Agroforestry and Smallholder Farmers: Climate Change Adaptation through Sustainable Land Use

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Abstract: Agriculture in the developing world will be extremely hard hit by climate change, and smallholder farmers in Least Developed Countries (LDCs) are among the most vulnerable to its impacts. There is a range of agricultural adaptations to climate change, and each context demands a unique appraisal of impacts and adaptations based on specific geography, local climate variability and expected change, and social conditions. The term "climate-smart agriculture" (CSA) has come to embody a set of practices in crop and livestock cultivation that 1) reduce greenhouse gas emissions (climate change mitigation), 2) build resilience to the impacts of climate change for farmers (climate change adaptation), and 3) boost agricultural productivity and farmer incomes (advancing food security). Agroforestry, a form of CSA, is a promising adaptation option for smallholder farmers throughout the developing world. The diverse adaptive benefits of agroforestry have been captured in case examples and scientific studies in developing countries in Asia, Africa, and Central and South America. This paper examines the emphasis on climate change mitigation through agriculture, pointing out that this is only a small additional benefit of climate-smart practices; the climate crisis will not be solved without far broader mitigation efforts targeting fossil fuel combustion. Further, focusing conversations about agriculture on climate change mitigation can take necessary attention away from the critical need to build resilience for the developing world's vulnerable smallholder farmers via agroforestry and other types of CSA. Based on the benefits it provides, agroforestry offers an emerging opportunity for local, community-level adaptation to climate change. The "re-greening" movement in Africa's Sahel region illustrates this point. Further, agroforestry promotes sustainable natural resource management and builds upon existing knowledge. Traditional knowledge needs to be actively sought out, thoroughly assessed, and acted upon. Successful adaptation policies via agroforestry bring together traditional knowledge of agroecological systems with modern scientific analysis and understanding of agroforestry's potential in individual geographical settings. Finally, agroforestry is a case study in the potential for a balanced relationship between human beings and their natural surroundings; this principle will be critical to addressing the climate crisis in the long-term, and seeking a sustainable arrangement for the future of human life on earth.

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Introduction

The world's rapidly growing population currently depends on conventional forms of agriculture that are unsustainable. Petroleum-derived chemical fertilizers, pesticides and herbicides fuel conventional agricultural production, which involves an intensive use of the land that leads to soil degradation and erosion. With growing public awareness of the effects of global climate change, there is a movement to embrace agricultural alternatives that move away from fossil fuels and promote a more responsible, sustainable and resilient relationship with the land. Based on long-term projections about the impacts of climate change on agriculture, this movement is absolutely imperative. Though the developed world may be able to sustain itself for a time with conventional agriculture, much of the developing world—particularly its poor smallholder farmers—are already suffering the effects of climate variability. A bleak future defined by harsh realities of climate change awaits these farming families. Climate-smart agriculture (CSA) has emerged as a set of practices that aim to improve the future for all farmers. CSA focuses on food security and agricultural adaptation to climate change. It also focuses on mitigation of climate change through agricultural methods that reduce greenhouse gas emissions. Unfortunately, no amount of sustainable agriculture will come close to canceling out the vast amount of emissions from combusted fossil fuels. Thus, CSA should focus more on the benefits that it can deliver to the developing world's smallholder farmers, who are among the most vulnerable to the onset of climate change.

In this paper I argue that agroforestry merits special attention because of the diverse benefits it provides for smallholder farmers across the developing world. Farmers vulnerable to climate change who embrace agroforestry will improve their livelihoods. Government policies regarding property and land-use rights should be crafted to support these agricultural adaptations. Blending forestry and agriculture builds human resilience, biodiversity and whole ecosystems. Agroforestry unites humans more closely with nature and provides insights for a sustainable future.

Impacts of Global Climate Change on Agriculture

Climate change has dire implications for agricultural production, particularly in developing countries. While warmer temperatures may bring increased agricultural yields to areas that traditionally have a colder climate, areas that are traditionally warmer will see reduced agricultural yields as temperatures rise to unproductive levels. In addition to lower yields, areas facing warmer temperatures will see increases in insect outbreaks (i.e. pestilence), which, in the absence of pest-resistant crops will exacerbate those crop yield reductions. Heavy rainfall events will damage crops and cause erosion and soil waterlogging, rendering land difficult to cultivate. Areas newly affected by drought will see similar if not worse impacts to crops and soil, as well as increased livestock deaths. Stronger and more frequent tropical cyclones will damage crops and coastal land. Lastly, higher sea levels will lead to salinization of coastal freshwater supplies, contaminating water that would otherwise be used for irrigation (IPCC, 2007).

Climate Change and Smallholder Farmers in the Developing World

Recent climate change projections depict enormous challenges for the developing world's smallholder farmers. According to a recent report from the World Bank (2012), increases as small as 1 to 2 degrees Celsius in local temperatures at lower latitudes will cause decreases in crop productivity and greater challenges for food security for the seasonally dry and tropical regions of the world. Flooding and storm surges in these latitudes are likely to reduce the amount of arable land available to farmers. This geography fits the description of land that is home to much of the developing world's small-scale agricultural production. Further, the total area of global land affected by drought disasters is projected to increase from about 15% to about 45%. Climate change is likely to make water scarcer in regions where scarcity is already an issue, such as Northern and Eastern Africa, and South Asia, while the Sahel and Equatorial Africa will likely see water shortages resulting from the pressures population rise (World Bank, 2012).

These climatic impacts will be devastating in developing countries where large portions of the population rely on subsistence and small-scale agriculture for food security and livelihoods. For instance, higher air temperatures can lead to the more rapid decay of soil organic matter, which affects the overall health and fertility of soils. In drier climates the depletion of soils leaves farmland more vulnerable to wind erosion, while in other areas extreme rain events can also cause degraded soil to erode. Warmer temperatures can also enable more active insect reproductive cycles, which could increase the occurrence of pestilence. A number of plant diseases are also likely to proliferate in warmer climates (Altieri & Koohafkan, 2008). Because smallholder farmers in developing countries rely on the health and productivity of agriculture to secure their nutrition and bolster their livelihoods, climate variability and overall changes in climate regimes are likely to send shockwaves through these types of social-agricultural contexts. Rural farmers throughout the developing world will have to increase their resilience to climatic shocks by adapting their agricultural methods to the new and projected climatic conditions.

Agricultural Adaptations for Smallholder Farmers

There are many ways in which smallholder farmers in the developing world can reduce their vulnerability to climate variability and change, the broadest of which is to improve the overall strength of their farms and households. As described by Thorlaksen (2011), this can more specifically include:

- Diversifying and expanding crop varieties;
- Increasing off-farm income opportunities;
- Improving access to markets;
- Accessing improved agricultural training;
- Improved modes of transport for agricultural products;
- Improved communication systems and community organizing;
- Access to better forecasting of weather events and drought patterns;
- Improved water storage facilities;
- Short-term migration; and,
- Planting of trees to improve vegetation cover and water filtration of soils, reduce soil erosion and runoff, and improve soil water retention (i.e. agroforestry).

The methods of adaptation on this list range from complex and reliant on outside sources of funding or support, to relatively simple and easy to implement at the farm level with limited financial or institutional support. The more complex adaptations, such as improving access to markets, may be difficult to pursue for a poor, rural farmer due to institutional, financial, legal or other barriers. According to Thorlaksen:

"The barriers to the adoption of these adaptation measures include poverty, lack of access to credit and lack of information. Studies have proven that farmers with more agricultural knowledge and skills, better access to credit, more secure property rights, higher levels of wealth, access to off-farm employment and higher educational levels are more likely to invest in adaptation measures" (2011, p. 21).

But what about farmers who remain poor and uneducated, with little or no access to credit, and may not have sufficiently secure property rights? These are the farmers who are the most vulnerable to the impacts of climate change, and who nevertheless need to seek ways to adapt to new challenges brought by increasing rainfall variability, warmer temperatures and longer droughts. For these farmers to adapt to climate change in a timely manner and within their own means—that is, not relying on outside institutional or financial support—they will have to look at the options that are most readily available to them such as diversified crop varieties and agroforestry.

Access to information about climate-smart farming techniques and weather patterns is also critical for poor farmers adapting to climate change. In theory information does not cost anything. However, someone needs to transfer the information, and it needs to be available in the appropriate language; farmers who are illiterate will require more attention in information transfers.

But in some cases traditional knowledge already comprises sustainable agricultural techniques such as agroforestry that can build resilience to climatological impacts. These traditional forms of agricultural resilience and adaptation can be shared and built upon at the community level, requiring minimal outside investment or involvement. The following section will discuss the concept of traditional adaptive knowledge in greater detail.

Finally, secure property rights—also known as tenure—are one of the greatest catalysts to resilient and sustainable cultivation of the land. On the other hand, a lack of property rights can be the greatest hindrance to adaptive agricultural practices. The relationship between tenure, agroforestry and adaptation will be discussed in greater detail later in this paper.

"Climate-Smart Agriculture" and Agroforestry

In 2009, the Food and Agriculture Organization of the United Nations coined a new term, "climate-smart agriculture" (CSA). CSA is not a specific tool or technology, but an approach to improving the productivity and sustainability of agriculture under climate change, for the purposes of advancing food security and strengthening the resilience of rural livelihoods (FAO, 2013b). Climate-smart agriculture "integrates the three dimensions of sustainable development (economic, social and environmental) by jointly addressing food security and climate challenges. It is composed of three main pillars:

1. sustainably increasing agricultural productivity and incomes;
2. adapting and building resilience to climate change;
3. reducing and/or removing greenhouse gases emissions, where possible" (FAO, 2013b, p. ix).

CSA is a donor term that covers a wide range of practices, from fisheries and aquaculture to urban farming, efficient livestock production, conservation agriculture, and most importantly agroforestry. Because of its inclusive nature and "smart" sounding name, other donor agencies and international actors have adopted CSA as an approach to agriculture under climate change. Yet some development practitioners might suggest that CSA is a glorified term that takes attention away from some of its more important components. Some would argue that, because of its high potential for building resilience to climate change, sequestering carbon dioxide, and strengthening rural farmer incomes and livelihoods, agroforestry is the most promising component of CSA. Subsequent sections of this paper will discuss the benefits of agroforestry as they concern climate change mitigation and adaptation, food security and livelihoods. But first it is important to describe what exactly agroforestry is, and its presence in the world.

An Introduction to Agroforestry

Agroforestry is a practice that has been used throughout the world for many years. It is particularly prevalent in Central and South America and Asia, however many countries in Sub-Saharan Africa have seen the local adoption of agroforestry systems as well. According to Branca et al (2011):

"Agroforestry refers to land use practices in which woody perennials are deliberately integrated with agricultural crops, varying from simple and sparse to very complex and dense systems. It embraces a wide range of practices (e.g. farming with trees on contours, intercropping, multiple cropping, bush and tree fallows, established shelter belts and riparian zones/buffer strips with woody species, etc.) which can improve land productivity providing a favorable micro-climate permanent cover, improved soil structure and organic carbon content, increased infiltration and soil fertility reducing the need for mineral fertilizers" (p. 15).

And according to the World Agroforestry Center:

"Trees play a crucial role in almost all terrestrial ecosystems and provide a range of products and services to rural and urban people. As natural vegetation is cleared for agriculture and other types of development, the benefits that trees provide are best sustained by integrating trees into agriculturally productive landscapes — a practice known as agroforestry. Farmers have practiced agroforestry for years. Agroforestry focuses on the wide range of working trees grown on farms and in rural landscapes. Among these are fertilizer trees for land regeneration, soil health and food security; fruit trees for nutrition; fodder trees that improve smallholder livestock production; timber and fuelwood trees for shelter and energy; medicinal trees to combat disease; and trees that produce gums, resins or latex products. Many of these trees are multipurpose, providing a range of benefits.

Agroforestry provides many livelihood and environmental benefits, including:

- Enriching the asset base of poor households with farm-grown trees.
- Enhancing soil fertility and livestock productivity on farms.
- Linking poor households to markets for high-value fruits, oils, cash crops and medicines.
- Balancing improved productivity with the sustainable management of natural resources.
- Maintaining or enhancing the supply of environmental services in agricultural landscapes for water, soil health, carbon sequestration and biodiversity" (2013, p. 1).

The fundamental idea behind the practice of agroforestry is that trees are an essential part of natural ecosystems, and that their presence in agricultural systems provides a range of benefits to the soil, other plant species and overall biodiversity. They also deliver co-benefits to farmers in the forms of wood, fruits and medicinal products, and build farmers' resilience to climatic conditions such as droughts and severe storms. It is for this variety of benefits that farmers have practiced agroforestry for many years at the local level. With the threats that smallholder farmers in the developing world face with ensuing climate variability and change, agroforestry is now being seen in the lens of reducing vulnerability and adapting to the conditions of a warmer, drier, more unpredictable climate. Because of trees' natural ability to sequester carbon from the atmosphere, agroforestry is also being seen as a tool for mitigating climate change through reducing the overall volume of greenhouse gasses that are causing the planet to heat up.

A recent analysis of satellite data capturing global agricultural land and tree cover density found that agroforestry is present in one form or another on 46% of agricultural land around the world. Agroforestry affects 30% of rural populations worldwide (over half a billion people). This data found that agroforestry is particularly common in Central and South America, and Asia (Zomer et al, 2009). The authors of this analysis are keen to point out that,

"Large-scale tree cover patterns cannot be fully explained by aridity, population density or region. This points towards the importance of other factors like tenure, markets, or other policies and institutions in affecting incentives for tree planting and management, as well as the historical trajectory that has lead to the current pattern" (Zomer et al, 2009, p. 47).

This paper will return to the issue of land tenure later on, making the argument that tenure (i.e. property rights) and fair government policies regarding individual use of natural resources such as trees are critical for smallholder farmers to control the destiny of their land, crops and trees, and adapt to short- and long-term climate variability and change.

Agroforestry and Climate Change Mitigation

Despite the fact that agroforestry has been practiced by farmers for many years as a way of improving production, efficiency and resilience to climate variability, the practice of agroforestry has more recently been incorporated into the debate about how to address the problem of greenhouse gas emissions and global warming.

A basic principle is the fact that trees absorb carbon dioxide (CO_2) from the atmosphere as part of the natural carbon cycle (see Annex 2). This of course helps to reduce the overall levels of carbon dioxide in the atmosphere, and thus trees play a role in regulating global warming. However, since Charles David Keeling began monitoring levels of atmospheric carbon in the atmosphere in 1958 from Mauna Loa, Hawaii, the annual concentration has risen each year. Examining a historical analysis of ice-core data, one can see that the steady increase in atmospheric carbon began during the industrial revolution and has increased much more rapidly beginning in the second half of the twentieth century (see Annex 1). Each year on the Keeling Curve shows a zigzag pattern because in the spring and summer in the northern hemisphere (where most of the world's seasonal vegetation exists and where the measurements are taken), trees are actively sucking carbon out of the air. In the fall and winter vegetation dies off and decays, causing the uptick in atmospheric carbon (Climate Central, 2013). Simply speaking, the world's trees and plants inhale carbon in the warm months and exhale carbon in the cold months. This points to a central component of the carbon cycle, or the exchange of carbon between vegetation, soil, oceans, humans and animals, and the atmosphere. According to the National Oceanic and Atmospheric Administration (NOAA),

> "Carbon is exchanged, or 'cycled' among Earth's oceans, atmosphere, ecosystem, and geosphere. All living organisms are built of carbon compounds. It is the fundamental building block of life and an important component of many chemical processes. It is present in the atmosphere primarily as carbon dioxide (CO_2), but also as other less abundant but climatically significant gases, such as methane (CH_4).

Because life processes are fueled by carbon compounds which are oxidized to CO_2, the latter is exhaled by all animals and plants. Conversely, CO_2 is assimilated by plants during photosynthesis to build new carbon compounds. CO_2 is produced by the burning of fossil fuels, which derive from the preserved products of ancient photosynthesis. The atmosphere exchanges CO_2 continuously with the oceans. Regions or processes that predominately produce CO_2 are called sources of atmospheric CO_2, while those that absorb CO_2 are called sinks (NOAA, 2013, p. 1).

The idea of *sources* and *sinks* is crucial to understanding how agroforestry can contribute to climate change mitigation; forests and trees act as sinks for atmospheric CO_2, so if we encourage the planting of trees on land that otherwise would not have them, we are helping to mitigate climate change. The process of measuring the amount of carbon sequestered from the atmosphere by agroforestry—and forestry in general for that matter—is complicated. This is because there are many different types of trees, differing forest densities, and varying agroforestry methods that can sequester different volumes of carbon in a given season. Geographic factors such as elevation also affect just how much carbon a plot of forested land will sequester from the atmosphere. But as one researcher has argued, despite the complexity of these measurements and the need for much more research to attain a clearer understanding of how much carbon can be sequestered, climate change mitigation is a "low hanging fruit" of agroforestry (Nair, 2012).

This brings up the broader concept of aiming to mitigate climate change through forest systems, embodied in a United Nations program called Reducing Emissions from Deforestation and Forest Degradation (REDD). REDD is,

"an effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development. 'REDD+' goes beyond deforestation and forest degradation, and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks" (UN-REDD Programme, 2013).

Recognizing that emissions from forest-related land use (or rather, the emissions that would not otherwise occur if forests were left unaltered) are a critical part of the overall carbon budget in our atmosphere is central to the concept of REDD. But some might also suggest that focusing on "forest emissions" is a distraction from the more significant problem of fossil fuels emissions. Some would say that putting too much promise in reducing forest emissions might give the false impression that the climate crisis can be solved by trees alone. In its 2007 report, the IPCC stated that 57% of greenhouse gasses in the atmosphere are carbon dioxide created by burning fossil fuels, whereas only 17% are carbon dioxide from deforestation, decaying biomass, and related sources (IPCC, 2007). The IPCC is due to release a comprehensive new report in 2014, but in the meantime there have been new estimates that revised down the level of atmospheric carbon resulting from deforestation. According to a 2011 report, somewhere between 52-65% of greenhouse gasses are carbon from fossil fuels, and as little as 12% (or as much as 25%) resulting from deforestation (Hilderman, 2011). It is clear from these numbers that all of the potential carbon storage and sequestration that could be achieved through sustainable forest management would not come close to balancing out the huge majority of greenhouse gasses that are a result of human combustion of fossil fuels.

Further, there is a degree of uncertainty about the carbon that is sequestered and stored by trees. Just because a tree is planted does not mean that a storm or a lightning bolt won't knock it down and reverse its mitigating effects. In theory, a whole forest that has been planted through a REDD+ scheme could go up in smoke in a wildfire, wiping out the carbon storage that it would have achieved. As an expert from the Center for International Forestry Research puts it, "Carbon storage is actually very easily reversible; it's difficult to store carbon long-term" (personal communication, August 1, 2013).

This uncertainty does not mean that initiatives like REDD+ are in vain, but it does mean that mitigating climate change requires a comprehensive approach that focuses first and foremost on emissions from fossil fuels.

In fact, of all agricultural land use methods, agroforestry offers the greatest potential for carbon sequestration (Verchot et al, 2007). And in addition to the ability of trees on farms to take greenhouse gasses out of the atmosphere, the use of land under agroforestry practices creates significantly less of its own greenhouse gasses than do other modes of agricultural intensification (Altieri & Koohafkan, 2008).

While policymakers and international climate negotiations focus on the role trees and agricultural systems can play in mitigating climate change, it may be difficult to translate the importance of these concepts to world's most vulnerable people, many of whom are smallholder farmers in LDCs. The climate crisis is already impacting them; they urgently need to find ways of coping with more extreme climate variability in the short-term and new climate regimes in the long-term. As Campbell (2009) aptly puts it, "mitigation initiatives are unlikely to provide a major pathway out of poverty for tens of millions of rural dwellers. Much more important for smallholders will be their ability to adapt to climate change" (p. 2).

Agroforestry and Climate Change Adaptation

Recent literature has taken the view that agroforestry can serve a role both in mitigating climate change and helping farmers adapt to the effects of climate change. The potential for building resilience and adapting to climate change through agroforestry is particularly promising for smallholder farmers in the developing world who are most vulnerable to its effects. Verchot et al (2007) describe four reasons why agroforestry can provide resilience for smallholder farmers:

"The most worrisome component of climate change from the point of view of smallholder farmers is increased interannual variability in rainfall and temperature. Tree-based systems have some obvious advantages for maintaining production during wetter and drier years. **First**, their deep root systems are able to explore a larger soil volume for water and nutrients, which will help during droughts. **Second**, increased soil porosity, reduced runoff and increased soil cover lead to increased water infiltration and retention in the soil profile which can reduce moisture stress during low rainfall years. **Third**, tree-based systems have higher evapotranspiration rates than row crops or pastures and can thus maintain aerated soil conditions by pumping excess water out of the soil profile more rapidly than other production systems. **Finally**, tree-based production systems often produce crops of higher value than row crops. Thus, diversifying the production system to include a significant tree component may buffer against income risks associated with climatic variability" (p. 13).[1]

But this description does not capture all of the adaptive benefits of agroforestry systems.

According to the World Agroforestry Center,

"Agroforestry – the incorporation of trees into farming systems – has enormous potential to mitigate the effects of drought, prevent desertification and restore degraded soils. Agroforestry can also help to boost food production (for humans as well as animals) and provide alternative sources of nutrition or income when crop yields are low. With climate change expected to lead to unpredictable seasons in the future, placing even greater pressure on agricultural systems, food production and food prices, agroforestry is a viable option to help buffer farmers against the impacts" (2012, p. 1).

[1] Bolding of words by me for added emphasis

Agroforestry systems also create greater biodiversity, attracting birds, insects and other organisms that interact with the immediate landscape surrounding the trees and enable more dynamic ecosystems. Nitrogen-fixing trees that are used in agroforestry systems improve soil fertility and reduce the need for chemical or mineral fertilizers, which is particularly important for farmers who may not be able to afford them (weADAPT, 2012). So it seems that, especially for the people who are most vulnerable, agroforestry holds enormous potential for climate change adaptation. Many forms of adaptation require outside assistance, be it financial assistance such as credit or institutional/state assistance such as infrastructure and service delivery. These forms of adaptation are excellent in theory, but all too often they are not extended to the poorest of the poor—the most vulnerable to the effects of climate change. This is why relatively simple, local-level adaptations like agroforestry hold so much promise. In theory planting trees requires little in resources, but delivers immense returns in both products and system resilience.

Because agroforestry holds so much promise as a tool for building the resilience of smallholder farmers in the developing world, and because of the difficulties involved with efforts at mitigating climate change through forestry, agroforestry has been called a "no regrets" option for climate change adaptation (Finlayson, 2013; Rao et al, 2007). Agroforestry is an intervention that has attractive benefits for the implementer, and potential benefits for the planet as a whole. So even if those global benefits don't work out (i.e. if agroforestry as mitigation fails), then the farmer who planted trees on his farm will not regret having done so because he will have already benefitted in more immediate ways. Because of this reasoning some argue to push agroforestry first as an adaptation; climate change mitigation through agroforestry could be seen as an added benefit. According to a recent article published by the World Agroforestry Center,

"It seems people are more likely to protect their own backyards than the whole planet and consider this a 'no regrets' strategy. This approach can help us in our work to promote agroforestry—since the tree-based systems we know and love can be an effective way of adapting to the impact of a changing climate while also helping to mitigate the changes ... The point is, we have to sell agroforestry as adaptation first; mitigation is a bonus" (Finlayson, 2013, p. 1).

Rao et al (2007) frame the discussion about no-regrets adaptation via agroforestry in academic terms, speaking to a comprehensive set of benefits:

"Agroforestry interventions, because of their ability to provide economic and environmental benefits, are considered to be the best 'no regrets' measures in making communities adapt and become resilient to the impacts of climate change. The important elements of agroforestry systems that can play a significant role in the adaptation to climate change include changes in the microclimate, protection through provision of permanent cover, opportunities for diversification of the agricultural systems, improving efficiency of use of soil, water and climatic resources, contribution to soil fertility improvement, reducing carbon emissions and increasing sequestration, and promoting gender equity" (p. 1).

Finally, in addition to being a no-regrets adaptation agroforestry is typically an inexpensive intervention. According to Chris Reij of the World Resources Institute, an expert on climate-smart agriculture in Africa, agroforestry is the least expensive way for farmers to adapt to climate change (WRI, 2012).

Resilience via Agroforestry: Around the Globe

Agroforestry is practiced around the world. While it is particularly prevalent in Central America, South America and Asia, it is now being practiced in African countries as well. As our understanding of the climate crisis has become clearer and the reality of the impacts of climate change—both current and future—has become more acute, there has been a growing focus on the use of agroforestry as a tool for building resilience and adapting to climate variability and change. This section of the paper will briefly highlight cases in Latin America, Asia and Africa in which agroforestry has proven effective in the context of climate change adaptation.

Africa

Verchot et al (2007) discuss the role that agroforestry plays in climate change adaptation in much of East and Southern Africa. Specifically they describe an improved fallow system that boosts maize yields by enhancing the fertility and water retention of degraded soils. They use models to predict that this improved agroforestry system may create resilience for farmers by maintaining those maize yields in dry years when ordinary maize cultivation would suffer.

Thorlaksen (2011) describes field research conducted in the Nyando District of Nyanza Province, in Western Kenya, that examines the use of agroforestry as a method of building resilience against climate-related shocks such as floods, drought and variability in rainfall. His study examines farmers practicing agroforestry compared with a nearby control group, and concludes that agroforestry creates more resilience to climate-related shocks.

Bishaw et al (2013) closely examine agroforestry's important role in adaptation to climate change in both Kenya and Ethiopia.

Perhaps most promising of all for Africa is the identification of a very unique tree called *Faidherbia albida:*

"*Faidherbia albida*, an indigenous acacia-like tree, is proving to be a successful agroforestry tree for Africa. It is widespread throughout the continent, thriving on a range of soils and occurring in ecosystems from deserts to wet tropical climates. The tree has not been shown to turn invasive and does not compete with other species. *Faidherbia* is a fertilizer tree which captures atmospheric nitrogen and makes it available to plants through the soil. What makes *Faidherbia* so special is its 'reversed leaf phenology' meaning it is dormant and sheds its leaves during the early rainy season and its leaves only regrow when the dry season begins. This feature makes it compatible with food crops because it does not compete with them for light, nutrients and water. The nutritive leaves can be used as fodder or as mulch. Farmers have frequently reported significant crop yield increases for maize, sorghum, millet, cotton and groundnut when grown in proximity to *Faidherbia*. *Faidherbia* can report 6% to more than 100% yield increases based on a review of published literature" (World Agroforestry Centre, 2009, p. 4).

This paper will return to the topic of *Faidherbia albida* later on in the section on re-greening the Sahel.

Latin America

Jost and Pretzsch (2012) describe the Achamaya river basin in Peru's central highlands, a region where traditional agriculture is prominent and midsummer droughts ("veranillos") have a significant effect on the lives of smallholder farmers. Disaster reduction and adaptation strategies include the planting of trees in agricultural systems in order to reduce the vulnerability of the systems to seasonal drought.

In Northern Peru, agroforestry has been identified as a tool for building the resilience of coffee production zones (Locatelli et al, 2011).

Altieri and Koohafkan (2008) find agroforestry used to reduce variability of microclimate and soil moisture in coffee agroecosystems in Chiapas, Mexico. They also find trees used to provide shade for cattle, as well as rice, maize, plantains and other crops in the dry climate of northeast Brazil, offering similar benefits and in particular, reducing soil moisture loss.

Finally, Oelbermann and Smith (n.d.) closely examine agroforestry's use for climate change adaptation in Costa Rica as part of a Payment for Ecosystems Services (PES) scheme through a Global Environment Facility (GEF) funded study.

Asia

Neyra-Cabatac et al (2012) describe a swidden system (a traditional form of slash-and-burn and a form of agroforestry) used by the indigenous Erumanen ne Menuvu group in the Philippines. The indigenous practice is altered to adjust to changing socio-economic conditions, as well as environmental conditions such as climate variability.

In Vietnam, one of the countries most vulnerable to the impacts of climate change, a recent study showed that tree-based agricultural systems were significantly less vulnerable to extreme drought and flooding than were treeless rice cultivation systems and rain-fed crops, which saw yield losses of more than 40% during years characterized by those events (Nguyen et al, 2013).

The Value of Property Rights and Land Use Policies

As shown in the previous section, there is evidence that agroforestry is practiced around the world as a sustainable mode of land use that enhances the livelihoods of smallholder farmers and advances resilience and adaptation to the impacts of climate change. Further, agroforestry's ability to mitigate the causes of climate change through the sequestration and storage of carbon is significantly stronger than other forms of agricultural land use, making agroforestry a particularly promising form of climate-smart agriculture. For all of these reasons one could say that climate-smart agriculture, and agroforestry in particular, is sustainable development in action. Yet many smallholder farmers in the developing world still practice forms of agriculture that are vulnerable to drought and other climatological impacts, and which seem to be unsustainable in the face of inevitable climate variability and change caused by anthropogenic global warming. If agroforestry and other forms of climate-smart agriculture hold so much promise for a resilient future, why are smallholder farmers everywhere not already taking advantage of the benefits? There are a number of reasons, including unequal distribution of knowledge and institutional support for CSA practices, state policies and funding that favor large-scale conventional agriculture or other unsustainable practices, and the problem of insecure property rights (tenure).

Agroforestry is practiced around the world in different capacities. Some forms are indigenous in nature and rely on traditional, local knowledge. Other forms of agroforestry are not necessarily native to a region but are promoted through institutional funding and support. This paper argues not that agroforestry is a silver bullet for climate change, but that it is a highly effective tool in the climate-smart agriculture toolbox that should be promoted and supported for smallholder farmers around the developing world. Because the African continent is particularly vulnerable to the impacts of climate change, and because smallholder farmers make up such a large portion of Africa's poor, it would appear that agroforestry holds a great degree of promise in the African context. This section of the paper will explain that, while multiple challenges exist, insecure land tenure and adverse government land use policies represent a defining challenge and a major barrier for African smallholder farmers' ability to adapt to the effects of climate change using sustainable agricultural practices such as agroforestry.

Land Tenure in Africa

The history of property rights in Africa goes back to the "Scramble for Africa" in the late-nineteenth century, when the colonial powers of Europe divided up the continent and dictated jurisdiction over the land. Property rights for indigenous farmers were insecure throughout much of the continent. When the continent was decolonized in the second have of the twentieth century, new sovereign governments inherited the legal systems that had been set up under colonial rule but began to reform and extend property rights to individual landowners. This extension often ignored customary, local understandings of ownership and access to property, causing conflicts between larger landholders and smallholders. Governments continue to reform their property laws, and to this day issues with tenure security remain in many African countries. The issue of tenure in Africa is complex, with varying conditions and states of legal reform from country to country. A common theme, however, is that insecure tenure rights have been harmful for smallholder farmers throughout much of the continent. In the context of climate change, with millions of African farmers who need to adapt to current variability and future shifts, tenure has become an even more defining issue in the struggle of the smallholder. Agroforestry requires changes in the approach to land management and farmers' rights to the use of the land and the resources that come with it. According Peter Veit, to an expert on tenure and Africa at the World Resources Institute,

"In most countries in Africa the right to the land is limited to the top ten inches of the soil, with no rights to resources above or below. Rights are acquired separately and distinctly for other resources including trees and wildlife. When those rights are passed on and a community has the capacity to use those rights, it usually means that natural resources will be better managed. Lots of long-term research shows that when the laws are reformed and communities have rights to trees, agriculture benefits in large measure because of the regeneration and re-greening of land through agroforestry and other investments" (personal correspondence, August 1, 2013).

So this means that when it comes to adopting and sustaining agroforestry systems, secure rights to the land are of central importance. According to the FAO (2013a),

"More than in other agricultural systems, trees on farms require stability and security of tenure rights. This is a significant issue in many developing countries. Due to the longer period relative to annual crops – through which farmers' testing, adaptation and eventual adoption of agroforestry technologies takes place – the importance of property rights is greater than in many other types of agricultural enterprises and practices. A clear guarantee of tenure rights can support a farmer's strategy to invest in trees on farms, including in cropland. Only then can farmers – as investors – make plans with the confidence that the parameters shaping their long-term vision will not change. There are few agroforestry success stories in an uncertain land tenure context" (p. 17).

But because of the history of land rights in Africa, there have been many cases in which smallholder farmers' planting and sustainable management of trees has been constrained or threatened because of insufficient or insecure tenure. In Cameroon in 1974, the government issued a land law that gave citizens the right to land ownership, but the certification process proved to be too complicated for much of the rural population and thus their land rights remained insecure (FAO, 2013a). Neef and Heidhues (1994) examine a case study in Benin where a lack of land resources, insecure land tenure, and restrictions on the planting of certain perennials kept farmers and pastoralists from adopting agroforestry systems. A natural resources and land tenure expert who was recently examining climate change vulnerability in Malawi observed widespread use of agroforestry by smallholder farmers, but simultaneously saw government policies that prioritized chemical fertilizers and firewood cultivation while turning a blind eye to the practice of agroforestry. The use of agroforestry by the farmers he engaged with is at risk because of a lack of good government policy concerning property rights (personal communication, August 2, 2013).

These cases bring up multiple factors that play into the lack of adoption: First, a farmer needs a sufficient area of land in order to even consider adopting agroforestry. Second, if a farmer has a sufficient area of land for agriculture but has insecure or indefinite rights to the use of the land, there is a lack of incentive for investing money, time and energy into vetting and planting tree species and managing the land sustainably; if short-term crop yields can be cultivated through cheaper and less sustainable forms of land management, this is a shortcut that may be appealing in the face of insecure tenure. A simplified analogy is the homeowner vs. the home renter. A renter is far less likely than an owner to invest in a repair or an upgrade to his or her home. Third, if insecure tenure also comes along with restrictions on the type of trees or crops than can be planted, this can hinder the adoption of an agroforestry system. These cases also show that smallholder farmers may, such as in the Malawi example, adopt agroforestry despite the unfavorable government policies regarding land use and tree cultivation. While these farmers may see positive results in the short-term through their independent adoption of agroforestry, they are vulnerable to uncontrollable political and institutional influences that may threaten the very existence of their sustainable practices, and thus their livelihoods.

Re-Greening the Sahel

Yet there are stories of relative success for sustainable adoption of agroforestry in Africa. In Mali, farmers have planted trees on roughly 500,000 hectares of marginal land in recent years, a programmatic effort called farmer-managed natural regeneration, or "re-greening". This effort has been pursued specifically to boost agricultural productivity for rural smallholder farmers, increase food security for the region, and enable adaptation to climate change. There have been similar initiatives in Senegal and Burkina Faso. In all three countries, challenges and setbacks to re-greening have been in large part attributed to unfavorable government policies, insecure tenure and land grabs (personal communication, August 2, 2013). The World Resources Institute, which has been a key player in the Sahel re-greening initiative, has advocated strongly for re-greening the Sahel via agroforestry to achieve resilience, food security and adaptation to climate change (2012).

The greatest re-greening success story in the Sahel has been in Niger, where over five million hectares of trees have been planted on previously degraded farmland at the edge of the Sahara over the past two decades. Funding for the initiative came from the International Fund for Agricultural Development (IFAD). One of the main "drivers of change" behind this landscape transformation has been ownership of farmland trees transferring from the government to farmers—in 2004 a new forest code was adopted which recognized landowners as the rightful owners of trees on farmland (not the state) (World Agroforestry Center, 2013b). In the areas of Niger under farmer-managed natural regeneration, yields of key crops such as millet have increased significantly (World Agroforestry Center, 2013b). In a region that has historically been prone to drought and famine, this practice is making an enormous impact for smallholder farmers. This success strikes a stark contrast with an earlier large-scale tree-planting program that the government had funded in order to combat desertification and drought exacerbated by an over-cultivation of trees for firewood in the 1960's and 1970's:

"It is estimated that some 60 million trees were planted over a 12-year period, but less than 20% survived. There are various reasons why these forestry schemes failed. For one thing, the rights to the trees were often ill-defined. For another, little effort was made to involve local communities in either the planting or the maintenance of the new forests. There was also a strong focus on planting exotic rather than native species" (World Agroforestry Center, 2013b, p. 8).

From the earlier re-greening failure in Niger one can deduce that proper ownership of natural resources such as trees can enable the sustainable management of those resources. There is also a lesson to be learned from this anecdote regarding local, traditional knowledge. Consulting local people about methods of planting and the types of trees to be selected could have improved the government's previous attempt at re-greening, but even with local knowledge it is unclear that more trees would have survived without proper individual ownership rights.

Finally, the success of Niger's re-greening initiative over the past two decades brings the focus back to the more specific idea of the inherent effectiveness and sustainability of certain agroforestry practices. *Faidherbia albida*, described earlier, has been at the heart of the re-greening push in Niger. The tree's natural nitrogen-fixing ability significantly improves soil fertility and reduces or even eliminates the need for artificial fertilizers. And it's not only the soil immediately around the trees that becomes more fertile—the leaves of the *Faidherbia* are taken by the wind to settle and boost the fertility of neighboring plots of soil as well. In addition to improved soil fertility and crop yields, *Faidherbia* is pruned by farmers for wood fuel and, from more mature trees, for wood to sell (World Agroforestry Center, 2013b).

In the case of Niger's re-greening, extending secure rights to smallholder farmers and promoting climate-smart agroforestry has led to wide-scale adoption of sustainable land management practices that build the resilience to climate-related shocks such as drought. However, this case illustrates a snapshot of success in a region that is chronically prone to climatological shocks. Countries in the Sahel will face greater challenges as their populations grow rapidly, and as the onslaught of climate change creates even greater challenges for their most vulnerable inhabitants.

Since population growth and climate change are two long-term, defining challenges for the developing world that show no signs of decelerating, the attention then turns to what can be done in the short-term. Climate-smart agricultural practices such as agroforestry can help address these challenges in the short-term, and quite possibly in the long-term as well. But as shown in the case of Africa, state policies such as insecure tenure are still obstacles to the wide-scale adoption of agroforestry by smallholders. So what should be done across developing countries in regards to land tenure and agroforestry? According to the FAO,

"Tree protection policies dating from the colonial era in many developing countries, and land and tree tenure policies and traditions that prohibit cutting and transporting of trees and tree products, have to be removed or revised. They significantly inhibit the development of tree-product markets and farmer interest in growing trees. Where forest regulations affect tree management, regardless of location, simple systems should be designed for the registration of tree farmers, who could then be freed from costly permit procedures and constraints regarding the use of their trees" (FAO, 2013a, p. 22).

The Organization also states that,

Additional measures linking agroforestry development with landscape planning and village land-use management can help. Depending on the social and ecological contexts, community-based land management may be promoted under detailed rules accepted by all stakeholders. Whichever tenure system is adopted, it must be clearly stated and must pave the way towards sustainable rural practices (FAO, 2013a, p. 23).

The reality of the climate crisis is that it is far-reaching and all-inclusive. Human civilization is already feeling its affects, and we are a very long way from figuring out how to fully adapt to the challenges that lie ahead. The poor, rural inhabitants of LDCs are the most vulnerable to the impacts of climate change, and they cannot count on the rest of the world to protect them against warmer temperatures, longer droughts and more intense floods. Although smallholders in the developing world may be on their own in many ways, the adoption of more just state policies concerning individual rights to land and resources can help them build their own resilience to climate variability in the short-term, and to long-term change.

Indigenous and Traditional Knowledge of Forests and Agriculture

Finally, a theme that has been touched on but not yet fleshed out in this paper is the idea of traditional adaptive knowledge. One of the strategies that development donors cite their lists of "best practices" is seeking out indigenous and traditional adaptive knowledge, particularly in the context of agriculture and natural resource management. Scientific modeling and projections about the impacts of climate change provide key insights about what a warmer world will look like, and how different regions, sectors, and communities must plan to adapt. Supporters of smallholder agriculture in the developing world will inevitably utilize modern science to deliver critical knowledge to farmers about projected climatological impacts and necessary resilience-building measures. However, there is much to be said about existing practices that are indigenous and traditional in nature, and developed from the ground up by agricultural communities over time. Some of these methods may have been used for many years to adapt agricultural systems to local climate variability, even before long-term climate change was a topic of discussion. This concept is of particular relevance at the intersection between forestry and agriculture. As Parrotta and Agnoletti (2012) explain,

> "The holders and users of traditional forest-related knowledge are on the front lines of global efforts to deal with climate change and its impacts. Because of their close connection with, and high dependence on, forest ecosystems and landscapes, indigenous and local communities are among the first to witness, understand, and experience the impacts of climate change on forests and woodlands as well as on their livelihoods and cultures. The history of forest and agricultural landscape management practices of indigenous and local communities based on their traditional knowledge offer insights into principles and approaches that may be effective in coping with, and adapting to, climate change in the years ahead. Global, regional, national and local efforts to mitigate and adapt to climate change, however, have not yet given adequate attention either to the forest-related knowledge and practices of traditional communities, or to the interests, needs and rights of local and indigenous communities in the formulation of policies and programmes to combat climate change. Due consideration of, and a more prominent role for, traditional forest-related knowledge and its practitioners could lead to the development of more effective and equitable approaches

for facing the challenges posed by climate change while enhancing prospects for sustainable management of forest resources" (p. 491).

The importance of connecting with those who are closest with the land when addressing land use in general—especially now in the context of climate change—cannot be understated. This point brings the concept of agroforestry back to its traditional roots, and reminds us that at the heart of agroforestry is the close relationship between the forest and humans. It was traditional knowledge and regard for forest ecosystems that enabled the joint practice of forestry and agriculture long before agroforestry could be touted by donors and institutions as a tool for addressing the effects of climate change. Because of the traditional and indigenous nature of agroforestry in the context of humans' relationship with the land and its resources, this level of knowledge should remain at the center of agroforestry practices in today's scientific discussion. A more targeted view on agroforestry research points out that,

"Most analyses on agroforestry techniques use field experiments led by researchers to assess the effects trees have on improving farm productivity. Relatively few studies analyze farmer-led projects. Farmer-led agroforestry projects are initiatives that allow farmers to choose the type of agroforestry techniques they prefer and put the responsibility of tree seedling survival in the their hands. Farmer-led projects are how agroforestry techniques are used under normal circumstances; therefore there is need for more extensive analyses of these types of projects. At the same time, scholarship on vulnerability is seeking better interdisciplinary evaluations that highlight practices that can improve farmers' ability to cope with climate-related hazards. This literature highlights the importance of community-led, location specific adaptation measures that harness the extensive indigenous knowledge and adaptation techniques of local farmers. Many existing analyses have not taken into account the perspectives of these local stakeholders" (Thorlakson, 2011, p. 2).

This elaborates on the importance of local-level farmer knowledge when it comes to researching and vetting different agroforestry practices. It also speaks to an important, broader concept about development work in general: that local-led initiatives based around an intimate understanding of the context of the project or initiative are absolutely vital to meaningful, effective results. When it comes to seeking resilience for some of the world's most vulnerable populations, this ethic could not be more critical.

Conclusion

Climate change will present enormous challenges for agricultural systems, food security, and the lives of smallholder farmers in the developing world. With the ever increasing focus on climate change in policy dialogues and international negotiations, Climate-smart agriculture (CSA) has emerged as a collection of practices that help to mitigate climate change through the sequester and storage of carbon, provide resilience to the impacts of global warming, build food security and strengthen the livelihoods of farmers. Agroforestry is one of the most promising components in the CSA toolbox, particularly as it applies to rural, smallholder farmers in need of adapting to harsher climatological conditions such as longer droughts, more severe floods, and greater rainfall variability. It should be treated as such in policy discussions, and these critical discussions about building resilience for some of the world's most vulnerable people should not be sidetracked by the less significant emissions-reducing characteristics of agroforestry.

Sustainable agriculture will not reverse global warming, but it can be a vital tool in adapting to its effects.

In order to accomplish this adaptation, policies will need to bring together traditional knowledge of agriculture, forests and agroecological systems with modern scientific analysis and understanding of agroforestry's potential in individual geographical settings. Traditional knowledge needs to be actively sought out, properly valued, and acted upon. But for smallholder farmers to be able to implement sustainable land use practices such as agroforestry, and to incentivize these practices, governments in the developing world need to deliver secure tenure to individual farmers, and proper policies regarding rights to natural resources. As the case of re-greening in Niger has shown, natural resource rights create incentives to better care for the land.

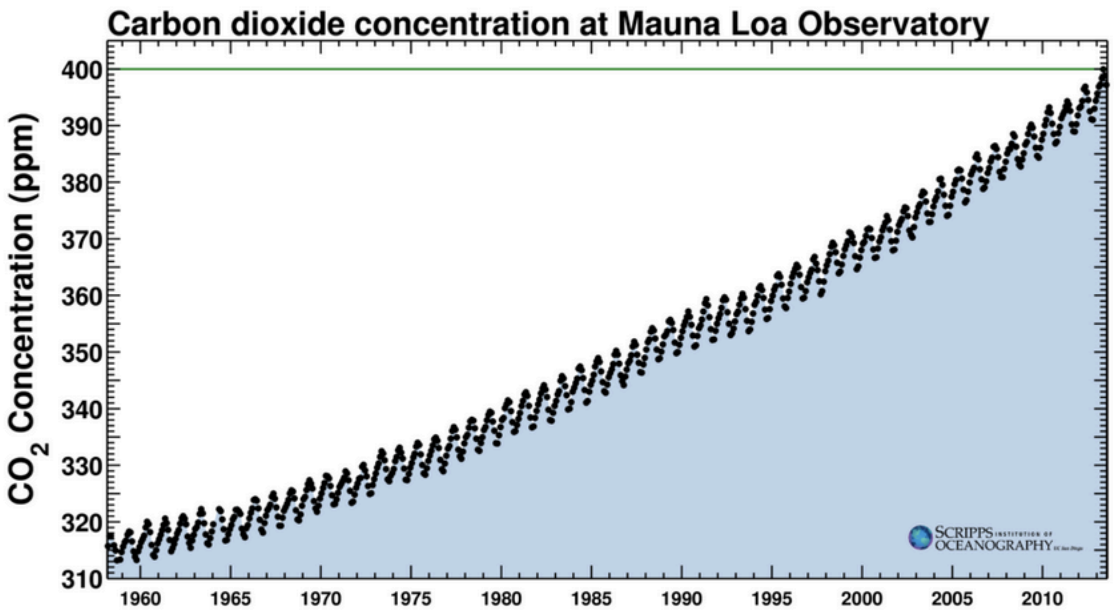
What is required is two-fold: an understanding by the individual of the importance of trees in building resilience for crop and livestock systems, and the active role of the government not only in promoting sustainable forms of land management such as agroforestry, but in actually passing and changing laws so that the basic rights to farm the land and develop its resources are guaranteed to the individual smallholder.

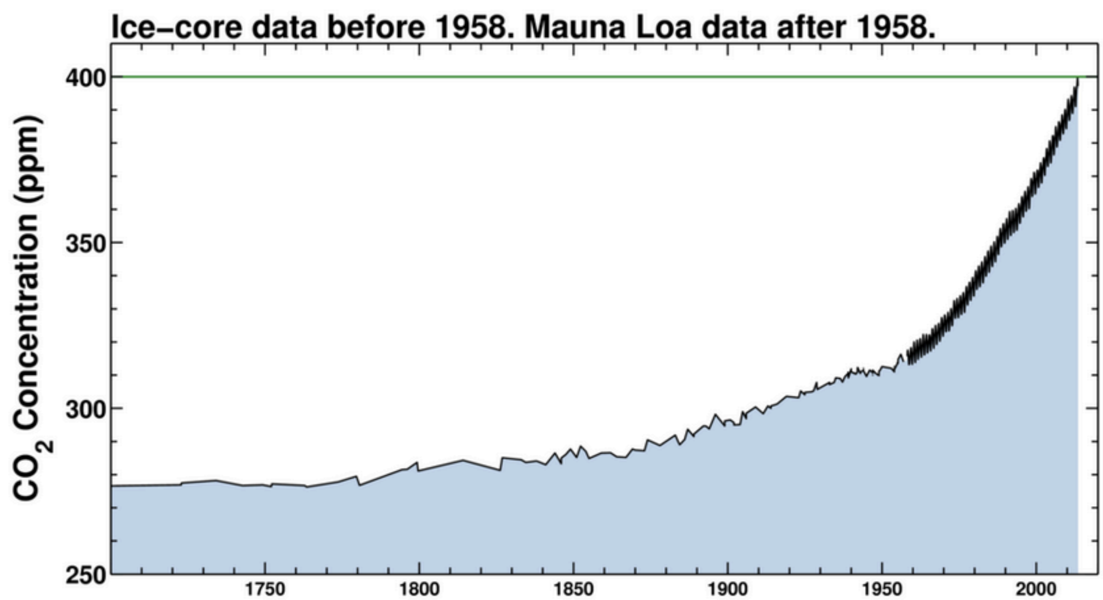
Finally, any earnest discussion of agroforestry must examine the historical relationship between humans and forests. McNeely (2004) posits that,

"The Western vision of an untouched wilderness has permeated global policies and politics in resource management. This view of forests is based on an outmoded ecological perspective, and on misunderstanding of the historical relationship between people and forests, and the role people have played in maintaining biodiversity in forested habitats" (p. 1).

Healthy ecosystems and biodiversity are at the center of productive agroforestry systems, and it is this fact more than anything else that makes agroforestry such a highly desirable practice. It is the very separation of agriculture from nature by large-scale cultivation, mechanization and artificial fertilization that has made conventional agriculture inherently unsustainable, particularly in the face of impending climatological shocks. Beyond the relationship between humans and forests, this speaks to the broader relationship between humans and nature as a whole. William Cronon (1995) wrote about the problem with the concept of "wilderness"—that this notion separates human beings from nature; it enables us to set aside portions of nature to be preserved while annexing vast swathes to be trashed by the activities of human civilization. He advocated for looking at the trees in your back yard as no different than the trees in the "wild". The practice of agroforestry offers solutions that Cronon would approve. Incorporating agriculture and trees in a sustainable way, humans who engage in agroforestry become more integrated with nature. Agroforestry will not solve the climate crisis, but if it can achieve resilience to climate change through the integration of basic human needs and healthily functioning ecosystems, then it will create opportunities for a more sustainable future.

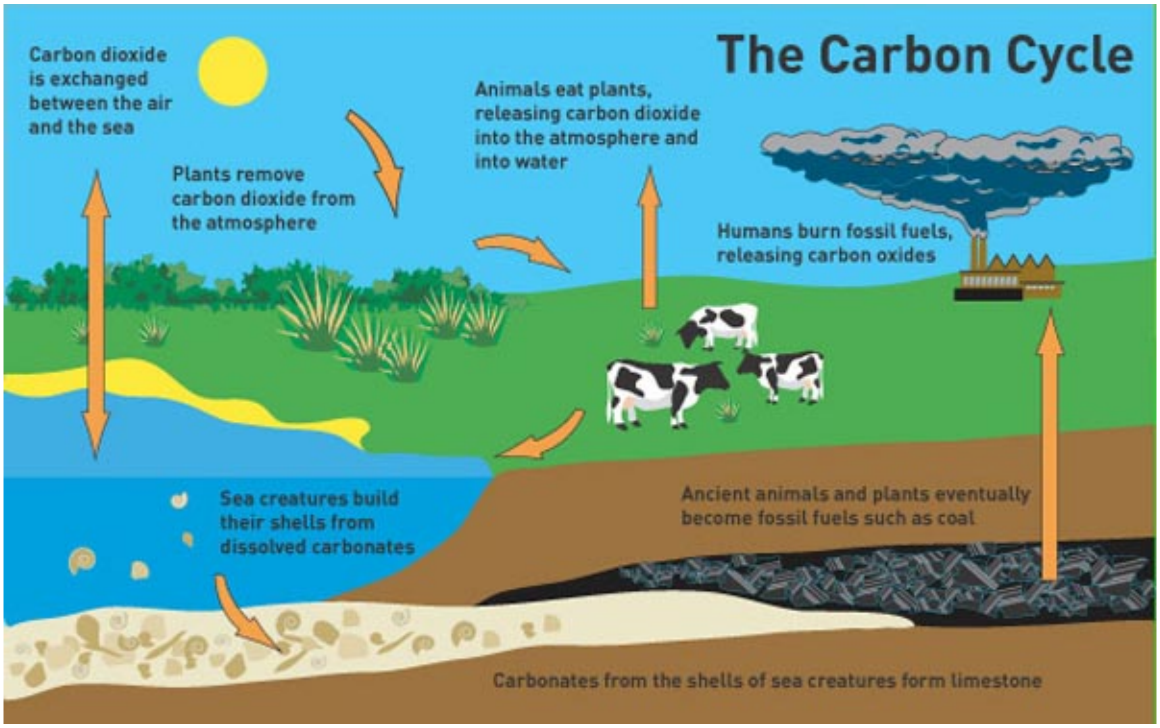
Annex 1: The Keeling Curve





Source: Scripps Institution of Oceanography (2013)

Annex 2: The Carbon Cycle



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