Climate-Smart Agriculture?

A review of current practice of agroforestry and conservation agriculture in Malawi and Zambia

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A review of current practice of agroforestry and conservation agriculture in Malawi and Zambia

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Abstract

Agriculture in Sub-Saharan Africa must undergo significant productivity improvements to meet the combined challenges of population growth and climate change. A proposed means of achieving such improvements is increased use of a 'climate-smart agriculture' approach to agricultural development policy-making, which emphasizes the use of farming techniques that (1) increase yields, (2) reduce vulnerability to climate change, and (3) reduce greenhouse gas emissions. Two countries that are prioritizing such an approach within the framework of a Climate-Smart Agriculture project are Malawi and Zambia. These countries are promoting the use of agroforestry and conservation agriculture with the aim of improving the productivity of their smallholder agricultural systems under climate change. This review synthesizes evidence on the use, yield and socio-economic impacts of these farming techniques. Key findings are that agroforestry is a promising option for smallholder farmers with well-documented yield and profitability improvements. Evidence supporting the use of conservation agriculture in the target countries is also positive but weaker. Adoption rates, although higher than those in other African countries, are lower than would be expected given the potential benefits, and resources spent on promotion. Key constraints and needs for further research are documented.

Key words: climate-smart agriculture, agroforestry, conservation agriculture, adoption, impact, Malawi, Zambia

JEL codes: Q1; O13

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Contents

1. Introduction

Agriculture in developing countries must undergo significant transformation if it is to meet the growing and interconnected challenges of food insecurity and climate change (FAO, 2010). Recent projections suggest global population will grow from a current 7 billion to more than 9 billion people in 2050 (UNESCO, 2012). Given both food consumption trends and population growth, it is expected that a 60 percent increase in global agricultural production will be required by 2050 (FAO 2012a).

This challenge is most acute in Sub-Saharan Africa (SSA), where population is expected to increase from approximately one billion in 2010 to between 1.9 and 2.4 billion people in 2050 (UNDESA, 2012). Ensuring adequate food supplies in the region will require faster growth in agricultural output than that observed over the past decade (World Bank, 2013). Consequently, many SSA countries have pledged to increase government support with the ambition of achieving an annual agricultural growth rate of 6 percent, a goal adopted by the Comprehensive Africa Agriculture Development Programme (CAADP, 2013). Although crop output has been increasing in SSA, this has been largely driven by an expansion in the area of cultivated land rather than by productivity gains. Average cereal yields in the region have remained below 1 tonne ha^{-1} for the past 50 years, compared to average yields of 2.5 tonne ha^{-1} in South Asia and 4.5 tonne ha^{-1} in East Asia (FAOSTAT, 2012).

The challenge of rapidly boosting productivity is compounded by the current and expected impacts of climate change. Changes to precipitation and temperature, especially in marginal areas, are expected to reduce productivity and make production more erratic (Cline, 2008; Lobell *et al.* 2008; Boko, *et al.* 2007). SSA countries in particular are most at risk: resources for adaptation are scarce, temperatures are already close to or beyond thresholds at which further warming reduces yields, and agriculture forms a larger share of national economies than elsewhere in the world (Cline, 2008).

Consequently, there is a need to simultaneously improve agricultural productivity and reduce yield variability over time under adverse climatic conditions. A proposed means to achieve this is increased adoption of a ‘climate-smart agriculture’ (CSA) approach (FAO, 2010). CSA, which is defined by its intended outcomes, rather than specific farming practices, is composed of three main pillars: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change and reducing and/or removing greenhouse gases emissions relative to conventional practices (FAO, 2013). The agricultural technologies and practices that constitute a CSA approach are, in most cases, not new, and largely coincide with those of sustainable agriculture and sustainable intensification. However, under a CSA approach, these are evaluated for their capacity to generate increases in productivity, resilience and mitigation for specific locations, given the expected impacts of climate change.

Both Malawi and Zambia have faced severe food security challenges over the past two decades, and despite some recent improvements, suffer from ongoing high rates of malnourishment (FAO, 2011). In Zambia, the proportion of the population which is malnourished has increased by 23 percent since 1990. Malawi has suffered from major droughts over the past decade. In response, both countries are currently experimenting with a range of policies that strongly prioritize improved food security (Garrity, *et al.* 2010; Denning, *et al.* 2009).

The most dramatic policy change has been the reinstatement of government subsidies for inorganic fertilizer in Malawi, a decision that has received much attention and has raised yields considerably (Figure 1) (see for instance Gilbert, 2012; Dorward and Chirwa, 2011; Denning, *et al.* 2009; Sanchez *et al.* 2009). These countries are also promoting alternative agricultural practices which may improve productivity: agroforestry, prominent in Malawi, and conservation agriculture (CA), prominent in Zambia. Whether, and to what extent these two practices can be considered examples of CSA requires a thorough understanding of adoption costs and benefits in various agro-ecological and socio-economic contexts.

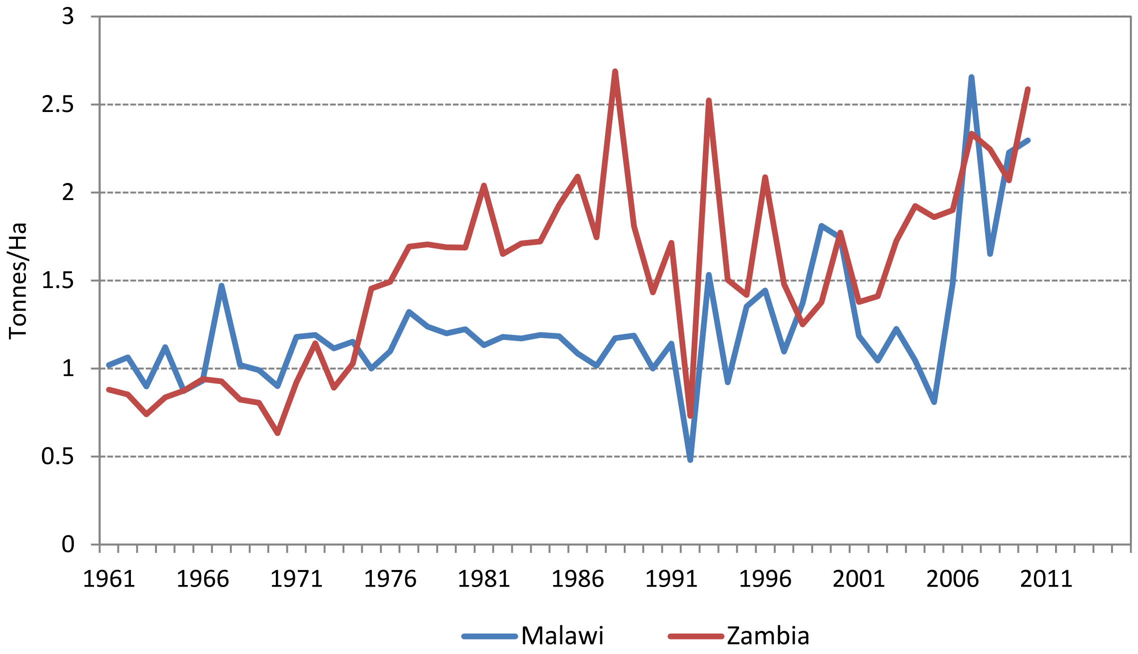

Figure 1: Average maize yields over time (source: FAOSTAT, 2012)

This paper provides a comprehensive review of literature on these two practices in Malawi and Zambia within the framework of a European Commission (EC) funded project entitled "Climate-Smart Agriculture: Capturing the Synergies between Adaptation, Mitigation and Food Security" implemented by FAO.[1] This project acknowledges the fact that there is no blueprint for CSA practices, which are determined by the specific contexts of the countries and communities where they are to be implemented. In this paper, we take a set of potential CSA practices that were determined with critical input from the ministries of agriculture and national research institutions on priority areas. The practices discussed in this paper are policy priorities in their respective countries and figure prominently in national climate change policies as well as the National Adaptation Plans of Action (NAPA) submitted to the UNFCCC.[2]

Part 2 of this review provides background to the agricultural challenges facing both countries. Part 3 contains a review of the use of agroforestry in Malawi, and Part 4 contains a review of the use of Conservation Agriculture (CA) in Zambia. We find that the literature available provides evidence supporting increased use of agroforestry and conservation agriculture in both countries. However, it is also clear that both practices are only suitable in particular situations. Overall, this review identifies numerous instances, where context-specific research is needed before the practices can be considered 'proven' CSA technologies. Socio-economic research regarding the impact of these CSA practices is particularly lacking. Part 5 provides a review of the literature on the carbon mitigation co-benefits of practices discussed in the paper, and part 6 concludes, highlighting the key findings of this review and underlines the topics that merit further research.

2. Agriculture and Climate Change in Malawi and Zambia

2.1 Malawi

Malawi is situated between 9° and 17° south of the equator, and has a landscape and climate dominated by Lake Malawi and the Great Rift Valley. The climate is sub-tropical and strongly monsoonal. Annual rainfall varies from 800 mm in the lowlands to 2300 mm in the northern highlands, and arrives predominantly in the wet season, between October and April (WFP, 2010).

[1] See http://www.fao.org/climatechange/epic/en/ for more information.
[2] See http://unfccc.int/resource/docs/napa/mwi01.pdf and http://unfccc.int/resource/docs/napa/zmb01.pdf.

Malawi has a small population – 14.9 million – but a rapid population growth rate of 2.8 percent and a high population density. Per capita income is USD 900 (at purchasing power parity, i.e. PPP) per year. 74 percent of Malawians earn USD 1.25 per day or less, and approximately 80 percent of Malawians live in rural areas (CIA, 2011).

Malawi's economy is highly dependent on agriculture and hence reliant on favorable climatic conditions. The agricultural sector accounts for approximately 30 percent of GDP and 90 percent of employment (CIA, 2011). The majority of these are smallholder farmers, with land size averaging 1.2 ha per household. Intensive land use has lead to soil degradation and low productivity (WFP, 2010; Denning, *et al.* 2009). In Malawi, as with much of southern Africa, the primary constraint to improved agricultural productivity is soil nutrient deficiency, particularly in nitrogen and phosphorous (Sanchez, 2002). The most important crop, maize, grown by over 90 percent of Malawian farmers, has an average national yield of just over 1.4 tonne ha^{-1} over the past two decades (FAOSTAT, 2012). Other major crops include groundnuts, beans, tobacco, potatoes and cassava. Malawi has faced significant food security crises in the past decade, with major droughts in the 2000/01 and 2005/06 growing seasons. These food security crises are directly related to insufficient crop production, rather than inadequate distribution (Sanchez, 2002).

The use of irrigation is limited, with 84 percent of farmers practicing rainfed agriculture only. Irrigation is more common in larger farming operations. Use of chemical fertilizer is common in the cultivation of maize but rare in the cultivation of other crops (WFP, 2010). Chemical fertilizer use has been successfully promoted by government subsidy programs, leading to greatly improved crop yields and reductions in food insecurity in recent years (Denning, *et al.* 2009).

Predicted impacts of climate change in Malawi particularly affect smallholder, rainfall dependent farmers, who form the large majority of the Malawian agricultural sector (Denning, *et al.* 2009). A synthesis of climate data by the World Bank (World Bank, 2012) indicated that in the period 1960 to 2006, mean annual temperature in Malawi increased by 0.9°C. This increase in temperature has been concentrated in the rainy summer season (December – February), and is expected to increase further. Long term rainfall trends are difficult to characterize due to the highly varied inter-annual rainfall pattern in Malawi. Similarly, future predictions are inconsistent. Assessments of climate change impacts on agriculture are highly variable across agro-ecological zones (Boko *et al.* 2007; Seo, *et al*. 2009), and the socio economic impact of such change on smallholder farmers is a function of their adaptive and coping strategies (Morton, 2007).

2.2 Zambia

Zambia is situated between 8° and 18° south of the equator on a large plateau. The climate is predominantly sub-tropical, with 95 percent of precipitation falling during the November – April wet season. Rainfall varies with latitude and agro-ecological region, with over 1200 mm falling annually on average in the north and northwest (Region III), to less than 700 mm in the south (Region I). Approximately 12 percent of Zambia's landmass is considered suitable for cropping, and a further 21 percent suitable for grazing (Jain, 2007).

The agricultural sector accounts for approximately 21 percent of GDP (CIA, 2011a). The country's rapidly growing population stands at approximately 14.3 million, two thirds of whom are reliant on the agricultural sector for their livelihoods. 64 percent of Zambians live in rural areas where subsistence, rain-fed agriculture is the dominant economic activity (Govereh, *et al.* 2009). Major crops grown are maize, sorghum, millet, rice (paddy), wheat, cassava, ground nuts, sunflower, cotton, soya beans, mixed beans and tobacco. Of these, maize, the staple food, is the most important. Over half the calories consumed in Zambia are from maize, although this proportion is decreasing (Dorosh, *et al.* 2009).

Per capita income in Zambia is very low at USD 1600 (PPP) per year. Despite rapid economic growth over the last decade, driven primarily by an expansion of mining, poverty levels are very high especially in rural areas (around 80%; Chapoto *et al.* 2011). 69 percent of Zambians earned USD 1.25 per day or less at the most recent estimate (World Bank, 2006). Over half of Zambian farmers sell little or no crops (subsistence only), with agricultural commercialization and surplus production concentrated in the hands of a small proportion of farmers (Hichaambwa and Jayne, 2012). The vast majority cultivate small plots, typically, less than 5 hectares, using only basic inputs and technologies (Jain, 2007).

As in Malawi, agricultural development provides a key means for economic development in rural Zambia (IDL, 2002; FAO/WFP, 2005), and for this reason, the country's Fifth National Development Plan (FNDP) strongly emphasized increasing agricultural productivity. Zambia has more underutilized agricultural resources such as groundwater and cropping land than neighboring countries (IDL, 2002; FAO/WFP, 2005; Hichaambwa and Jayne, 2012). Despite this, land is limited in the more densely populated areas, and infrastructure is lacking in those areas underexploited (Hichaambwa and Jayne, 2012).

Predicted impacts of climate change in Zambia differ between the country's three agro-ecological zones, defined mainly by rainfall. In the western and southern parts of the country, (approximately 15 percent of the land area), rainfall has been low, unpredictable and poorly distributed for the past 20 years, despite historically being considered a good cereal cropping area (Jain 2007). The central part of the country is the most populous and has the highest agricultural potential, with well distributed rainfall and fertile soil. The northern part of the country receives the highest rainfall but has poorer soils. About 65 percent of this region is underutilized (Jain, 2007). Across these zones, despite considerable agricultural potential, Zambia's maize harvest fails to meet national market demand on average one year in three (Dorosh, *et al.* 2009).

The dominance of rainfed agriculture in the Zambian agricultural sector means that climate change poses a considerable challenge. The yield during a severe drought in 1991-1992 was less than half that of the preceding season. Droughts in 1993-1995, 2001-2002 and 2004-2005 similarly had large impacts on yields and consequently on food security (FAOSTAT, 2012). Global climate models predict that temperatures will increase in Southern Africa by 0.6-1.4 degrees Celsius by 2030. Rainfall predictions are more ambiguous, with some models suggesting increased precipitation, and some suggesting reduced precipitation (Lobell, *et al.* 2008). Crop yields in the region are predicted to suffer as a result, with maize yields predicted to fall by 30 percent and wheat by 15 percent, in the absence of adaptation measures (Lobell, *et al.* 2008).

It should be noted that the impact of climate change on crop production is not limited to total rainfall and temperature effects: intra-seasonal rainfall variation is also important. A 'false start' to the rainy season due to erratic rainfall can be disastrous for crop establishment. Similarly, intra-seasonal dry spells may be more damaging to growth than low total rainfall (FAO, 2011). Such temporal variation is predicted to increase in many parts of Africa under climate change scenarios (Boko, *et al.* 2007). The conservation agriculture practices reviewed in this paper are intended to strengthen farmers' capacity to adapt to these conditions.

3. Agroforestry in Malawi

3.1. Background

Malawian farmers have achieved large increases in cropland productivity, primarily in maize, over the past decade via increased use of subsidized inorganic fertilizers. The fertilizer subsidy program has reduced food insecurity considerably and has done so relatively cost effectively (Dorward and Chirwa, 2011). However, the subsidy faces budget constraints: the program costs 9 -16 percent of the national government budget, depending on yearly fertilizer prices (Denning, *et al.* 2009; Carr, 1997). In addition, inorganic fertilizer, along with other inputs, may cause soil degradation in the long term due to the depletion of organic matter in the topsoil (Branca, *et al.* 2011; FAO, 2011; Tilman, *et al.* 2002).

Agroforestry may represent a cost effective and sustainable complement, or in some cases a substitute, to the use of inorganic fertilizer, especially if fertilizer costs rise in the future (Ajayi, *et al.* 2008). Agroforestry as practiced in Malawi is termed 'fertilizer tree systems'. Selected tree and shrub species are planted either sequentially (during fallow) or contemporaneously (intercropped) with an annual food crop. Doing so helps maintain soil cover, improves nutrient levels, increases soil organic matter (via the provision of mulch), improves water filtration, and provides a secondary source of food, fodder, fiber and fuel (Garrity, *et al.* 2010). Leguminous agroforestry species are generally used due to their ability to fix atmospheric nitrogen in the soil in a form available to plants. In addition to offering potential food security benefits, agroforestry goes some way towards countering deforestation, estimated in Malawi to occur at a rate of 1.0 to 2.6 percent annually (1990 – 2000 data, FAO, 2005). In countering soil erosion, agroforestry helps mitigate losses of nutrients estimated to be worth USD 6.6-19 million annually in Malawi (Bojo, 1996).

Although agroforestry can be applied to various crop systems, this review focuses primarily on maize due to its overriding importance for food security in Malawi. Maize is grown on over 70 percent of arable land, and on over 90 percent of cereal cultivation area. Malawians are the world's largest consumers of maize, with 148 kilograms consumed per capita annually (Smale and Jayne, 2003).

Fertilizer tree systems often do not produce enough available nitrogen to match the results of optimally applied inorganic fertilizer. However, there is substantial evidence that they can still provide considerable yield benefits, and do so at low cost (see for instance, Snapp *et al.* 2010; Garrity, *et al.* 2010; Kamanga, *et al.* 2010, amongst others reviewed below). It should be noted that agroforestry and inorganic fertilizer application are not mutually exclusive. A half- or even a quarter-application of inorganic fertilizer in conjunction with agroforestry techniques can deliver yields equal or superior to monocropped, fertilized crops (see Snapp *et al.* 2010). The immediate question facing researchers and policy makers is what conditions make the economic returns to agroforestry more or less attractive than inorganic fertilizer and/or alternative CA measures. More broadly, there is an ongoing debate over whether agroforestry productivity gains are enough to deliver the substantial improvements to food security required in SSA (Gilbert, 2012). To the extent possible these questions are addressed in this review.

The remainder of this section addresses the yield impact of agroforestry techniques, organized by functional categories of agroforestry. Evidence regarding profitability, socio-economic impacts and adoption follows. Given that agroforestry has received the attention of researchers in SSA since the 1970s (and many techniques have been practiced traditionally for generations before then) there is a large literature on the topic. The existence of substantial, broad-based reviews of agroforestry means that a global review is not attempted here. Instead, the majority of this review concentrates on those studies specifically relevant to Malawi. There is a need to consider impacts within the country of interest given that the results of agroforestry vary greatly in different agro-ecological contexts.

3.2. Agroforestry and Crop Yields in Malawi

Before considering country-specific evidence, it is worth noting the findings from two meta-analyses on agroforestry from across SSA. Akinnifesi *et al.* (2010) reviewed the yield and soil quality results of agroforestry from on-station and on-farm trials in Malawi, Tanzania, Zambia and Mozambique. They found that fertilizer trees can add to the soil more than 60 kg of nitrogen ha^{-1} per year, enough to replace 75 percent of the nitrogen otherwise required from mineral fertilizer inputs. This doubled yields over unfertilized, monocropped maize plots. Indicators of environmental health such as soil structure and soil biota populations were similarly improved. Sileshi *et al.* (2008) undertook a comprehensive meta-analysis of maize response to legumes across SSA. They considered both agroforestry type systems (woody legumes) and crop rotations with herbacaeus green manure legumes. Through their review of 94 studies they found that woody legumes delivered an average increase in maize yield of 1.3-1.6 tonnes ha^{-1} over unfertilized, monocropped maize. They also found that agroforestry systems could substantially (although not entirely) alleviate the need for inorganic fertilizer additions.

In the reminder of this section, we consider the literature specifically for Malawi. The review of country-specific evidence is organized into four categories of agroforestry 1) permanent tree intercropping, 2) sequential tree fallow, 3) annual relay intercropping and 4) biomass transfer.[3]

a. *Permanent tree intercropping:*

Permanent tree intercropping commonly takes one of two forms: parkland systems or tree intercropping systems. The former involves planting scattered nutrient-fixing species in a field, or protecting existing scattered trees. The latter involves a closer planting of nutrient fixing trees in rows, with annual crops planted in between. Tree intercropping systems often require trees to be coppiced in order to reduce light competition with crops, a process which also provides mulch. Two key species for permanent tree intercropping in Malawi are *Faidherbia albida (henceforth F. albida)* and *Gliricidia sepium (henceforth G. sepium),* which fix nitrogen while complementing the resource use of an annual maize crop (Akinnifesi *et al.* 2008).

The pairing of maize and *F. albida* – a hardy species indigenous to much of Africa – has been practiced traditionally by Malawian farmers for generations (Garrity, *et al.* 2010). An estimated 500,000 Malawian farmers have *F. albida* trees on their property (Phombeya, 2009, in Garrity, *et al.* 2010). In addition to nitrogen fixing properties, *F. albida* sheds its leaves in the rainy season, thus reducing competition for water and light during the growth period of the annual maize crop (Akinnifesi *et al.* 2008). Crop productivity benefits occur due to improved soil water content, microclimate regulation and nutrient mineralization. Optimum crop response requires 20 to 30 mature trees per hectare (Kang and Akinnifesi, 2000).

Formal research into *F. albida* systems has been undertaken since the 1980s by the Malawian Government Department of Agricultural Research and Technical Services (Garrity, *et al.* 2010). *F. albida* systems have also been the focus of research by a number of independent, academic studies. Saka (1994) reported on 22 farmers' experiences with *F. albida* in Khombedza, Bolero and Mvera (Lake Malawi lakeshore plain area). Maize yields near *F.*

[3] For more information regarding these techniques see Akinnifesi *et al.* (2008).

albida (between 2 and 10 m) were more than double the yields away from trees (15-30 m). Similarly large productivity increases were reported by Garrity, *et al.* (2010) for Zambian farmers. Barnes and Fagg (2003) reviewed literature on the effects of *F. albida* agroforestry and found maize yield improvements from studies across Africa of 6-200 percent.

A disadvantage of *F. albida* systems is the length of establishment time. *F. albida* has initially slow growth due to the development of deep roots. Maturity, and thus the full benefits of this agroforestry system can take as long as 20 years to occur. Rhoades (1995) reported on farmer experiences in the same lakeshore plains field sites as Saka (1994, described above). He found that benefits are greater under mature trees than under young trees, meaning that the short term incentive to plant *F. albida* is reduced. Recent unpublished research, discussed briefly by Akinnifesi, *et al.* 2010, suggested that closer *F. albida* spacing could realize benefits earlier, in 12-15 years. Another possibility is to integrate *F. albida* with other agroforestry species or short rotation fallow in order to speed yield improvements, although further research appears necessary here.

Overall, the evidence for *F. albida's* positive impact on yields is well established, especially in areas of poor soil (Garrity, *et al.* 2010; Barnes and Fagg, 2003). Consequently the use of this system is currently promoted by the Departments of Agriculture in both Malawi and Zambia. However the success of *F. albida* in field trials has not always translated to success in extension programs. Carr (2004) and Bunderson (2004) (in Akinnifesi, *et al.* 2008) found that poor germination rates and slow growth had hampered success of Malawian *F. albida* programs.

An alternative, well researched agroforestry species is *G. sepium.* Trees are planted in rows and pruned 2 or 3 times a year. The resulting biomass is incorporated into the soil, improving topsoil nutrient levels and carbon content (Akinnifesi, *et al.* 2010; Garrity, *et al.* 2010). The most comprehensive testing of this system in Malawi was undertaken by Akinnifesi *et al.* (2006) in a ten year trial at Makoka Agricultural Research Station, Southern Malawi. The authors found that *G. sepium* intercropping increased yields by 300 percent on average over unfertilized control trials. This approach also outperformed monocropped maize fertilized with half the recommended inorganic nitrogen. Although the trees require labor and space, labor poses little constraint in densely populated Malawi, and the practice of pruning leads to a space efficient arrangement (Akinnifesi, *et al.* 2010). The authors demonstrated that the addition of small amounts of nitrogen fertilizer to maize/*G. sepium* plots could raise yields even further during the system's early years, but over time these additions became increasingly unnecessary as soil health improved. A related, 12 year study at the same site found that the intercropped treatments also had greater yield stability (less fluctuation from year to year) than the fertilized, monocropped treatments (Sileshi, *et al.* 2012).

b. Sequential tree fallow:

Sequential tree fallow (a type of improved fallow) is a functionally different approach to agroforestry. Under such a regime, fallow fields are improved by the planting of fast growing leguminous tree or shrub species such as *Sesbania sesban*, *Tephrosia* species and *Cajanus* species (e.g. *Cajanus cajan* - pigeon pea). These species remain in place for 1 to 3 years to fix atmospheric nitrogen, improve existing soil nitrogen availability and add organic matter to the soil. Given that the benefits of fallowing depend on the accumulation of nutrients and biomass, longer fallows usually have larger yield effects but a higher opportunity cost (Harrawa, *et al.* 2006). When the field is to be reused for food cropping, the trees are mulched or burned to return nutrients and carbon to the soil in a form suitable for crop uptake.

Improved fallow shows a significant yield advantage over natural fallow or no fallow. Akinnifesi *et al.* (2008) provided a meta-analysis of a variety of maize intercropping studies in Malawi, including such sequential tree fallow systems. This meta-analysis includes findings from 7 publications based on data from experimental plots at the Makoka field research station. They found yield improvements of between 55 and 255 percent from species *T. vogelii*, *S. sesban* and *C. cajan*. They also note that fallow rotations with tall-growing woody legumes caused superior yields compared to those with herbaceous legumes as their deeper roots provide greater influence over deeper soil horizons. The meta-analysis by Sileshi, *et al.* (2008), introduced earlier, allows for a useful comparison of agroforestry species. *Gliricidia* species, studied at 5 sites in Malawi, led to an average improvement in maize yields of 345 percent over unfertilized monocropped maize. *Sesbania* species (studied at 7 sites) led to an average improvement of 161 percent and *Tephrosia* species of 232 percent.

The benefits of sequential tree fallow can materialise not only through improved maize yields, but also through the potential for higher total calorie yields when edible legumes are used (*C. cajan* or groundnuts, for instance). Snapp and Silim (2002) reported on participatory trials involving 46 farmers in central and southern Malawi. They found that total calorie production could be boosted by 28 percent through the use of *C. cajan* rotations.

c. *Annual relay intercropping:*

Annual relay intercropping is the planting of fast growing legumes alongside a crop, with planting occurring shortly after the crop itself becomes established. After the crop is harvested the legumes are allowed to grow throughout the off season, until they are plowed into the soil shortly before the field is to be re-sown the following year. Key species used for this technique are the same as those used for sequential tree fallow: *T. vogelii*, *S. sesban* and *C. cajan.* The major advantage of this approach is that farmers do not have to fallow, or wait for an initial period of tree establishment. High population densities and very small farm sizes means that extended fallow periods are impractical in many parts of Malawi (Harrawa *et al.* 2006).

A three year study by Phiri *et al.* (1999) in southern Malawi assessed yield impacts of annual relay intercropped *S. sesban* and maize in experimental plots managed by local farmers. Their study compared the suitability of this farming approach on three landscape positions, Dambo valleys, margins or steep slopes. They found yield improvements of 30-60 percent in the valleys and low slopes. Yield improvements dissipated in subsequent years of rotation and were inferior to mineral N fertilizer. They also concluded that the technique is unsuitable for use on steep slopes. A related study by Harawa *et al.* (2006) similarly found *S. sesban* relay intercropping to be unsuited to steeper slopes in southern Malawi, but found *G. Sepium*-maize intercropping to be more successful in such locations.

Boeringer, *et al.* (1999) (in Akinnifesi, *et al.* 2008) reported on a 3 year on-farm intercropping trial from southern Malawi. They found maize yield increased by 73 and 79 percent with the use of *S. sesban* and *T. vogelii,* respectively. Despite this result, Akinnifesi, *et al.* (2008) concluded, through a review of a number of studies, that the productivity enhancement from this technique is less than that under other agroforestry approaches, and cannot match that of inorganic fertilizer additions.

d. *Biomass transfer:*

Biomass transfer is the shifting of leaf and twig matter from fertilizer vegetation in one area to be used as mulch on fields. Material can be sourced from natural forests, roadsides, hedges or otherwise unused farmland. The practice is unsustainable in instances where the transfer of nutrients outstrips their fixation at the source, therefore careful, site-specific consideration of nutrient dynamics is required (Akinnifesi *et al.* 2008).

The yield response of maize to biomass transfer is highly positive. The use of nutrient accumulating *Tithonia diversifolia, G. sepium* and *Leucaena leucocephala* are reported to increase maize yields by 216, 140 and 86 percent, respectively, in Malawian field trials (Ganunga and Kabambe, 2004; Chilimba *et al.* 2004, both in Akinnifesi *et al.* 2008). However the labor involved in transferring biomass means that the practice is only profitable for higher valued crops such as vegetables (Sanchez, 2002).

3.3. Economic Feasibility

There is a small literature on the economic feasibility of agroforestry for smallholder agriculture. Related to this are papers which have examined the food security and livelihood outcomes from agroforestry impediments to, and enablers of, agroforestry adoption. These latter studies are reviewed in the next two sections respectively. In this section, we review evidence on the profitability of agroforestry which in most cases will be the most important determinant of farmers' adoption decisions.

One of the few papers on the economics of agroforestry in Malawi is by Kamanga, *et al.* (2010), who assessed the suitability of different approaches based on economic return and risk. 32 farmers from the semi-arid/sub-humid Dowa District took part in the four year field study. These farmers represented a range of wealth levels. The authors recommended legume intercropping over legume rotation based on superior returns to total costs (including returns to labor). Although neither technique in the absence of inorganic fertilizer could match the yields resulting from monocropped maize *with* fertilizer, a combination of fertilizer *and* legume rotation or intercropping was best. Intercropping with *T. vogelii* and *C. cajan* (pigeon pea) were recommended due to superior economic returns to land and labor. Intercropping with *C. cajan* in particular delivered consistent positive returns for both resource-poor and resource-rich farmers. The authors also found that some low yielding legume-maize technologies could *increase* vulnerability for the poorest farmers.

Snapp *et al.* (2010) similarly assessed economic returns in their comprehensive study of legume diversification in maize across Malawi. Data was collected from 991 experimental plots country-wide. Profitability was measured with value-cost ratios (VCRs). All improved systems considered (fertilized monocropped maize, and intercrops and rotations with *C. cajan*, *Mucuna pruriens* and *T. vogelii*) delivered positive VCRs. At 2001 fertilizer prices (when the study was undertaken) all systems had a VCR > 3. For comparison, a VCR of 2 is considered acceptable, and > 4 is considered attractive to risk-averse, resource-poor farmers. A rotation of *C. cajan,* groundnut and maize delivered the highest VCR of 7.3–9.4. The authors also considered the impact of higher fertilizer prices: 2008 prices were double those of 2001. At 2008 prices, the diversified systems delivered VCRs > 4, while the monocropped system's VCR had fallen to 2.5.

A third relevant paper is by Ngwira, *et al.* (2012), who undertook a financial analysis of intercropping approaches to maize production in Ntcheu district, Malawi. Intercropping species tested were *C. cajan, Mucuna pruriens* and *Lablab purpureus,* tested on 72 plots managed by 24 farmers. Their three year study found significant increase in maize yields from low till, intercropped fields compared to conventional monocropped fields. However, a substantial proportion of the yield benefits appeared to be attributable to the tillage practice rather than the intercropping.

The financial analysis by Ngwira, *et al.* (2012) found that gross margins for *C. cajan* intercropping (USD 705 ha^{-1}) were approximately double those under conventional practice (USD 344 ha^{-1}), primarily because *C. cajan* fruits can be sold at market. Labor costs were lower under the intercropped regimes with farmers spending at most 47 days ha^{-1} producing maize, compared to 65 days ha^{-1} under conventional tillage. An additional benefit was the production of firewood from the stems of the intercropped shrubs. However, the low tillage intercropped system required higher input costs, likely contributing to its low adoption rates. A more comprehensive treatment of the costs and benefits of tillage management can be found in section 4.5.

Although to the best of our knowledge, papers specific to Malawi farming are limited to those above, valuable research has been undertaken in neighboring countries. One useful study is by Ajayi *et al.* (2009) who undertook a cost-benefit analysis of agroforestry in Eastern Zambia, which borders Malawi. Participating farmers kept a logbook of their inputs, outputs and decisions on a total of 89 plots across the province. Both intercropping with *Gliricidia* (net profit of USD 269 ha^{-1}) and improved fallow with *Sesbania* (USD 309 ha^{-1}) were more profitable than unfertilized maize (USD 130 ha^{-1}). Despite the disadvantage of the fallow requirement, the *Sesbania* improved fallow had better returns over a 5-year cycle. Inorganic fertilized maize was found to be more profitable than either agroforestry approach, and much more so when fertilizer subsidies were taken into account. However, per unit of investment (benefit-cost ratio), agroforestry systems were slightly superior.

3.4. Livelihood and Food Security Impacts

ICRAF (2008) estimated that approximately 80 percent of smallholder Malawians face food deficiencies between November and February, despite the recent success of the maize fertilizer subsidy program (Denning, *et al.* 2009). In 2006-8, an estimated 27 percent of Malawians were undernourished[4] (FAO, 2011a). In an attempt to alleviate this problem, and to complement the fertilizer subsidy program, the Malawian Government has promoted agroforestry through programs such as the 'Agroforestry Food Security Program.'

The livelihood and food security implications of such interventions in Malawi are less well understood than the biophysical science of agroforestry. The majority of agroforestry research in Africa published to date focuses on the agricultural science of yield response to particular farming approaches. Studies considering how improved yields contribute to food security and higher incomes are sparse.

Akinnifesi *et al.* (2008) reported World Agroforestry Centre survey data of 31 Malawian farmers who adopted agroforestry farming methods. The data show that 94 percent of farmers experienced a 'significant food security' improvement.[5] Of these farmers, 19 percent reported a tripling of maize yields, and 29 percent reported a doubling of maize yields. 58 percent of farmers reported an increase in income, and 97 percent reported an increase in savings. Similarly positive numbers were reported for Zambian farmers in the study. Ajayi *et al.* (2007) reported that given average fallow sizes and per capita maize consumption, agroforestry fertilizer trees generated between 54 and 114 extra person days of food for households in Zambia.

The study by Snapp *et al.* (2010), introduced earlier, reported a comprehensive, country-wide study comparing yields, profits and crop variability under different variants of crop diversification with legumes. 991 farmers participated in the study, which was run with the

[4] More recent statistics are not available due to a revision of the calculation methodology used by FAO.
[5] 'Significant food security' is defined by Akinnifesi *et al.* (2008) as a 2 or more month reduction in the number of months of insufficient food.

support of the Maize Production Task Force of the Malawian Government. Monocropped maize (fertilized and unfertilized) was compared to partially fertilized rotations and intercrops of *C. cajan* (pigeon pea), *Mucuna pruriens* and *T. vogelii*. Yields from the legume systems were high across soil and rainfall zones, with rotations superior to intercrops.

The Snapp *et al.* (2010) study showed that food security was improved most notably through the use of the maize, *C. cajan* and groundnuts rotation. Although maize production was slightly lower, overall protein production was 12-23 percent higher than under-fertilized, monocropped maize. The nutrition benefits of this system were recognized by female farmers in particular during follow up interviews. Crop yield variability was also reduced under the diversified systems. The observed yield variability measured by the Coefficient of Variation (CV) for diversified systems was 9-17 percent, for fertilized maize 12-26 percent, and for unfertilized maize 18–30 percent. Overall, this study demonstrated that inorganic fertilizer and agroforestry legume systems do not need to be substitutes, but that when used in a complementary fashion can improve food security and decrease crop yield variability across a wide range of soil and climate zones in Malawi.

A related paper by Kerr *et al.* (2007) reported on a particular case study within the larger research program reported on by Snapp *et al.* (2010). The 5-year case study, involving over 3,000 farmers from Ekwendei, north Malawi, investigated the preferences and food security implications of legume diversification. The project involved a ‘mother-baby’ experiment setup, where professionally managed trials were undertaken on village land to act as examples for farmers’ own experiments, which were used to corroborate the findings from the researcher’s plots. Trialed farming systems were those described above for the Snapp *et al.* (2010) paper.

Kerr *et al.* (2007) found that there was a strong preference for edible legumes such as *C. cajan* and groundnuts, rotated with maize. 70 percent of participating farmers used the legumes primarily as a food source, with some additional firewood and seed collection benefits. Improving soil condition, a primary advantage of agroforestry diversification was infrequently cited by farmers as a reason for their choice of crop. Female farmers in particular heavily emphasized the nutrition benefits from the produce of legume rotations. Pigeon peas *(C. cajan)* are harvested at the end of the dry season (known as the ‘hunger season’), conferring recognized food security benefits. There was a statistically significant increase in children’s consumption of high protein legumes amongst households who participated in the legume diversification trials, compared to control farmers. The authors also comment on the gender aspects of legume diversification: tree species of legumes are preferred by men, while herbaceous legumes are preferred by women. Furthermore, agroforestry has higher labor requirements, and trees in Malawi are seen as male property.

Quinion *et al.* (2010) interviewed adopters of fertilizer tree technology in Malawi to evaluate socio-economic impacts. Their sample of 131 farmers in two study sites, Kasungu and Machinga, was limited by the lack of randomization or a control group. However, they drew some conclusions regarding the benefits of agroforestry. Incomes were diversified due to opportunities to harvest wood for construction materials and firewood, in addition to improved yields. There was also an increase in incomes following the adoption of agroforestry in Kasungu, although not in Machinga, which the authors argued is due to smaller plot sizes there. A quantitative estimate of food security was not provided, however, the authors argued that income and yields improved in general.

In summary, the profitability and socio-economic impacts of agroforestry in Malawi are understudied. The few papers published tend to use case studies with small sample sizes. The exception to this is the comprehensive, ten year study undertaken by Snapp *et al.* (2010), featuring both country-wide farm trials and detailed case studies. These studies documented an improvement in food security due to increased profitability and diversification of production. There appears to be evidence that superior economic returns can be achieved through the use of certain methods: for instance, intercropping or rotation with *G. sepium*, *C. cajan* and/or groundnuts, and improved fallow with *S. sesban.* However, relatively slow adoption rates (see section 3.5) suggest that more research is needed, especially on the drivers of adoption.

3.5. Adoption of Agroforestry in Malawi

Based on the evidence regarding improved yields, agroforestry has received extensive promotion by both government and non-government organizations over the past decade. Agroforestry was prioritized by the Malawian Government as a key component of the 2005 National Agricultural Agenda. The largest example of such prioritization in Malawi is the ‘Agroforestry Food Security Program,’ a joint Government-ICRAF endeavor to provide tree seeds, nursing materials and extension advice for farmers (ICRAF, 2011). Such direct assistance has allowed over 180,000 farming households to undertake agroforestry practices so far (Garrity, *et al.* 2010). However, the extent to which such success can be maintained or emulated without direct subsidy is unclear. Despite the success of this particular program, and despite increasing recognition of the benefits of agroforestry, adoption rates are low across southern Africa (Sirrine, *et al.* 2010).

The reasons for low adoption rates are being addressed by a growing literature on agroforestry adoption (Ajayi, *et al.* 2008; Mercer, 2004). Such studies are necessary for improved design of agroforestry programs and policies (Akinnifesi, *et al.* 2010; Sirrine, *et al.* 2010; Chirwa and Quinion, 2005). There are two broad types of adoption study approaches: *ex post* analysis, which determines the drivers responsible for adoption of an established agroforestry approach, and *ex ante* analysis, which predicts the likelihood of adoption of a new, often experimental agroforestry approach given the potential benefits offered. The latter is most common in the adoption literature for Malawi. In this section, we consider both types, firstly those undertaken across a wider geographic region, and secondly those specific for Malawi.

At the broadest level, there are a number of studies, which searched for fundamental determinants of agroforestry adoption – characteristics of farms and farmers which consistently drive the decision to adopt. Pattanayak *et al.* (2003) reviewed the agroforestry adoption literature globally and conducted a meta-analysis on 32 studies. They divided up determinants of adoption into 5 categories: preferences, resource endowments, market incentives, bio-physical factors and risk/uncertainty. They found that soil quality, plot size, extension and training, tenure, and household wealth/assets were the most important fundamental determinants of adoption. They also argued that much research had neglected the importance of market incentives, bio-physical factors and risk/uncertainty. Mercer (2004) provided a broad review of the agroforestry adoption literature and largely concurred with the findings of Pattanayak *et al.* (2003). He also highlighted the difficulty agroforestry adoption faces due to the long wait before benefits are fully realized. Consequently, agroforestry projects will be slower to become self-sustaining and self-diffusing than earlier ‘Green Revolution’ advances (based on annual crops). In general, agroforestry uptake is particularly complex due to the multiple components and multiple years through which testing and adaptation takes place (Mercer, 2004; Ajayi, *et al.* 2008).

Ajayi *et al.* (2007), Ajayi *et al.* (2008), Akinnifesi *et al.* (2008) and Akinnifesi *et al.* (2010) summarized determinants of agroforestry adoption across southern Africa as found in a number of empirical studies. Some general findings included (1) households with a larger pool of labor or larger land holdings are more likely to adopt; (2) agroforestry approaches that provide an additional marketable product (e.g. grain or fruit from fertilizer trees) or can be planted directly from seed are more likely to be adopted; and (3) a poorly functioning fertilizer tree seed market is a serious constraint, as are bush fires and livestock browsing, especially in the absence of perennial private rights to land. Interestingly, there is a large variation in the impact of specific factors on adoption between different study sites (Ajayi *et al.* 2008). Concluding similarly, Knowler and Bradshaw (2007) argued that research on the fundamental causal factors of agroforestry adoption is now less valuable than research which aims to identify (and utilize) the causal factors relevant for a specific project in a specific location.

There are a number of studies on the adoption of agroforestry specifically in Malawi. Sirrine *et al.* (2010) undertook a 10 year, participatory trial with 48 farmers near Zomba in southern Malawi. They found that the type of agroforestry adopted was based more on immediate livelihood benefits, such as the provision of a secondary food or fuel source, than on long term soil quality or maize yield benefits. *C. cajan* (pigeon pea) was the preferred agroforestry system for this reason. However, wealthier and younger farmers, and those with larger landholdings were more likely to adopt the *S. sesban* agroforestry system, which has the greatest impact on maize yields via improved soil health.

Kerr *et al.* (2007) undertook an assessment of farmer adoption decisions as part of the larger, cross country study by Snapp *et al.* (2010). Kerr *et al.* (2007) used data from 1,000 farmers in Ekwendeni, northern Malawi, who participated in a 5-year participatory research and education project. Farmers learned about alternative legume approaches (including fertilizer trees) through village research plots and chose whether or not to adopt the approach on their own plots. The use of legumes expanded by 862 m^2 on average per farm by the project's completion. 72 percent of farmers reported utilizing legume biomass in 2005, compared to 15 percent before the project. As in the study by Sirrine *et al.* (2010), *C. cajan* (pigeon pea) was most commonly adopted.

Thangata and Alavalapati (2003) investigated farm and farmer characteristics that influenced adoption of agroforestry approaches in the densely populated Domasi valley of southern Malawi. 59 farmers participated in the study, which considered the adoption of mixed inter-cropping of *G. sepium* and maize. As found in other studies, younger farmers and farmers with frequent contact to extension staff were more likely to adopt. They also found that larger households were more likely to adopt, likely due to the higher labor requirements of agroforestry relative to monocropped maize. An earlier study by Thangata *et al.* (2002) addressed the same question but used a linear programming approach and data from Kasungu in central Malawi. They found that adoption of improved fallow was driven by available land and labor resources, and that gender was inconsequential (it should however be noted that this study did not differentiate between types of improved fallow, which other studies suggest is influenced by gender). The authors also reported that the ability to sell agroforestry species seeds (either to an NGO, government program or private buyers in a market) increased adoption.

Thangata *et al.* (2002) also argued that the decisions made by smallholder farmers are likely to reflect farmer perceptions of worst-case climate and yield scenarios rather than average scenarios. Resource limitations force farmers to be risk averse, who thus may be less likely to deviate from established farming practices even when the alternatives may provide superior yields. The reporting of average results, rather than worst-case results may lead researchers to be more in favor of alternative farming methods than risk-averse smallholder farmers.

In summary, there is a large and growing literature on the adoption of agroforestry globally, and a small number of papers directly relevant to policy development in Malawi. The results of the Malawi studies are largely consistent: younger, wealthier farmers with greater access to land and labor are more likely to adopt. Of the competing approaches, *C. cajan* (pigeon pea) was preferred and most often adopted, especially by female farmers. Overall, smallholder farmers have been found to be prepared to adopt agroforestry but only at low levels. Adoption is based less on a desire for long term soil regeneration (and thus higher maize yields) and more on short term alternative food or fuel wood production. High labor requirements (even in densely populated areas), access to seed markets (for both purchasing and selling of seed), and access to improved legume genotypes are constraints to adoption. Research and extension focused on the multifunctionality of agroforestry products, as well as complementary programs to facilitate seed markets may increase adoption.

4. Conservation Agriculture in Zambia

4.1. Background

CA is based on the integrated management of soil, water and biological resources, and external inputs. It attempts to achieve ‘resource-efficient’ crop production by utilizing three farming principles: (1) minimum soil disturbance, (2) organic soil cover and (3) diversified crop rotations (FAO, 2011; Hobbs, 2007). In focusing on three specific farming practices, the CA concept is more limited in scope than CSA, which is defined less by specific practices and more by a set of outcomes (e.g. food security, adaptation and mitigation). CA, in theory, has the potential to be part of a CSA strategy to agricultural policy making, however, its suitability should be assessed on a case by case basis as local agro-ecological and institutional environment plays a role in determining its adoption and impacts.

The three components of CA practice jointly aim to maintain a permanent or semi-permanent organic covering on the soil, either with dead mulch or the crop itself. This covering protects the soil from erosion and provides a more amenable environment for soil biota (Gowing and Palmer, 2008; Knowler and Bradshaw, 2007). In contrast, mechanical tilling degrades soil microstructure, buries organic material and disturbs natural biological processes. CA’s avoidance of mechanical tilling helps maintain soil porosity, allowing water to infiltrate the soil, reach crop roots and slow erosion processes. CA does not avoid the use of synthetic chemicals. For instance, weed control previously achieved through tilling may be replaced by increased herbicide use, at least initially. However, a long term reduction in input requirements is often stated as a benefit of CA (Knowler and Bradshaw, 2007; Hobbs, 2007).

It should be noted that a number of authors (see for instance Erenstein, 2002; Kassam *et al.* 2010) argue that CA is not a single technology that can be appended piecewise to existing practices. It is a bundle of complementary management practices, which in aggregate, replace much of the conventional cultivation approach. This necessitates a considerable investment in farmer training and tools, new types and quantities of inputs, and furthermore, entails risk during transition.

In the next section, we provide a general summary of the potential impacts of CA. In sections 4.3 and 4.4, we consider the use and yield impacts of CA specifically in Zambia. Sections 4.5, 4.6 and 4.7 summarize the published research on the profitability, socio-economic impacts and adoption of CA, respectively.

4.2. Impacts of Conservation Agriculture

CA delivers well recognized economic and environmental benefits in a range of agro-ecosystems globally. The total worldwide area of adoption in 2011 was estimated at 125 million ha, or 9 percent of arable cropped land (Kassam, *et al.* 2012). Most of this is located in North America, South America and Australia. In Southern Africa, CA has risen in prominence due to active promotion by the NGO community, farmer organizations, research institutions and the FAO (FAO, 2011b; Knowler and Bradshaw, 2007). The basis for this promotion is the contention that CA yields are equal or better than those under conventional agriculture and, in addition, that the sustainability of those yields is more certain (see for instance Kassam *et al.* 2010; Kassam *et al.* 2012, Branca *et al.* 2011, Hobbs, *et al.* 2007; Erenstein, 2002). There is a large and growing literature assessing the productivity potential of CA, including a number of valuable meta-studies. However, CA literature focused on Africa, where CA use is small, is limited. Given the urgent need to improve agricultural productivity in Africa, it is increasingly recognized that CA research and extension in Africa should be a high priority (Fowler and Rockström, 2001).

There are a number of meta-studies which attempt to quantify the average impacts of CA based on disparate uses. These assessments pertain both to environmental impacts and, to a lesser extent, yield impacts. Lal (2009) reviewed the literature on soil conservation globally and concluded that mulching and no-till clearly improved soil health, sometimes improved yields (depending on conditions) and usually improved profits (due to lower inputs). Farooq *et al.* (2011) reviewed 25 long term CA trials (mainly from North America, Australia and Europe) and found that crop yields showed a slight increase, which grew over time, relative to conventional tillage. The CA advantage is most pronounced in dry conditions. Pretty *et al.* (2006) gathered evidence on the effect of CA from 286 developing country case studies. The selected cases were examples where ‘best practice’ sustainable agriculture interventions had occurred. For interventions related to smallholder CA, average yield improvement was over 100 percent.

Branca *et al.* (2011) undertook a comprehensive, empirical meta-analysis of 217 individual studies on CA globally. Their empirical analysis showed that improved agronomic practices such as cover crops, crop rotations (especially with legumes) and improved varieties has increased cereal productivity by 116 percent on average across the studies consulted. Similarly, reduced tillage and crop residue management caused an increase of 106 percent, and agroforestry techniques caused an increase of 69 percent. Tillage management and agroforestry were found to be particularly beneficial in dry agricultural areas. Of particular relevance to this study was the finding that CA adoption in sub-Saharan Africa caused greater productivity increases (in percentage terms) than CA adoption in Asia, likely due to the low input nature of agricultural practices in the former region.

It should be noted, however, that Pretty *et al.* (2006) purposely selected 'best practice' examples, and both Pretty *et al.* (2006) and Branca *et al.* (2011) mainly considered those studies examining CA practices as utilized on farms already (as opposed to trial plots). Given that only demonstrably successful technologies will be widely adopted, and then presumably only under circumstances where they are suitable, positive results are to be expected. Hence, although there is general agreement that CA can improve yields under at least some circumstances, a debate continues over how extensive these circumstances are in practice.

Nkala *et al.* (2011), Giller *et al.* (2009), Gowing and Palmer, (2008), Knowler and Bradshaw (2007) and Lal *et al.* (2004) outlined a number of reasons why CA may not be suitable in particular contexts. For instance, crop residues are often used as animal feed: the benefits of mulching with crop residues may not be worth the trade-off of reduced livestock numbers. Similarly, there may be a trade-off between labor saved on tillage and labor spent on increased weeding, in the absence of herbicides. These authors also raised questions about which elements of CA drive yield improvements: changes to tillage, crop rotation or soil cover. Many published studies do not vary only one factor, but instead examine the effects of CA overall (Giller *et al,* 2009; Gowling and Palmer, 2008). This often includes confounding changes to herbicide and fertilizer regimes. While proponents of CA argue that the method is 'holistic', and thus cannot be reduced to a single element, such information would allow for ongoing refinement of the CA approach.

The circumstances in which CA is beneficial are also related to the time after adoption. Erenstein (2002) concluded, through a review of literature, that in the short term, yields can rise, fall or remain unchanged. Over time the productive benefits of improved soil chemistry, biology and structure are more likely to deliver increased yields, however, discrepancy between short term and long term yields can hinder adoption (Nkala *et al.* 2011; Giller *et al,* 2009; Fowler and Rockström, 2001).

The debate over whether the CA approach has the potential to make a large impact on yields and food security is particularly relevant for sub-Saharan Africa, where rates of CA uptake are very low. Estimates by Friedrich *et al.* (2012) indicated that 368,000 ha of cropland is managed using CA in Africa, approximately 0.1 percent of the continent's arable crop land. This represents only 0.3 percent of the CA area globally. In contrast, 69 percent of arable land in Australia and New Zealand, and 57.5 percent of arable land in South America is cultivated under CA.

4.3. The Use of Conservation Agriculture in Zambia

Although the use of CA in sub-Saharan Africa is limited overall, its use in Zambia is relatively substantial: 40,000 ha are cultivated using CA practices, a greater amount than in any other SSA country (Friedrich, *et al.* 2012). The number of farmers who practice CA is not clear as estimates vary depending on how CA is defined. Neubert *et al.* (2011) reported that in 2007 around 120,000 Zambian farmers used some form of CA, (approximately 10 percent of smallholder farmers), while the Conservation Farming Unit puts the estimate around 170,000 (CFU, undated). CA use is highest in the southern, semi-arid parts of the country (with annual rainfall between 650 and 1,000 mm) due to the greater suitability of CA techniques there. Farmers in these areas undertake mixed crop and livestock operations, and grow mainly maize and cotton (Baudron, *et al.* 2007).

This relatively widespread adoption is a product of agricultural crisis (Rockström, 2007; Haggblade and Tembo, 2003) and sustained promotion, mostly including subsidized inputs (Umar *et al.* 2011; FAO, 2011b). Economic difficulties led to the defunding of Government-financed agricultural subsidies and extension programs in the 1990s, which had previously underpinned maize production in Zambia. Between 1991 and 2003 there was no explicit agricultural policy held by the National Government. At the same time, Zambian farmers were struggling with soils depleted from years of monocropping, a serious drought, an outbreak of livestock disease and high fuel prices (Haggblade and Tembo, 2003).

In response, the Zambia National Farmers Union (ZNFU) began promoting CA to smallholder farmers in 1995 through a newly formed Conservation Farming Unit (CFU). Commercial farmers had used CA previously to reduce fuel expenditure, but discovered yield and soil conservation benefits also. These practices were adapted for smallholder operations and promoted with demonstration plots (Haggblade and Tembo, 2003). The promotion of CA to smallholders was endorsed as an official priority by the Zambian Government in late 1999 and was included in the 2004 'National Agriculture Policy' (Neubert, *et al.* 2011). A number of non-government organizations, international organizations (e.g. FAO, World Bank, SIDA, Norad and the EU) and government departments have since assisted the ZNFU/CFU in their promotional efforts (Umar, *et al.* 2011; FAO, 2011b).

The CA techniques promoted in Zambia are known collectively as 'Conservation Farming' (CF). These are (1): reduced tillage to no more than 15 percent of the field area without soil inversion, (2) precise digging of permanent planting basins (to maintain soil moisture) or ripping of soil with a 'Magoye ripper' (the latter used where draft animals are available), (3) keeping of crop residues (no burning), (4) rotation of cereals with legumes and (5) dry season land preparation. This suite of techniques has been promoted through the subsidized offering of input packages (seed, fertilizer and lime) conditional on adoption. Not all smallholder farmers practice the entire suite of CF techniques: in 2003 approximately one quarter of farmers applied all five, while three quarters applied only a selection (Baudron, *et al.* 2007). A separate set of CF guidelines exists for mechanized commercial farmers.

The use of the ripper or planting basins limits soil disturbance to only those places where seed will be directly sown (5-15 percent of the surface area). The depth of soil disturbance is similarly minimized. By undertaking land preparation during the dry season farmers can avoid the labor shortages that often arise at the start of the rainy season. Advance land preparation also means seed can be sown immediately after the first rains arrive, allowing the developing crops to take advantage of the elevated moisture and nitrogen levels found in the soil at this time. Haggblade and Tembo (2003a) reported that yields of maize and cotton typically fall by 1-2 percent for every day planting is delayed after the first rains.

4.4. Conservation Agriculture and Crop Yields in Zambia

There is a small literature that assesses the yield impacts of CA as practiced in Zambia. Langmead (undated) analyzed pooled data from 5 trials in agro-ecological regions IIa and III (with 800-1,000 mm and more than 1,000 of rainfall, respectively) during the 2002/2003 season. The trials represent different interventions related to CF under different cropping systems and lime applications. They found that timely farming is the most important determinant of yield and yield variability. Timely conventional farming increased yields by 50 percent, and CF (planting basins plus lime) increased yields by 68 percent. The authors found that timeliness is the most important component of CF.

Rockström *et al.* (2009) presented results from a 2 year on-farm trial of different farming systems in Zambia, amongst other SSA countries. The Zambian trial site was Chipata (East

Zambia), a moderate rainfall location (approximately 1,000 mm annually) that supports mixed crop-livestock operations. Their experiment compared the CF approach (as described above) with conventional tillage as practiced in the study area. Farmers played a key role in choosing the specific crop management practices applied, and also managed the plots. Maize yields on the CF plots (> 6,000 kg ha^{-1}) were double those on the conventional plots, with no significant difference between the use of planting basins and rip lines. Both treatments and the control received fertilizer inputs. The authors expressed some surprise at this result and recommend further research given that they could not completely explain its magnitude.

Rockström *et al.* (2009) also noted that CA appeared to improve yields most directly by improving soil moisture, especially for the lowest productivity systems. They concluded that for smallholder farmers in savannah agro-ecosystems, CA is primarily a water harvesting strategy, valuable even when crop residue retention efforts were unsuccessful. They also noted that the soil moisture effect works in conjunction with fertilizer application. Their findings from their Kenyan and Ethiopian plots suggested that at least some fertilizer input (applied precisely to planting basins and rip lines) was required for crops to take advantage of the additional soil moisture, and likewise, increased soil moisture was required to take advantage of fertilizer. Unfortunately, the extent to which this finding holds in the higher rainfall context in Zambia cannot be determined from this study given its limitations.

Similar findings with regard to soil moisture benefits were presented in two related papers by Thierfelder and Wall (2009; 2010). These authors undertook a multiyear, researcher-managed cropping trial at Monze, Southern Zambia (annual rainfall of 748 mm) to evaluate the impact of tillage practices on water infiltration, runoff erosion and soil water content. Infiltration rates were 57-87 percent higher on CA plots. Resultant higher soil moisture levels were found to improve yields in poor seasons, demonstrating that CA has the potential to reduce the risk of crop failure due to low or poorly distributed rainfall.

A third paper by Thierfelder and Wall (2010a) used data from the same experiments to assess the impact of crop rotations. Monocropped maize was compared to maize-cotton-sunhemp (the latter is *Crotalaria juncea,* a leguminous manure crop) rotations under different tillage and CA regimes. Soil quality as measured by aggregate stability, total carbon and earthworm populations was significantly improved on CA plots. Maize yields were 74-136 percent higher under the 3-species CA rotation regime, and even in a simple maize-cotton rotation were 38-47 percent higher. These benefits of rotation were found in the absence of pests and diseases, indicating that CA has benefits beyond pest and disease control.

FAO (2011b) provided an assessment on the yields and profits under CA in Zambia. Data for the study is based on a combination of previously published information and group discussions with CA farmers in the Chongwe district (located in south-central Zambia with rainfall between 600 and 1,000 mm). The authors reported that CA (defined either by the use of planting basins or rip lines) yielded an average of 3,000 kg of maize grain per ha, 42 percent more than conventional draft tillage. Even larger percent increases were found in a parallel assessment of CA in neighboring Zimbabwe. It is not clear, however, how many farmers participated, or how they were selected for the study. An unfortunate lack of background information in this report means that these results can be considered suggestive only.

In addition to the trial-based analyses, there are also some publications based on socio-economic surveys of farmers (both CF and non-CF farmers). Haggblade and Tembo (2003) conducted a comprehensive CF assessment in central and southern provinces during the 2001/2 cropping season. The authors aimed to assess the yield and profit impact of CF, taking into account other changes (such as fertilizer use) that could otherwise confound findings. This is particularly important given that many CA programs in Zambia have been promoted through the provision of 'input packs' from sponsors, which contain hybrid seeds, fertilizer, lime and other productivity-enhancing materials. 125 randomly selected farmers, with multiple plots each (both CA and conventional tillage), were surveyed. For each farmer, plots were selected for assessment that were comparable in terms of soil and rainfall, but differed in terms of farming practice.

Average maize yields were 3,054 kg ha^{-1} under basin planting CF and 1,339 kg ha^{-1} under conventional tillage. Of this large increase, the authors found that CF techniques themselves were responsible for 700 kg of yield improvement, and increased fertilizer and hybrid seed use were responsible for 300-400 kg. A large positive impact was found due to earlier planting, which although possible under either conventional or conservation farming, is facilitated by the latter.

Haggblade *et al.*(2011) used a simulation (linear programming) model calibrated with Post Harvest Survey data from 2004 in order to assess the productivity impact of CF on smallholder cotton farmers in region IIa. They show that CF has the potential to increase yields (of both maize and cotton) by around 40 percent due to early planting and improved soil quality.

These findings were supported by a small study by Umar *et al.* (2011). These authors interviewed 129 randomly selected farmers in the Central and Southern province of Zambia, who practiced both conventional and conservation agriculture. Yields were significantly higher under basin planting CF than under conventional tillage (5,200 versus 3,800 kg ha^{-1} respectively). As was the case in the Haggblade and Tembo (2003) study, these authors found no significant improvement of the ripping CF method over conventional tillage.

A different approach is taken by FAO (2011c) in their assessment of CA and climatic risk in Southern Africa. The authors reported the results of agricultural production systems simulator models (APSIM) on outputs in varied biophysical circumstances. They concluded that in semi-arid environments, CA can improve yields in drier seasons and thus improve climate change resilience. In sub-humid environments, they found that CA offered little yield benefit at least in the short term. A key reason for this is the danger of water-logging which can occur in wet seasons, a conclusion also reached by Thierfelder and Wall (2009; 2010).

Based on the studies specifically on the yield impacts of CA in Zambia reviewed here (8 independent studies in 10 publications), the evidence for improved yields is positive but weak. Five of the eight sources may be hampered by confounding variables, endogeneity or selection bias. One source lacks adequate background information to assess the quality of the research, and the other two rely on simulations rather than observed output from an unbiased sample of CF and non-CF farmers. While it is clear that CA practices have a positive effect on yields, particularly in drier parts of Zambia, how large this effect is and how much of that can be attributed to the practice itself (rather than changes in input and timing of cropping operations) requires further research.

4.5. Economic Feasibility

The evidence for improved economic circumstances due to CA adoption is similarly limited. Although there is some evidence (presented above) that CA techniques improve yields, evidence of resulting higher incomes is scarcer. Studies that do address this topic, specifically with regard to Zambia, are Haggblade and Tembo (2003); Haggblade *et al.* (2011) and FAO (2011b; 2011c).

Haggblade and Tembo (2003), introduced previously, undertook a financial analysis of farm operations in order to compare returns under CF and conventional tillage. Gross margin per ha of maize were 64 percent better under CF (basin planting, hand weeding) than under conventional tillage. Labor requirements, however, were 25 percent higher for CF in the absence of herbicide use. For farms with access to draft animals, there was no profit advantage of ripping CF.

The study by Haggblade *et al.* (2011) updated these results based on a linear programming model introduced above. They reported gross margins of USD 139 ha^{-1} for unfertilized, conventional maize (average yield of 900 kg ha^{-1}). Unfertilized maize grown using CF techniques (basin planting using a hand hoe) generated a gross margin of USD 200 ha^{-1} (average yield of 1300 kg ha^{-1}). The addition of fertilizer to CF maize improved yields dramatically (3,000 kg ha^{-1} on average) and led to a slight improvement in profitability (USD 205 ha^{-1}). Cotton farming profitability similarly improved, with unfertilized, conventional cultivation generating a gross margin of USD 246 ha^{-1} and unfertilized, CF cultivation generating USD 328 ha^{-1}. The fertilized CF systems require cash or credit to cover input costs, however, the unfertilized CF systems do not. Based on this, Haggblade *et al.* (2011) argued that the poorest smallholder farmers can improve gross margins by 140 percent, without the need for cash inputs, by using CF regimes.

FAO (2011b) similarly undertook a financial analysis of farm operations. The authors reported gross margins for maize that were more than 100 percent greater under CF (basin planting, hand weeding) than under conventional tillage. Unlike Haggblade and Tembo (2003) they found higher profits from the use of ripping CF compared to planting basin CF. Due to higher input use (seed, fertilizer and labor), costs were higher under CF (USD 376 ha^{-1} for basin planting) than conventional tillage (USD 295 ha^{-1}) however superior yields compensated for this.

FAO (2011b), Haggblade and Tembo (2003) Umar *et al.* (2011) and a number of other authors commented on the labor requirements of CF. FAO (2011b) estimated that the CF basin planting required 69 percent more labor overall than conventional tillage. Although labor is saved on tillage, the digging of basins and the more frequent weeding required in the absence of tillage more than negates this advantage. The high labor requirement can be reduced significantly by the use of herbicides, but in many areas these are unavailable or expensive. There is also a gender dimension to this labor requirement: in Zambia, traditionally men are responsible for field preparation while women are responsible for planting, weeding and harvesting. An increase in weeding requirements due to a decrease in tillage may shift the burden of work towards women.

4.6. Livelihood and Food Security Impacts

Literature specific to the livelihood and food security impacts of CA in Zambia is limited, although conclusions regarding benefits can be drawn from the findings on profitability above. A number of papers have argued that CA practices improve livelihood prospects based on reviews of studies from diverse locations (see for instance Bianca *et al.* 2011; Hobbs, *et al.* 2008; Pretty *et al.* 2006). However, a positive conclusion has not been reached by all authors. Nkala *et al.* (2011), Baudron *et al.* (2011) and Giller *et al.* (2010) argued that the ‘fundamental’ benefits of CA have been overstated and, that if anything, benefits are highly context specific. Unfortunately there is very little literature specific to the Zambian context.

Nyanga (2012) documented results from a 4-year study assessing the food security impacts of CF in 12 agricultural districts in central and eastern Zambia. Survey responses from 640 randomly-selected farmers (practicing both CF and conventional farming) were used to form a panel dataset. Analysis focused on the impact of legume cultivation, which are often grown as part of the rotation regime promoted by the Zambian CF approach, on food security narrowly defined as increased consumption of legumes. Legume cultivation was, unsurprisingly, higher under CF, which led to higher legume consumption and higher income from legume sales. The increased diet diversity and increased cash income were considered to be indicators of improved food security. The author also reported that planting basins allow crops to be harvested earlier, reducing hunger that would otherwise occur before conventional crops are mature. Nyanga (2012) attributed these food security improvements to crop rotations (of which legumes are a key component) rather than tillage per se. Quantitative results in this study are based on overly simplistic specifications and hence may suffer from problems of endogeneity, and the panel nature of the data is not fully utilized. However, the study provides a positive indication of the benefits of legume rotations on dietary diversity.

Overall, the socio-economic impacts of CA in Zambia are not well known, despite the fact that the practice is better integrated in the Zambian agricultural sector than in any other African country. The limited evidence available suggests that the practice is profitable, however, it may be constrained by higher labor requirements. This may mean that for many farmers, CA is an insurance technique, where a small area is cultivated using planting basins in case of drought. FAO (2011b) reported that the area of land that can be effectively cultivated under planting basins by a single household is 0.6 ha due to labor requirements. Evidence of yield improvements from both on-farm and research trial plots suggest that CF is particularly effective at boosting yields during poor seasons – and thus represents a promising approach to climate change adaptation.

4.7. Adoption of Conservation Agriculture in Zambia

Despite the benefits of CF outlined above, and its promotion over the last fifteen years, adoption is relatively limited. As mentioned above, the number of farmers who use some form of CF is estimated to be between 120,000 and 180,000 (out of a total of around 1.2 million small/medium-scale farmers) (Neubert *et al.* 2011; CFU, undated). The number of farmers who have spontaneously adopted is likely considerably lower. Haggblade and Tembo (2003) reported that 20 percent of CF farmers in the 2002/3 season were spontaneous adopters, with the 80 percent majority practicing CF as a condition for receiving subsidised input packages.

Adoption rates are highest in the drier parts of Zambia (in agro-ecological zones I and II). While the danger of water-logging – a risk of CF – is lower in these areas, and the risk of drought –which CF can mitigate – is higher.

Primary constraints to adoption in Zambia are found to be the use of crop residues for other purposes (e.g. high opportunity costs of crop residues), labor constraints and the limited potential to grow cover crops during the dry season. Mixed crop-livestock farming operations have a high demand for crop residues for use as fodder, fibre and fuel. Leaving crop residues to provide soil cover thus entails a high opportunity cost (Rockström, *et al.* 2009; Giller *et al.* 2009).

Of these three constraints to CF adoption in Zambia, a number of authors argue that labor constraints are the most important (FAO, 2011b; Umar et al. 2011; Baudron, et al. 2007; Haggblade and Tembo, 2003). There are two components to this constraint: land preparation and weeding. Land prepared through the digging of planting basins is highly labor intensive. Baudron, *et al.* (2007) stated that the hiring of labor is rarely feasible due to unaffordable daily wages at peak times, and because hiring is not widely accepted culturally. Although land preparation ideally should take place in the dry season, alleviating labor requirements during peak times, this coincides with maximum soil hardness. Furthermore, farmers who prepare their land in advance often find that basins are destroyed by wind, rain or livestock before planting (FAO, 2011b). Secondly, there is a much larger weeding requirement (in the absence of herbicide use). Both sources of labor constraint may be lessened through the use of recent technological developments – a cost effective herbicide sprayer called the 'zamwipe', and an improved manual digging tool, the 'chaka hoe'. In addition, the ease of dry season land preparation is reported to improve over time, with labor requirements for this task approximately halving by the fifth year (Haggblade and Tembo, 2003a).

The relationship between land and labour resources and CF adoption is reported on by Chomba (2004). His study, based on survey data from 2,524 farmers in Eastern, Southern, Central and Luksaka Provinces, found that household size and land size positively influenced adoption rates of CF during the 1998-2000 seasons. He also found that distance to markets, support and extension services were important. This may be particularly so given that this study uses data collected early in the promotion of CF in Zambia. Length of land tenure influenced uptake of intercropping, an unsurprising finding, given that the full benefits of this approach are not realized for several years.

A number of authors suggest that adoption tends to be incremental and partial. Umar *et al.* (2011) found that almost all farmers practice both conventional and conservation agriculture on different plots. Farmers gradually convert additional plots if and when they are convinced of the benefits in doing so, up to the limit imposed by constraints such as labor availability. Given the constraints, such partial adoption may be a useful strategy for improving food security. Haggblade and Tembo (2003b) reported that 0.25 ha of carefully managed basin-planting CF can provide a minimal food security safety net for a family of four.

Nyanga *et al.* (2011) surveyed smallholder farmers' perceptions of climate change and CF in an effort to understand attitudinal and knowledge-based drivers of adoption. 469 farmers from 12 eastern and southern agricultural districts were interviewed in 2009. The authors documented a widespread awareness of increased climate variability, however most attributed this to supernatural forces rather than human activity. There was a positive correlation between perception of increased climate variability and the use of CF, but no correlation between attitudes towards climate change itself and CF. Interestingly, the authors found a widespread expectation of subsidy, input packages or material rewards for uptake of CF, which they argued has developed as a result of previous program's use of such incentives. This is concordant with a finding of Baudron *et al.* (2007), who reported that 50 percent of farmers dis-adopt CF if they no longer qualify for such incentives.

A recent paper by Arslan *et al.* (2013) provides the only panel data study on the adoption of CF practices in Zambia. The authors use nationally representative data from rural Zambia merged with historical rainfall data to analyze the determinants of adoption and the intensity of adoption of planting basins/zero tillage. They showed very low adoption (5 percent) and high dis-adoption rates (> 90 percent) between 2004 and 2008. Adoption rates are shown to be even lower when two of the CF practices are considered: only 3percent of households adopted minimum soil disturbance with crop rotations. Their econometric analysis controlled for the household fixed effects that confound the determinants of adoption in cross-sectional studies, and concluded that historical rainfall variability and extension coverage are the most important (and robust) determinants of adoption. They concluded that CA seems to provide adaptation benefits to highly variable rainfall, and policies to promote CA need to consider this in targeting.

In summary, CA has higher adoption rates in Zambia than other sub-Saharan African countries. However, adoption rates are lower than expected– and dis-adoption rates are higher than expected– given the apparent benefits. There is a small literature publishing the results of farmer surveys which documents the reasons for (low) adoption: whereas cross sectional studies conclude that the most important reason is labor constraints, the only panel study concludes that high rainfall variability is the most important determinant of adoption. However, elements of this literature also provide grounds to believe that these constraints can be at least partially alleviated through technological change and agricultural extension that tailors interventions to the local agro-ecological and socio-economic conditions.

5. Carbon Mitigation Co-benefits

The third key component of the Climate-Smart Agriculture approach is the mitigation of green house gas emissions. Improved agricultural practices, such as agroforestry and CA, can deliver significant carbon mitigation and reduced greenhouse gas emissions (Bianca, *et al.* 2011). Based on this, some authors have argued that there is the potential for carbon offset payments, which could pay for investments in improved farming, sequester emissions and simultaneously improve food security (Garrity, *et al.* 2010; Bryan *et al.* 2010; Palm, *et al.* 2010). For such a possibility to occur, however, precise estimates of carbon sequestration quantities under different farming regimes are required, with strong institutional oversight. The literature suggests that such a possibility in Africa is currently remote. In this final section we consider the mitigation potential of agroforestry and CA as determined by studies from across Africa, with a focus on Malawi and Zambia where possible.

Agroforestry stores carbon in above-ground biomass and, over time, increases organic matter, and hence carbon stocks in the soil. Rotations with legume crops or improved fallow reduces soil exposure and thus reduces CO_2 release. Minimal tillage practices reduce soil erosion and soil exposure, which otherwise facilitate the decomposition of soil organic matter and thus release CO_2.The incorporation of crop residues or agroforestry biomass into the soil directly increases soil organic matter and hence CO_2 storage. In mechanized farming operations (relevant only to larger farmers in Zambia and Malawi), minimal tillage practices save fossil fuel use that is otherwise expended on tilling (Bianca, *et al.* 2011; Smith, *et al.* 2007).

Although these general principles are well established, the dynamics of soil carbon flux are complex and difficult to predict, especially when other greenhouse gases (NO_x and CH_4 for instance) are considered (Palm *et al.* 2010; Smith, *et al.* 2007). The way in which net carbon intake changes over time is also important. Before implantation of improved farming techniques, a conventional plot may be releasing CO_2 sequestered prior to cultivation (thus acting as a CO_2 source). After implementation of an agroforestry or a no-till regime, net carbon intake may become positive as CO_2 is sequestered in biomass and stored as soil organic matter. Rates of uptake will be highest soon after the period of system establishment, and will gradually slow as the quantity of carbon held by the soil reaches a new, higher equilibrium (West and Post, 2002). The improved agricultural system must be maintained to ensure that the carbon remains sequestered.

There are two ways of assessing and reporting the sequestration potential of agricultural systems. Some studies report a *rate* (per year) of carbon sequestration. This rate is likely to vary depending on the quality of the season and the maturity of the system, and only applies while the system has not yet reached its carbon equilibrium. Others report the total soil organic carbon quantity, which represents the total amount of carbon that could be sequestered if the improved system is maintained. Such a quantity is thus a 'one-off' contribution, made over the time taken for the system to reach equilibrium. This can take 15-60 years (West and Post, 2002).

There is a substantial literature quantifying sequestration quantities from both agroforestry and CA. These estimates, however, vary widely under different systems and different agro-ecological zones. For instance, IPCC (Smith *et al.* 2007) estimated that no-till has a mitigation potential of 0.17 tonnes C ha^{-1} yr^{-1} in cool-dry conditions and 0.72 tonnes C ha^{-1} yr^{-1} in warm-moist conditions. They noted also that the mitigation benefits of no-till are often periodically reversed due to occasional or sporadic tillage, making assessment of the carbon balance highly uncertain. Another global assessment of no-till (West and Post, 2002), based on a meta-analysis of 67 long-term studies, found that a change from conventional till to no-till sequestered between 0.44 and 0.70 tonnes C ha^{-1} yr^{-1}, with a new soil carbon equilibrium being reached after 15-20 years on average.

With regard to agroforestry, Albrecht and Kandji (2003) reviewed studies from across the global tropics and found that such systems in Africa have a mitigation potential of 29 - 53 tonnes C ha^{-1} *in total.* They also summarized results from a number of studies investigating the mitigation potential of improved fallow. Trials in Kenya of *C. cajan, S. sesban and T. vogelii* sequestered 12.4, 21.5 and 14.8 tonnes C ha^{-1} in the first 12 months. These species are commonly used in agroforestry in Malawi and Zambia, although climatic and soil differences are likely to alter sequestration amounts found there. Vagan *et al.* (2005) undertook a comprehensive review of carbon sequestration potential in different African ecosystems, and found that agroforestry could sequester up to 5.3 tonnes C ha^{-1} yr^{-1}. An earlier Africa-wide estimate by Unruh *et al.* (2003) indicated that agroforestry could sequester 4.5 to 19 tonnes C ha^{-1} *in total,* depending on the type, location and management regime.

Kaonga and Coleman (2008) studied carbon sequestration in experimental fallows at Msekera, eastern Zambia. In a comparison with maize monoculture after *ten years*, they found that soil carbon stocks were more than 6 tonnes C ha^{-1} greater in coppicing fallows, and over 3 tonnes C ha^{-1} greater in non-coppicing fallows, using a variety of agroforestry tree species. These higher carbon stocks were achieved by accumulation of an extra 0.7 - 1.4 tonnes C ha^{-1} yr^{-1} relative to unfertilized monocropped maize. A related study (Kaonga and Bayliss-Smith, 2009) undertaken at this site found carbon stocks in the above ground biomass of fallow trees ranged from 2.9 to 9.8 t ha^{-1}, equivalent to a net carbon intake of 0.8–4.9 tonnes C ha^{-1} yr^{-1}. Once again, coppicing fallows were found to have much higher soil organic carbon levels than non-coppicing fallows.

Makumba *et al.* (2007) investigated the carbon mitigation potential of agroforestry practices in Southern Malawi, specifically, that of *G. sepium*-maize intercropping. Their ten-year field experiment at the Makoka Agricultural Research Station found that intercropping, and incorporating the tree mulch into the soil, resulted in 1.6 times more soil carbon than monocropped maize. In addition, 17 tonnes C ha^{-1} were sequestered in the biomass of the trees themselves, although this carbon would be returned to the atmosphere when the trees died or were burnt for firewood.

Thangata and Hildebrande (2012) took such estimates a step further by modeling the economic and carbon sequestration outcomes from providing carbon-credit payments to smallholder farmers. Their simulation used economic and farm data from 40 households in the Kasungu region of central Malawi. Models were constructed to predict each household's farm decisions – given resource constraints, economic objectives and market conditions – and from that, carbon outcomes. They predicted sequestration of 3.92 - 4.17 tonnes C ha^{-1} due to the use of improved fallow adoption incentivized by a small carbon payment (USD 6 t^{-1}). This study provides evidence that payments could have a substantial positive impact on carbon sequestration while meeting household food production requirements.

The studies regarding reduced tillage suggest that sequestration from this practice occurs in much smaller quantities than from agroforestry: approximately 0.2–0.4 tonnes C ha^{-1} yr^{-1}. (Garrity, *et al.* 2010). A number of authors have argued that CA offers the potential for large scale sequestration given the areas of land used for cropping (see for instance Farage *et al.* 2007; West and Post, 2002). However the circumstances under which reduced tillage achieves sequestration is not clear (Smith, *et al.* 2007; Baker, *et al.* 2007).

The specific sequestration quantities being achieved by CF in Zambia do not appear to have been studied. To the best of our knowledge there is a single study from Malawi: Ngwira *et al.* (2012) conducted soil carbon measurements in farmers' fields in Kasungu and Mzuzu districts. They found that organic carbon levels were 41 percent higher under zero till, in comparison to conventional till maize, over a 4-year period. Over a 5-year period, organic carbon levels were 75 percent higher.

In summary, there is considerable evidence that agroforestry leads to large carbon sequestration benefits, globally, and specifically under the conditions found in Malawi and Zambia. Estimates are highly variable, reflecting different soil and climatic conditions, tree species, tree densities and plot maturity. The study by Thangata and Hildebrande (2012) is a useful extension to such biophysical research. Their integrated agricultural-economic model suggested that agroforestry use in Malawi could and would be expanded if a small carbon-credit payment was made available, although this study relies on the strength of the previous studies. The evidence for carbon sequestration under reduced tillage is more mixed. Although a number of authors have found positive evidence from various locations, some argue that the benefits are insignificant. The depth at which soil organic carbon is measured is an important component in this debate. There is very little research into the carbon sequestration potential of CF as practiced in Zambia (or similar practices in Malawi).

6. Conclusion

Agriculture in developing countries must undergo significant transformation if it is to meet the growing and interconnected challenges of food insecurity and climate change (FAO, 2010). This need for transformation is most acute in Sub-Saharan Africa, where population growth is high and agricultural productivity has remained low for decades. The challenge of raising productivity is complicated by the current and expected impacts of climate change.

A proposed means of achieving productivity increases is increased adoption of a ‘climate-smart agriculture’ (CSA) approach (FAO, 2010). CSA, which is defined by its intended outcomes, rather than specific farming practices, is any policy or practice that contributes to the following three goals: (1) a sustainable increase in agricultural production, (2) an increase in agricultural resilience to climate change, and (3) a reduction in greenhouse gas emissions from agriculture relative to conventional practices (FAO, 2012).

Agroforestry and conservation agriculture (CA) are two farming techniques that are well aligned with the goals of CSA. This paper summarizes the potential for agroforestry and CA to contribute to improved food security and carbon-emissions mitigation in Malawi and Zambia respectively. Both countries are prioritizing these farming approaches as a means for tackling the severe food security challenges they face.

A range of published literature – primarily peer-review journals –regarding the use and impact of these farming approaches in the target countries was consulted. This review is not intended to be globally comprehensive for two reasons. Firstly, there are a number of such ‘global’ reviews already published, and secondly, the experience with these farming approaches varies greatly in different agro-ecological and social settings. Instead, this review attempts to include all recent literature relevant to the topic specific for Malawi and Zambia. In section 6.1 the results are summarized in the form of six key findings. A final section outlines opportunities for further research.

6.1. Key Findings

Key Finding 1: There is strong evidence for the benefits on annual food crop yields from agroforestry in Malawi, both as a substitute and a complement for inorganic fertilizers.

Agroforestry involves the planting of selected tree and shrub species either alongside, or sequentially (during fallow) to an annual food crop. The trees help maintain soil cover, improve nutrient levels, increase soil organic matter (via the provision of mulch), improve water filtration, and provide a secondary source of food, fodder, fiber and fuel.

There is abundant evidence that such practices can deliver dramatic increases in crop yields. For instance, the use of *Gliricidia sepium* intercropping led to an average improvement in maize yields of 345 percent, based on trials at 5 different sites in Malawi. Other species have shown similarly dramatic benefits. Published yield improvements from Malawi field trials of *Tephrosia vogelii, Sebania sesban* and *Cajanus cajan* ranged between 55 and 255 percent over monocropped, unfertilized maize.

Yields from agroforestry occasionally match those attained with the use of inorganic fertilizer. However, the best results occur through combined use. A half- or even a quarter-application of inorganic fertilizer in conjunction with agroforestry techniques can deliver yields equal to or superior to monocropped, fertilized crops. Furthermore, there is evidence that intercropped systems have more stable yields over time than monocropped, fertilized crops.

There is a considerable body of literature on the agricultural science of agroforestry, and numerous studies on the yield benefits of different techniques. The most comprehensive study is by Snapp, *et al.* (2010), which was conducted over 10 years in districts across the country. This study, along with contributions from others, provides a strong biophysical basis for designing policy.

Key Finding 2: Agroforestry appears to offer income and livelihood benefits, but adoption in Malawi has been slow to date.

The profitability and socio-economic benefits of agroforestry in Malawi are understudied. The few papers published tend to use case studies with small sample sizes, with the exception of that by Snapp *et al.* (2010).

The available literature documents numerous cases where the profitability of agroforestry systems is superior to that of unfertilized monocropped maize, and a few instances where it is also superior to that of fertilized monocropped maize. Cases of the latter involve partially fertilizing the agroforestry system. Under a future situation of higher fertilizer prices – a distinct possibility given high global energy prices – the profitability of agroforestry (either unfertilized or partially fertilized) relative to monocropped maize improves considerably.

The importance of secondary products from agroforestry production is a consistent theme in the relevant literature. Agroforestry species that provide edible legumes are particularly valued. In some cases, maize production is found to fall in an agroforestry system (for instance, under sequential fallow) but total calorie output is found to rise. Improving soil condition, a primary advantage of agroforestry, was infrequently cited by farmers as reason for adopting a particular agroforestry technique. Female farmers in particular heavily emphasized the nutritional benefits from the produce of legume rotations.

Despite these profit and food security advantages, adoption of agroforestry in Malawi (and across southern Africa) has been slow. It is argued by a number of authors that agroforestry projects will be slower to become self-sustaining and self-diffusing than earlier 'Green Revolution' advances. Agroforestry uptake is particularly complex due to the multiple components and multiple years through which testing and adaptation takes place. Some systems, notably *F. albida* require a long 'investment period' in which trees are developing but not yet contributing to improved yields.

There are notable successes, however. The largest in Malawi is the 'Agroforestry Food Security Program,' a joint Government-ICRAF endeavor to provide tree seeds, nursing materials and extension advice for farmers (ICRAF, 2011). Such direct assistance has allowed over 180,000 farming households so far to undertake agroforestry practices. A second stage of the program is currently underway.

The available literature highlights some consistent determinants of adoption: (1) households with a larger pool of labor or larger land holdings are more likely to adopt; (2) agroforestry that provides an additional marketable product (e.g. nuts or fruit from fertilizer trees) or can be planted directly from seed is more likely to be adopted; and (3) a poorly functioning fertilizer tree seed market is a serious constraint, as are bush fires and livestock browsing, especially in the absence of perennial private rights to land. Of the competing approaches, *C. cajan* (pigeon pea) was preferred and most often adopted, especially by female farmers.

Overall, adoption is based less on a desire for long-term soil regeneration (and thus higher maize yields) and more on short term alternative food or fuel wood production. High labor requirements (even in densely populated areas), lack of access to seed markets (for both purchasing and selling of seed), and lack of access to improved legume genotypes are constraints to adoption. Research focused on the multifunctionality of agroforestry products, as well as ways to facilitate seed markets may help identify ways forward.

Key Finding 3: There is modest evidence of yield benefits of conservation agriculture in Zambia.

Conservation agriculture (CA) attempts to achieve 'resource-efficient' crop production by utilizing three farming principles: (1) minimum soil disturbance, (2) organic soil cover and (3) diversified crop rotations. These three components of CA, practiced jointly, aim to maintain an organic covering on the soil. This covering increases the soil organic carbon content, improving fertility, soil structure and soil biota levels.

CA is used on only 0.1 percent of Africa's arable crop land (compared to 9 percent globally). Its use in Zambia, promoted in its specific form known as 'conservation farming' (CF) is relatively substantial – claimed to be practiced on 40,000 ha – the largest of any SSA country. However, it is difficult to assess exactly which components of CF are practiced or how stable adoption is when subsidized inputs provided at the beginning of promotion efforts are discontinued.

There is a large global literature on CA and a small number of papers specifically relevant to Zambia. Evidence for improved yields is positive but weak. A number of the papers consulted for this review contained suspected methodological problems. While it is clear that CA practices have a positive effect on yields, particularly in drier parts of Zambia, how large this effect is and how much of that can be attributed to the practice itself (rather than changes in inputs and the timing of planting) requires further research. Estimates reviewed ranged from a 42 to 200 percent increase in maize yields as a result of use of the CF system, although we consider this a tentative indication only.

A number of authors found that CA improves yields most directly by improving soil moisture, especially for the lowest productivity systems. They concluded that for smallholder farmers in savannah agro-ecosystems, CA is primarily a water harvesting strategy. Consequently the technique has the greatest benefits during poor seasons and thus represents a useful climate change adaptation strategy. The disadvantage of this is an elevated danger of water-logging in wet seasons. CA is thus best suited to dry areas of Zambia.

An advantage of CA is that it allows for dry season land preparation, allowing for crop sowing immediately after the first rains arrive. However, dry season land preparation is not always possible (see Key Finding 5).

Key Finding 4: There is modest evidence for financial and livelihood benefits of conservation agriculture in Zambia.

The evidence for improved economic circumstances due to CA adoption in Zambia is positive but inconclusive. This review consulted four studies that undertook financial analyses of CA practices in Zambia. The improvement in gross margins over conventional tillage ranged from 44 to 140 percent. These improvements were most commonly achieved using planting basins, and sometimes herbicide and inorganic fertilizer.

Some authors found that costs were higher under the CA system, primarily due to increased labor requirements (see Key Finding 5). CA requires labor-intensive digging of planting basins although this labor requirement diminishes in subsequent seasons. It also requires increased weed control, either by herbicide application or hand weeding. Both reduce the profit advantage of CA relative to conventional tillage.

Beyond the positive but limited results in Zambia, there is a debate regarding the economic benefits of CA in SSA. A number of authors (see for instance Nkala *et al.* (2011), Baudron *et al.* (2011) and Giller *et al.* (2010)) have argued that the 'fundamental' benefits of CA have been overstated and that any benefits are highly context specific. Although several studies on CA effects in Zambia are positive, more recent work has raised questions about its widespread viability (Arslan et. al. 2013). Thus there is a need for further research to identify in what contexts CF is best promoted.

Key Finding 5: There are considerable constraints to the adoption of conservation agriculture in Zambia.

Despite the benefits of CA outlined above, and its promotion over the last fifteen years, adoption is relatively limited. In 2010 around 170,000 Zambian farmers used some form of CA, approximately 10 percent of smallholder farmers. The number of farmers who have spontaneously adopted is likely considerably lower, as many farmers seem to practice CA due to incentives offered by government programs. For instance, 20 percent of CA farmers in the 2002/3 season were reported to be spontaneous adopters, with the remaining 80 percent practicing CA as a condition for receiving subsidised input packages. Adoption rates are highest in the drier parts of Zambia (in agro-ecological zones I and II with rainfall between 600 and 1,000 mm), as is expected given the dangers of water-logging in wetter areas.

There is a small literature on the constraints to adoption in Zambia – the most important ones being labor constraints and the opportunity cost of crop residues (given traditional cattle grazing rules). Estimates of increased labor needs ranged from 16 to 69 percent over conventional tillage. Although labor is saved on reduced tillage, the digging of basins and the more frequent weeding required in the absence of tillage outweighs this advantage. The high labor requirement can be reduced significantly by the use of herbicides, but in many areas these are unavailable or expensive. The preparation of land during the dry season – described as a key benefit of CA as it frees up labor during the peak sowing season – is not always possible due to soil hardness and the use of the fields by livestock.

There is also a gender dimension to this labor requirement: in Zambia, men are traditionally responsible for field preparation while women are responsible for planting, weeding and harvesting. An increase in weeding requirements due to a decrease in tillage may shift the burden of work towards women.

Due to these constraints and others, CA is usually practiced incrementally and partially by Zambian farmers. Almost all farmers practicing CA also practice conventional tillage, and most only practice some of the elements of the CA package. For many farmers this means a small area is cultivated using planting basins in case of drought, thus acting as a type of insurance.

Key Finding 6: Literature suggests that agroforestry offers high potential to sequester carbon while conservation agriculture offers lower potential. There is very little evidence specific to Malawian and Zambian conditions.

The third key component of the Climate-Smart Agriculture approach is the mitigation of green house gas emissions. Improved agricultural practices, such as agroforestry and CA, can deliver significant mitigation benefits. Agroforestry stores carbon in above ground biomass, and over time, increases organic carbon matter in the soil. Minimal tillage practices reduce soil erosion and soil exposure, which otherwise facilitate CO_2 release. Minimal tillage also reduces the need for tractor fuel, however the vast majority of farmers in Malawi and Zambia use only manual or animal power.

There is considerable evidence that agroforestry leads to large carbon sequestration benefits, globally, and specifically under the conditions found in Malawi and Zambia. Estimates are highly variable, reflecting different soil and climatic conditions, tree species, tree densities and plot maturity. The evidence for carbon sequestration under reduced tillage is more mixed. Although a number of authors have found positive evidence from various locations, some argue that the benefits are insignificant. The literature consulted for this review suggested that CA systems have the potential to sequester between 0.2–0.7 tonnes C ha^{-1} yr^{-1}. Agroforestry systems have a higher potential of between 2–5 tonnes C ha^{-1} yr^{-1}. Short term rates (such as during establishment) can be higher.

Based on this, some authors have argued that there is the potential for carbon offset payments, which could pay for investments in improved farming, sequester emissions and simultaneously improve food security. For such a possibility to occur, however, precise estimates of carbon sequestration quantities under different farming regimes are required. Strong institutions for overseeing the payment and monitoring process would also be required. The literature reviewed here suggests that such a possibility in Malawi and Zambia is currently remote, despite some positive indications in the case of agroforestry.

6.2. Further research needs

The state of knowledge regarding agroforestry and CA is well developed from a scientific perspective but poorly developed from an economic perspective. This final section summarizes the strength of evidence, as determined by this review, for the impact of agroforestry and CA. It then outlines a framework for further research into CSA in Malawi and Zambia, and identifies specific gaps in the literature. The ultimate ambition of such a framework is to develop an information base sufficient to reliably inform policy development.

The studies considered above are primarily drawn from the agricultural science and agricultural development literatures. These studies are typically based on experimental trials of specific techniques on research stations or on farms. The biophysical knowledge base appears suitable for providing reliable input to policy (Table 1). For instance, this review finds strong evidence for positive increases in maize yields from the use of agroforestry in

Malawi. The yield impact from CA in Zambia is also positive, although the evidence for this is weaker. Knowledge of the impacts of both techniques on farm gross profit margins is limited. The feasibility of carbon sequestration from both techniques receives positive support, but again is only weakly quantified by the literature for the target countries (Table 2).

Table 1: Summary of literature review findings (strength of evidence) regarding the impact of agroforestry (Malawi) and conservation agriculture (Zambia) on maize yields and farmer profits, and the rate of adoption of each.

	Yields	Profits	Adoption
Malawi (Agroforestry)	Positive (55-345 percent increase). Strong evidence.	Positive. Moderate evidence.	Slow. Need for further research.
Zambia (Conservation Agriculture)	Positive (42-200 percent increase). Moderate evidence. Mainly in dry areas.	Positive (44-140 percent increase in gross margins). Weak evidence.	Slow. Considerable constraints. Need for further research.

Table 2: Summary of literature review findings (strength of evidence) regarding carbon sequestration potential of agroforestry (Malawi) and conservation agriculture (Zambia).

	Malawi (Agroforestry)	Zambia (Conservation Agroforestry)	
Carbon mitigation	2-5 tonnes/ha/yr. Weak evidence.	0.2-0.7 tonnes/ha/yr. Weak evidence.	Carbon financing possibilities seems remote – less so for agroforestry in Malawi.

Opportunities for further research are discussed briefly under the following three categories: (1) research on outstanding biophysical questions, (2) research on outstanding socio-economic questions, and (3) research on the institutional dimensions of CSA promotion. There is an emphasis on the second and third categories due to the greater lack of understanding in these areas.

Biophysical research:

The scientific understanding of CA would benefit from further research into its yield impacts and carbon sequestration potential. Both topics are the source of some debate. While a number of studies in Zambia have assessed the yield impact of CA, these have tended to use small case studies. Geographically broad, time series analysis of CA performance under farmer-managed conditions and climate change indicators would be valuable. Further research that disentangles the separate yield impacts of different components of CA would help refine the technique. Research into carbon sequestration potential is also required if CA is to play a role in climate change policy. Sequestration quantities reported in the broader literature are highly variable. Although there is a current initiative at the Forestry Department of Zambian Government to develop tools to measure and monitor soil carbon within the context of UN-REDD Programme, the issue appears to be largely unstudied in the specific context of CA in Zambia.

Socio-economic research

There remains a need to better understand the farm-level economic implications of both agroforestry and CA. The summary of results from this review suggests that there is some disconnect between gross profit margins results and adoption rates. Both technologies have been promoted for some time, often with incentives (e.g. subsidized inputs), yet uptake remains limited despite the often positive benefits purported. Dis-adoption rates of CA in Zambia are reported to be high (Baudron, 2007). Potential reasons include constraints to adoption that are poorly understood, slow dissemination of CA knowledge, or smaller benefits than field trials suggest in the absence of incentives provided by CA programs. Understanding the reasons for this will be useful for future CA policy development.

The extent to which adoption and dis-adoption is influenced by poverty levels, and vice versa, is unclear from the literature reviewed here. Understanding this relationship may require more detailed research into particular socio-economic impacts of agroforestry and CA. For instance, these techniques are reported in some instances to be used as household food security insurance, rather than profit-increasing activities per se. A better understanding of this could help improve the effectiveness of CA and agroforestry promotion efforts. Similarly, an improved understanding of the auxiliary socio-economic benefits of agroforestry and CA may be useful. Fuel wood availability and extra harvests of nuts and fruits from agroforestry, for instance, may be important for farm-level decision making. It is suggested by a number of researchers that adoption is considerably influenced by consideration of such auxiliary benefits.

Conclusions from previous studies suggest that research on agroforestry and CA adoption should concentrate on long term analyses of specific practices in the field in addition to the fundamental determinants (such as farmer characteristics) that drive adoption. Such research can better inform policy that needs to target different farming approaches under different agro-ecological zones.

Institutional context

Both Malawi and Zambia have reinstated large scale fertilizer subsidies in the past ten years with dramatic impacts on yield. There is a need to identify how CA and agroforestry can complement, or in some cases, substitute for inorganic fertilizer input, and how policies regarding these approaches can achieve synergies. There are a number of reasons why CSA alternatives have an important role to play alongside fertilizer policies. For instance, the best yield, soil health and drought resistance occurs when both inorganic fertilizer and the alternative techniques are combined. However, there is little existing research on how to improve incentives for their parallel use. Research focusing on the interaction between fertilizer subsidies and alternative agricultural practices would thus be valuable. Research focusing on how to improve the efficiency of fertilizer use alongside its combination with these practices is also necessary to decrease the budgetary burden of fertilizer programs in these countries and to potentially provide mitigation side-benefits.

There is also a need to consider the cultural context in which agroforestry and CA are promoted. For instance, there may be gender equality implications for different types of agricultural policy. CA is suggested to increase the burden of labor on women due to an increase in weeding responsibilities, while decreasing the burden of labor on men due to a reduction in tillage responsibilities (the latter is traditionally a male role, and the former a female role, in Zambia). A more detailed understanding of this and other attitudinal or cultural barriers to increased adoption may also be valuable.

6.3. Final Remarks

Improving food security in Malawi and Zambia, in the face of rapidly growing populations and climate change impacts, is a daunting challenge. However, considerable recent success of conservation agriculture programs and agroforestry programs are cause for optimism. This review documents considerable, positive evidence for the benefits of both. It also identifies the substantial need for further research, particularly with regard to the socio-economic impacts of these approaches.

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