pastoralists towards rangeland degradation in the Borana zone of southern Ethiopia. Journal of Environmental Management 82: 481-494.

Spaan W (2003). Consuming the savings: water conservation in a vegetation barrier system at the Central Plateau in Burkina Faso. Tropical Resources Management Papers 42, pp. 14.

Stadlmayr B, Charrondière U, Eisenwagen S, Jamnadass R, Kehlenbeck K (2013) Nutrient composition of selected indigenous fruits from sub-Saharan Africa. Journal of the Science of Food and Agriculture 93: 2627-2636.

Stevenson JR, Serraj R, Cassman KG (2014) Evaluating conservation agriculture for small-scale farmers in Sub-Saharan Africa and South Asia. Agriculture, Ecosystems & Environment 187: 1-10.

Tengberg A, Ellis-Jones J, Kiome R, Stocking M (1998) Applying the concept of agrodiversity to indigenous soil and water conservation practices in eastern Kenya. Agriculture Ecosystems and Environment 70: 259–272.

Thomas M, Godfray H, Read A, van den Berg H, Tabashnik B, van Lenteren J, Waage J, Takken W (2012) Lessons from Agriculture for the Sustainable Management of Malaria Vectors. PLoS Med 9(7): e1001262.

Thornton PK, Jones PG, Alargaswarmy G, Andresen J (2009) Spatial variation of crop yield response to climate change in East Africa. Global Environmental Change 19: 54-65.

Thornton P, Gerber P (2010) Climate change and the growth of the livestock sector in developing countries. Mitigation and Adaptation Strategies for Global Change 15: 169-184.

Thornton P, Jones P, Ericksen P, Challinor A (2011) Agriculture and food systems in sub-Saharan Africa in a 4 °C+ world. Philosophical Transactions of the Royal Society A 369: 117-136.

Tingem M, Rivington M (2009) Adaptation for crop agriculture to climate change in Cameroon: Turning on the heat. Mitigation and Adaptive Strategies for Global Change 14: 153-168.

Tittonell P, Scopel E, Andieu N, Posthumus H, Mapfumo P, Corbeels M, van Halsema GE, Lahmar R, Lugandu S, Rakotoarisoa J, Mtambanengewe F, Pound B, Chikowo R, Naudin K, Triomphe B, Mkomwa S (2012) Agroecology-based aggradation-conservation agriculture (ABACO): Targeting innovations to combat soil degradation and food insecurity in semi-arid Africa. Field Crops Research 132: 168-174.

Tittonell P, Giller K (2013) When yield gaps are poverty traps. The paradigm of ecological intensification in African smallholder agriculture. Field Crops Research 143: 76-90.

Tscharntke T, Clough Y, Wanger T, Jackson L, Motzke I, Perfecto I, Vandermeer, J, Whitbread, A. (2012). Global food security, biodiversity conservation and the future of agricultural intensification. Biological Conservation 151: 53-59.

United Nations, Department of Economic and Social Affairs, Population Division (2014). World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352).

Vanlauwe B, Giller KE (2006) Popular myths around soil fertility management in sub-Saharan Africa. Agricultural Ecosystem and Environment 116: 34-46. 200

Vanlauwe B, Coyne D, Gockowski J, Hauser S, Huising J, Masso C, Nziguheba G, Schut H, Van Asten, P (2014) Sustainable intensification and the African smallholder farmer. Current Opinion in Environmental Sustainability 8: 15-22.

Vermeulen S, Challinor A, Thornton P, Campbell B, Eriyagama N, Vervoort J, Kinyangi J, Jarvis A, Laderach P, Ramirez-Villegas J, Nicklin K, Hawkins E, Smith D (2013). Addressing uncertainty in adaptation planning for agriculture. Proceedings of the National Academy of Sciences USA 110: 8357-8362.

Vose et al., (2011) Forest ecohydrological research in the 21st century: what are the critical needs? Ecohydrology 4: 146-158.

Waha K, Müller C, Bondeau A, Dietrich JP, Kurukulasuriya P, Heinke J, Lotze-Campen H (2013) Adaptation to climate change through the choice of cropping system and sowing date in sub-Saharan Africa. Global Environmental Change 23: 130-143.

Wasige, JE, Groen, TA, Smaling, E, Jetten, V (2013). Monitoring basin-scale land cover changes in Kagera Basin of Lake Victoria using ancillary data and remote sensing. International Journal of Applied Earth Observation and Geoinformation, 21: 32-42.

Wei X, Sun G, Vose J, Otsuki K, Zhang Z, Smetterm K (2011) Forest ecohydrological processes in a changing environment. Ecohydrology 4: 143-145.

Westengen O, Okongo M, Onek L, Berg T, Upadhyaya H, Birkeland S, Khalsa S, Ring K, Stenseth, N, Brysting, A (2014) Ethnolinguistic structuring of sorghum genetic diversity in Africa and the role of local seed systems. Proceedings of the National Academy of Sciences USA 111: 14100-14105.

Williams A, Funk C (2011) A westward extension of the warm pool leads to a westward extension of the Walker circulation, drying eastern Africa. Climate Dynamics 37: 2417-2435.

Williams A, Funk C, Michaelsen J, Rauscher S, Robertson I, Wils T, Koprowski M, Eshetu Z, Loader N (2012) Recent summer precipitation trends in the Greater Horn of Africa and the emerging role of Indian Ocean sea surface temperature. Climate Dynamics 39: 2307-2328.

Williamson D, Majule A, Delalande M, Mwakisunga B, Mathé PE, Gwambene B & Bergonzini L (2014) A potential feedback between landuse and climate in the Rungwe tropical highland stresses a critical environmental research challenge. Current Opinion in Environmental Sustainability 6: 116-122.

Woniala J, Nyombi K (2014) Soil fertility management by smallholder farmers and the impact on soil chemical properties in Sironko District, Uganda. Research Journal of Agriculture and Forestry Sciences 2: 5-10.

Wyckhuys K, Lu Y, Morales H, Vazquez L, Legaspi J, Eliopoulos P, Hernandez L (2013) Current status and potential of conservation biological control for agriculture in the developing world. Biological Control 65: 152-167.

Zhu Y, Chen H, Fan J, Wang Y, Li Y, Chen J, Fan J, Yang S, Hu L. Leung H, Mew TW, Teng PS, Wang Z, Mundt C (2000). Genetic diversity and disease control in rice. Nature 406: 718–722.

Zingore S, Delve R, Nyamangara J, Giller K (2007) Multiple benefits of manure: The key to maintenance of soil fertility and restoration of depleted sandy soils on African smallholder farms. Nutrient Cycling in Agroecosystems 80: 267-282.

Zingore S, Giller K (2012) Optimising phosphorous and manure application in maize-soybean rotations in Zimbabwe. Better Crops 96: 23-25.

Zingore S, Mutegi J, Agesa B, Tamene L, Kihara J. (2015). Soil degradation in sub-Saharan Africa and crop production options for soil rehabilitation. Better Crops with Plant Food 99: 24-26.

Zulu L, Richardson R (2013) Charcoal, livelihoods, and poverty reduction: Evidence from sub-Saharan Africa. Energy for Sustainable Development 17: 127-137.

GREENPEACE

RSA Office:
10A and 10B Clamart House, Clamart Road, Richmond, Johannesburg, South Africa

Postal address:
Greenpeace Africa, PostNet Suite 125, Private Bag X09 Melville, Johannesburg, 2109, South Africa

DRC Office:
Greenpeace Environmental Organisation N°11, Avenue Kauka/Quartier le Royal Commune de la Gombe, Kinshasa/RDC

Senegal Office:
2, Avenue Hassan II, 6eme etage, Dakar, Senegal

iafrica@greenpeace.org
www.greenpeaceafrica.org

Greenpeace exists because this fragile Earth deserves a voice. It needs solutions. It needs change. It needs action!

Greenpeace is an independent global campaigning organisation that acts to change attitudes and behaviour, to protect and conserve the environment and to promote peace. It comprises of 28 independent national/regional offices in over 40 countries across Europe, the Americas, Asia, the Pacific and Africa as well as a co-coordinating body, Greenpeace International.

Greenpeace has been working in Africa to end environmental destruction and fighting for the right of Africans to a healthy environment since the early 1990s. Our campaigns focus on climate change, halting the destruction of tropical forests, supporting ecological farming and preventing the degradation of marine ecosystems.