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Evaluating Conservation Agriculture and its Adoption Potential in Developing Countries

MS Major Paper

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Abstract

In developing countries, demand for food is increasing at a rapid pace while constraints such as arable land, availability of water, and climate change pose threats to the food production system. Conservation Agriculture (CA) practices such as zero tillage, soil cover, and crop rotation are widely practiced in the developed world to improve soil health, reduce water use, and as an adaptation tool for climate change. However, there are many challenges to implementing CA in the developing world. Among the challenges are the perception that conventional tillage is necessary for high crop production, insufficient affordable and locally produced equipment, limited knowledge and experience with CA practices, the perception that CA worsens weed, pest and disease infestation, and limitations with respect to the policy environment and extension services.

Gender based adoption of CA, an area that requires further research, is constrained by land ownership, access to capital, training, and traditional decision making roles with respect to farm and family. Opportunities for improved adoption include capitalizing on awareness of land degradation, labor and cost savings with CA, better training and access to Extension workers, and promoting the interdependence of farm productivity with family well being.

This paper will conduct a literature review to examine the underlying science behind CA, evaluate its benefits, explore some of the challenges to adoption in developing countries, review interventions that might help overcome these challenges, and consider gender related issues relating to adoption.

Keywords

Conservation agriculture, conservation tillage, cover crops, crop residues, crop rotation, soil fertility, soil organic matter, water holding capacity, water infiltration, soil structure, soil biodiversity, carbon sequestration, climate change, technology adoption, developing countries, smallholder farmers, food security, gender.

Introduction

With land degradation, scarcity of resources such as water, and frequent droughts, adoption of CA technologies will become increasingly important if developing countries are to meet their food security needs. Although CA has many benefits, including organic matter retention, improved water holding capacity and infiltration, greater microbial activity, less soil erosion, carbon sequestration and lower CO2 emissions, understanding the challenges to adoption and evaluating interventions that can help overcome these challenges will make CA more viable in developing countries.

Gender can play an important role in CA adoption because of its many benefits to women including higher income potential and labor and time savings. However, challenges relating to land ownership, capital constraints, inadequate training, access to information, and on-farm decision making limit adoption.

Materials and methods

The underlying science behind CA and its benefits will be examined based on a literature review.

The three underlying principles behind CA are:

1) Minimum soil disturbance through tillage ("Conservation Tillage")
2) Maintenance of permanent or semi-permanent soil cover ("Plant Residues")
3) Regular crop rotations ("Crop Rotation")

CA also promotes management practices such as integrated disease and pest management, human and mechanical traffic on agricultural soils, the use of green manure crops, and the burning of crop residues. Other major benefits of CA include reduction of fossil fuel use, greenhouse gas emissions, and power/energy use by farmers who use manual or animal powered systems (Cornell University 1, 2015)

1. Conservation Tillage

Tillage, which has to do with the plowing of land for weed and pest control and to prepare for seeding, has traditionally involved the use of instruments such as a plough, disk harrow, or rotary cultivator. Although these methods have shown an improvement in crop yields in the short run, they lead to reduced soil quality over time due to the decomposition of soil organic matter which plays an important role in soil structure, water holding capacity and infiltration, and biodiversity. It can also reduce carbon sequestration in the soil which is important in controlling greenhouse gases that impact climate change (FAO, 2015).   CA requires at least 30% of the surface of the soil to be covered by residue after planting.

Four conservation tillage methods, no-till, strip-till, ridge-till, and mulch-till, are discussed below.

No-Till

No-till involves growing crops without the use of mechanical instruments for seedbed preparation and minimum disturbance of the soil. It is also known as direct seeding, zero tillage, no-tillage, and direct drilling. The equipment used in no-till penetrates the soil cover and places the seed directly into a seeding slot. The size of the seed slot and disturbance to the soil are kept to a minimum and mulch or plant residue is generally used to cover the seed so no loose soil is visible (UNEP, 2006).

Strip-Till

Strip-till uses minimum tillage and only disturbs the portion of the soil that contains the seed row. It combines the drying and warming benefits of conventional tillage with the conservation benefits of no-till. It does require a high-horsepower tractor, however, but the energy requirement is believed to be less than conventional tillage systems (Wikipedia, 2015)

Ridge-Till

Ridge-till involves planting on ridges that were built during the cultivation of the prior year's crop. It generally involves row crops planted in the spring with the use of herbicides. The ridges and rows are preserved in the same location each year to control traffic and reduce compaction. The labor, fuel, and equipment costs are generally higher than no-till (University of Missouri, 2015).

Mulch-Till

Mulch-till utilizes non-inversion tillage such as chiseling and disk harrowing to partially incorporate soil material left on the soil surface. It generally involves uniformly spreading residue on the soil surface, the use of equipment designed to operate in high residue situations, and minimal removal of organic residue (USDA NRCS Mulch-Till, 2015).

I a1. CA and Soil Organic Matter

Organic matter supplies plants with nutrients, promotes aggregation of soil particles, prevents erosion, improves water infiltration and water holding capacity, controls the decomposition and movement of pesticides, and encourages microbial activity. Intensive tillage, by breaking up the soil surface and exposing soil organic matter to air, leads to its rapid decomposition through microbial activity and carbon oxidation (Iowa State University, 2005).

Soil organic carbon (SOC) is considered to be an mportant indicator of soil quality and sustainability due to its impact on physical, chemical and biological properties. Studies have shown that continuous cropping can result in a loss of SOC with the rate of decline dependent on soil and climatic factors. Management practices such as the use of manure, fertilization, crop residues, conservation tillage, and crop rotation can ameliorate this decline.

Several studies have shown the benefits of SOC on soil biological, physical, and chemical properties including its affects on microbial activity (Reeves, 1997), plant available water capacity (Hudson, 1994), infiltration (Tisdall and Oades, 1982), bulk density (MacRae and Mehuys, 1985), cation exchange capacity (Chan et al., 1992), and soil strength (Ekwue and Stone, 1995).

Inputs and outputs of SOM are governed by two main biological processes, namely primary plant production and microbial activity. SOM turnover, which is controlled by biotic and abiotic factors, is a function of the balance between them. Soil fertility and reducing environmental impacts through carbon sequestration, reduced soil erosion, and soil biodiversity require appropriate levels of SOM. The combination of conservation tillage and residue addition can lead to a build up of SOM in surface soils (Anyanzwa, 2008).

1 a2. CA and Soil Structure

The use of tillage tools can subject soil structure to mechanical stresses such as tension, shear, and compression. When these stresses exceed soil strength, structure can fail or get deformed depending on whether the soil is in a friable or plastic state (Soil Quality, 2011).

Microbes play an important role in soil structure by forming and stabilizing soil aggregates through hyphal entanglement and by the deposition of polysaccharides that help bind soil particles (Tisdall, 1994). The depletion of soil organic matter with conventional tillage reduces microbial activity and can adversely affect soil aggregation. No-till and minimal till systems, by conserving soil organic matter, improve soil aggregation and structure and reduce erosion.

Loss of SOM is dependent on the clay content of the soil with greater loss observed in coarse textured soils than fine textured soils (Chivenge, 2007). This is due to the physical protection organic matter provides in sandy soils (Hassink, 1995 and Feller and Beare, 1997) while in fine textured soils, clay and silt particles chemically stabilize SOM and form the building blocks for aggregates which provide physical protection of SOM by occulation. The disturbance with conventional tillage is a major cause of the destabilization of soil aggregates and organic matter depletion (Six et al., 2000).

1 a3. CA and Soil Water Holding Capacity and Infiltration

Organic matter can increase a soil's ability to hold water, both directly and indirectly. It increases the soil's ability to hold water at field capacity as well as at permanent wilting point, thereby increasing the amount of water available for plant use. Indirectly, it increases soil structure and aggregate stability which increases pore size and volume and improves infiltration and water holding capacity. Poor soil structure and aggregation, on the other hand, can result in compaction which reduces pore space and volume and reduces infiltration and water holding capacity. Improvements in soil quality with organic matter promote greater infiltration, flow of water through the soil, and available water holding capacity (USDA, 2008).

In a study in a high potential evapotranspiration (ET) area in Mallawi, water infiltration and soil water content improved under no-till conditions and residue retention. However, this was not the case in another study in Malawi in an area with lower potential ET where there was no improvement in infiltration and soil water content (TerAvest, 2015).

A study was also conducted in Zambia and Zimbabwe between 2005 and 2007 to evaluate water infiltration in CA fields versus conventionally ploughed fields. In Zimbabwe, in a sandy soil, water infiltration rates improved by over 45% and 49% in two separate studies under direct seeded CA treatments while in Zambia, in a fine-textured soil, infiltration rates improved by 57% and 87%. In treatments that included reduced tillage and residue retention, there was less water runoff and erosion and higher soil moisture levels (Thierfelder and Wall, 2009).

1 a4. CA and Soil Biodiversity

Soil microorganisms play an important role in regulating carbon and nitrogen cycling and in providing nutrients to plants. Bacteria and Fungi help in the production of soil aggregates and in the formation of soil organic matter from plant residues. No till and reduced till systems reduce soil erosion and slow down the decomposition of soil organic matter, thereby preserving microbial activity in the soil (Sheibani et al, 2013).

The accumulation of crop residues and the build-up of SOM in surface layers under conservation tillage create favorable feeding conditions and provide protection for soil microorganisms, thereby contributing to their abundance and creating greater diversity. Various studies have shown that microbial biomass increses by 80% to 200% with conservation tillage when compared to conventional tillage (Sapkota, 2012).

The influence of conservation tillage on the soil and on microorganisms was studied in long term field experiments and it was found that conservation tillage stimulated rhizosphere bacteria with winter wheat, barley, and rye and with maize. In sandy loam soils, nitrogen fixation and nodulation with pea plants showed a significant increase. However, no difference was observed in the colonization of the rhizospere by mycorrhiza and saprophytic fungi (Hoflich et al., 1999).

In a study conducted on subtropical rice (*Oryza sativa L.*) in Chongqing, China, the effects of tillage on soil nitrogen dynamics were evaluated. The study investigated whether combination ridge with no-tillage decreases nitrification in rice-based ecosystems. It was observed that mineralization and nitrification rates decreased after several years of ridge no-till when compared to conventional tillage. The study results suggest that nitrification may not be closely correlated with the number of microorganisms in the soil and that nitrogen retention in the amonium state reduces potential losses through leaching (Li et al., 2015).

1 a5. CA and Soil Carbon Sequestration

Plants assimilate carbon through photosynthesis and return some of it to the atmosphere through respiration. The carbon in plant tissue is added to the soil as residue or consumed by animals. The primary way carbon is stored in the soil is through soil organic matter which is a combination of decomposing plant and animal tissue, microbes, and carbon associated with soil minerals. This carbon can either be stored in the soil or released back into the atmosphere depending on climatic conditions and management practices. Conservation tillage sequesters carbon by leaving plant residue on the soil surface. It also reduces the amount of fossil fuels consumed in agricultural production, thereby reducing greenhouse gas emissions.

In 1998, the amount of organic carbon in the soil in the United States that could be attributed to conservation practices was estimated to be 12.2 metric tons. By 2008, this amount was expected to increase by about 25% (Uri, 2001).

In a study conducted in the highlands of Mexico, minimum till, residue retention, and crop rotations were studied to evaluate the impact on soil carbon retention and CO_2 emissions. The study found greater carbon retention in macro-aggregates of the topsoil due to increased aggregate stability and reduced CO_2 emissions when compared with conventional tillage (Fuentes et al., 2011).

A field experiment conducted in the lowland of Chitwan Valley, Nepal between 2002 and 2006 evaluated the effects of tillage, crop residue, and timing of nitrogen application on SOC sequestration. The experiment showed significantly higher amounts of SOC in the whole soil profile with a more pronounced effect in the topsoil under no-tillage as compared to conventional tillage. When crop residues were added to no tillage soils, they outperformed other treatments. The study concluded that in a rice-wheat system, adding residues under no-tillage would serve as a greater sink of SOC than under conventional tillage (Ghimire, 2011).

2. Crop Residues

When plants are left growing or their residue is killed and allowed to decompose in the field, organic matter in the topsoil is enriched and the soil is protected against chemical and physical weathering. The residues also intercept energy from falling raindrops, provide a barrier against strong winds, improve water infiltration, and reduce the loss of water from evaporation. In addition, surface cover enhances biological activity by providing food for microbes, especially in tropical and semi-tropical areas (Cornell University 2, 2015).

Optimizing fertility in conservation tillage systems can benefit from crop residue management. Greater immobilization in reduced and no-till systems helps conserve the soil and fertilizer nitrogen. Fertilizer requirements decrease over time because of reduced losses from erosion and the accumulation of larger pools of readily mineralizable organic nitrogen. If residues are rich in nitrogen, such as with legumes, volatilization losses may be high unless the residues are incorporated into the soil. Crop residues can also increase soil moisture which impacts soil biological activity and nutrient availability (Schoenau and Campbell, 1996).

In a field experiment conducted in Tsukuba, Japan between 1983 and 1992, the effects of tillage on soil conditions and crop growth were evaluated in a light-colored Andosol. The study found that the positive effect of fused magnesium phosphate fertilization was greater when residues were added with no-tillage than with conventional tillage for summer cropping. It did not find similar benefits for winter cropping and concluded that the application of phosphate and crop residues could reduce the risk of lower yields by improving soil nutrient status and the moderation of soil temperature (Tsuji et al., 2006)

The impact of no-till and residue cover on soil moisture with wheat and corn was studied in semi-arid Morocco with a clay loam soil. Under no-till and minimum till residue management for wheat, available soil moisture was dependent on the amount of wheat straw cover on the soil surface. Similar improvements were not observed for corn under no-till. The study concluded that the benefits of no-till systems under crop residues could increase over time if appropriate machinery was available for mulched soils (Rachid, 1997)

3. Crop Rotation

Crop rotations can reduce pest and disease problems that result from not tilling the soil, including the proliferation of pests and harmful bacteria, and increase the abundance and diversity of beneficial soil biota that reduce pests and diseases. It also interrupts the life cycle of weeds which can lead to a reduction in weed growth. This can translate to an improvement of about 10 percent in yield when compared to crops grown in monoculture (Cornell University 2, 2015).

The impact of tillage (moldboard, chisel plow, no tillage) and crop rotation (continuous corn, corn-sybean, corn-soybean-winter wheat) on weed species diversity and density was evaluated in a 6-year study in Ontario, Canada. The study found that tillage had the largest effect on weed diversity and density with the highest species diversity and lowest density under no tillage. It therefore concluded that reduced tillage, when combined with crop rotation, can reduce expenditures on weed management (Murphy et al., 2006).

In a 4-year field experiment in the Indo-Gangetic Plains of northwestern India, soybean-wheat rotation on irrigated soil was evaluated under CA and convention tillage. The study concluded that yields can be improved when CA is used in conjunction with nitrogen and phosphorous fertilizer application while soil water can be conserved by applying crop residues to reduce evaporative losses. However, the cooling effects of surface cover under CA delays seed germination for wheat, reduces crop growth in the initial stages, and can reduce wheat yield (Aulakh et al., 2012).

A study was conducted in a cereal farming area in Spain from 1994 to 2004 to determine the effect of tillage systems (conventional, minimum till, and no-till) and cropping sequences (cereal/cereal, cereal/fallow, cereal/legume) on SOC. The study found that SOC under no-till was the highest at a depth of 0-10 cm and that over ten years SOC was

25% higher with no-till than conventional tillage. It also found that crop residue returning to the soil was significantly higher in plots where legumes were grown after cereals and SOC sequestration was enhanced in no-till and minimally tilled soils (Sombrero and de Benito, 2010)

4. Green Manures/Cover Crops (GMCC's)

Cover crops are grown to improve soil fertility and productivity. GMCC's increase soil organic matter by decreasing erosion and by adding plant residues to the soil. Some cover crops, such as legumes, can also fix nitrogen from the atmosphere and add it to the soil, thereby increasing nitrogen availability for other crops. Cover crops are generally mowed, sprayed with herbicide, or killed before or during soil preparation for the next primary crop (Cornell University 2, 2015).

The retention and release of nitrogen following the incorporation of cover crops was studied in northeastern Scotland. Although the amount of nitrates produced were reduced in the treatments, so was the nitrogen uptake by crops. Reduced nitrate production has environmental benefits as it lowers the potential for leaching and gaseous nitrogen losses. Residue incorporation produced lower mineralization rates and reduced N_2O emissions than the bare ground due to the temporary immobilization of nitrogen in the soil. No significant improvement in yield of the subsequent oats crop was noted in the study which suggests that nitrogen was not sufficiently limiting in the soil (Baggs et al., 2000).

The effects of tillage and green manure on Bt transgenic cotton was evaluated in a study in central India between 2005 and 2008. Transgenic Bt cotton makes up more than 90% of cotton area in India. Weed density and biomass were significantly lower in the reduced tillage treatments while seed cotton yield was significantly higher with reduced tillage and mulched green manure. Soil moisture was also greater in treatments with mulched green manure up to a depth of 0.60m. The improved yield with reduced tillage and mulched green manure was likely due to the improvement in soil physical properties . The study demonstrated that Bt cotton can be grown under reduced tillage with an in situ legume green manure (Blaise, 2011).

5. Burning of Crop Residues

Crop residue are the permanent element of soil cover so should not be burned or removed from the surface of the soil. They should instead be left on the soil surface to protect organic matter and enrich the topsoil from erosion while adding fresh organic matter upon decomposition. Burning can also create air pollution and dramatically increase mineralization rates which deplete soil organic matter and nutrients (Cornell University 2, 2015).

The burning of stubble has been used in semi-arid agriculture for pest and weed control and to remove excess residues prior to seeding in conservation tillage systems. In a 10-year trial in semi-arid north-east Spain, the impact of burning crop residues on soil organic matter, aggregation, and earthworm populations were compared under no-tillage and conventional tillage. The study found that stubble burning along with no-till lowered particulate organic matter content and mineralization potential and increased the penetration resistance of the soil which led to a trend towards larger earthworms (Virto et al., 2007).

6. Integrated Disease and Pest Management

CA depends on biological activity to control pests and diseases in the soil. Integrated pest management (IPM) utilizes crop rotations and other practices as well as chemical pesticides, herbicides, and fungicides to control pests and diseases. Enhancing biological activity over time with CA should result in decreased applications of agrochemicals (Cornell University 2, 2015).

The International Center of Insect Physiology and Ecology, Rothamsted Research (UK) and its partners have developed a conservation agriculture approach to managing pests, diseases and soil health based on "push-pull technology" (www.push.pull.net). Napier grass, acting as a trap plant (pull), attracts stemborers while desmodium, a legume intercrop (push), repells stemborers from the main cereal crop. Desmodium also fixes nitrogen, provides natural mulch, improves biomass, and controls erosion, thereby improving soil fertility. In addition, both companion plants provide animal fodder which facilitates milk production, helping farmers' diversify their income sources. This technology has been adopted by over 30,000 farmers in East Africa (Khan et al., 2011).

7. Reduction in Fossil Fuel and Greenhouse Gas (GHG) Emission

Conservation tillage significantly reduces the use of tractors and heavy farm machinery and diesel when compared to conventional tillage which often requires several tractor passes in a typical growing season. It also preserves soil organic matter and increases plant-available nitrogen which greatly reduces the need to apply large amounts of chemical fertilizers requiring significant fuel energy to process. As a result, fossil fuel use and GHG emissions are greatly reduced (Cornell University 2, 2015).

Climate and soil type are considered important factors impacting GHG from conservation tillage practices. Farmers need to modify which practices they use based on climate and soil since this can affect plant biomass and influence crop residues and vegetation cover. Since climate also impacts soil moisture, it can affect soil compaction and GHG emissions. The implications for N_2O emissions are mixed but most studies have found that conservation tillage reduces CO_2 emissions, improves retention of SOM and enhances soil structure (Abdalla, 2013).

8. Controlled/Limited Human and Mechanical Traffic

One of the downsides of CA is that it can increase soil bulk density. However, this can be corrected by limiting the use of heavy farm equipment, especially when soils are wet and are prone to compaction, and by converting to a permanent raised bed systems (Cornell University 2, 2015).

The effects of tillage and traffic on runoff, soil water and crop production under rainfed conditions were evaluated over 6 years on a clay Vertisol in Queensland, Australia. The study found that mean annual runoff from controlled traffic plots was 36% less than for wheeled plots and runoff for no-till plots was 15.7% less than for wheeled plots. Infiltration from rainfall with controlled traffic no-till soil was 12% greater than it was for wheeled stubble mulched soil. Plant available water in soil depth of 0-500mm increased by 11.5% and mean grain yields improved by 9.4% in controlled traffic plots. Improved infiltration and increases in plant available water resulted in a 14.5% improvement in yield in controlled traffic zero tillage plots (Li et al., 2007).

Discussion

In developing countries, land degradation and scarcity of resources such as water make CA an important technology for sustainable food production. Moreover, as climate change threatens to worsen desertification and result in more frequent and severe droughts, its benefits for dryland agriculture will become increasingly important. In semi-arid and arid regions, the problem is particularly acute because of insufficient amounts of residue from water shortages, degraded soils, competing uses of crop residues, and resource poor smallholder farmers.

The adoption potential for CA in the world's dryland agro-ecosystems was reviewed by ICARDA and is discussed below (ICARDA, 2015).

CA Adoption in Dryland Agro-ecosystems

Despite the many benefits of CA and the minimal additional cost, adoption remains low in developing countries because policymakers, donors, and development partners have failed to recognize its value and support its implementation. The successful adoption of CA in these countries will require access to technologies as well as a favorable policy environment. Changing the perception among policymakers and farmers will require greater engagement and sharing of information so the potential benefits are understood.

Constraints to CA Adoption

According to ICARDA, there are several constraints to the adoption of CA, namely:

1) The mistaken perception that plowing of the soil is essential to improve crop production
2) The limited availability of affordable, locally produced seeding machinery
3) Inadequate knowledge and experience on adoption of CA practices
4) The perception that weed, pest and disease infestation is worsening
5) Policy and extension environments that are unwelcoming

1) Perception that plowing is essential to improve crop production

Potential change agents in agriculture such as academic experts, successful farmers, and extension personnel have been slow to accept CA. Smallholder farmers, who are cautious because of their vulnerability, are also resistant to change when presented with new technologies. Well educated farmers, on the other hand, have been more willing to try CA.

Approaches to create an enabling environment for CA include improving education and information access to overcome unfavorable perceptions, sharing knowledge and experience derived from other countries, and encouraging public-private partnerships to develop and deliver mechanical seeders and other inputs.

2) Locally made and affordable seeders

Commercially available seeders for conservation tillage are made mostly in wealthier countries such as the US and Brazil with extensive areas under CA cultivation. These seeders typically cost $50,000-60,000 or more, putting them out of reach of smallholder farmers in developing countries.

As part of a research partnership in Iraq and Syria between 2007 and 2009, ICARDA, local equipment producers, and farmers designed low-cost seeders that can be manufactured and sold for $2,000 to $6,000. In tests conducted by ICARDA, the performance of the local seeders was comparable to the higher cost imported seeders. They were also easier to maintain as locally produced parts were available.

3) *Limited knowledge and expertise*

In addition to overcoming the perception constraints mentioned earlier, there continues to be a knowledge gap involving CA and its techniques and effectively packaging it for dissemination in developing countries where it has the potential to do the most good.

4) *Perception of worsening weed, pest and disease infestation*

CA became a viable technology with the use of modern herbicides. ICARDA, in its research and trials, found weeds to be of minimal consequence in CA trials in the Middle East since the dry summer means that few weeds emerge and pre-sowing herbicide application is only needed on occasion. Post-sowing crop management practices are similar under CA and conventional agriculture.

Leaving crop stubble and residue from the previous crop raises the risk of plant pests and diseases being passed on to the next crop rather than succumbing to the plowing between crops. CA overcomes this problem by integrating crop rotation which breaks the cycle that perpetuates crop diseases. It also promotes biological pest control as the first option to manage pests and diseases.

Opportunities for CA Adoption

ICARDA makes several recommendations to improve CA adoption in developing countries, including:

1) *Raise awareness*
This can be accomplished through education and the national agricultural extension systems upon which they depend.

2) *Local verification and modification of technology*

CA needs to be adapted for local modification of the amount of stubble and residue left in the field, the time of sowing, management of soil fertility, weed control, and integrated pest management.

3) *Provide appropriate and affordable seeders*

   In order for smallholder farmers to overcome their natural skepticism, they need to be able to use the seeders at no cost and have no liability in case the seeders break down. If their interest in CA creates local demand, policymakers and development partners need to help entrepreneurs develop the capacity to manufacture new seeders.

4) *Organize participatory research and demonstrations*

   Once farmers and extension personnel understand the principles behind CA, they need to see it in practice. This will require collaborative research and demonstration on the part of scientists, extension officers, economists, policymakers and farmers.

<u>CA Adoption and Climate Change</u>

With climate change change posing a major challenge to global food production and its disproportionate impact on smallholder farmers, CA can be promoted as an adaptation strategy to climate change.

In a study conducted with smallholder farmers in Zambia on perceptions of climate change, most attributed it to supernatural forces and few recognized CA as an adaptation strategy. The study therefore recommends focusing not just on technical aspects of CA but also the social aspects to change how CA is perceived. It suggest providing farmers with climatic information to enable them to recognize CA as an adaptation strategy to climate change (Nyanga et al., 2011).

Another study in Zambia examined the impact of minimum tillage and crop rotation on maize yields and incomes for smallholder farmers adoption CA strategies. The study showed that on-farm productivity for maize improved by 26%-38% for minimum tillage and 21%-24% for crop rotation. Improving the socioeconomic status of smallholder farmers is critical to CA adoption strategies (Kuntashula et al., 2014).

An analysis of the socio-economic factors that impact CA adoption as a mitigating activity for climate change was evaluated in Austalian dryland grain production. The study found that that significant reductions in CO_2 emissions can be achieved by the adoption of CA practices. However, economic and social factors appear to drive adoption with the need to achieve productivity gains outweighing the need to achive environmental benefits. The study therefore recommends policy makers promote productivity benefits instead of a market-based approach involving carbon payments to achieve emission reductions (Rochecouste et al., 2015).

CA Adoption and Smallholder Farmers

In a study conducted with smallholder farmers in Zimbabwe, CA adoption was monitored to evaluate why some farmers stopped using CA after it was actively promoted and others continued using it. The study found that one of the main factor for abandonment of CA was the absence of support from non-governmental organizations (NGO's). Farmers who had more experience, larger lots, and bigger households were more likely to continue using CA while wealthy farmers and those in drier areas were likely to stop using it (Pedzisa et al., 2015).

A literature review of CA adoption with smallholder farmers was conducted in southern Africa (Malawi, Zambia and Zimbabwe) to evaluate adoption claims and better understand the conseptual framework. CA was first introduced as a soil and water conservation measure but has now been reframed as a production enhancing technology. The use of incentives and promotional projects to support use of fertilizers, seeds, and herbicides has also limited the value of adoption claims due to bias from the incentives and promotions. The study recommends a more thorough analysis of farming households and how they allocate resources to understand adoption constraints faced by farmers. It also suggests looking at adoption in a wider framework to include market, institutional and policy frameworks (Andersson and D'Souza, 2014).

Reducing the risk of crop failure by resource-poor smallholder farmers with CA adoption was examined in a study in Africa. The study recommends strategies to convert farmers from conventional agriculture to CA using a step-wise approach where farmers gradually incorporate CA while adding higher value crops that improve their income potential. Development of multi-stakeholder "innovation networks" that are site and farmer specific and take into account local conditions are essential for CA adoption (Thierfelder and Wall, 2011).

CA Adoption and Food Security

The role of CA in food security was evaluated in a 4-year study in Zambia with farmers growing pulses such as groundnuts, cowpeas, soya beans and other beans. The study found that the percentage of households growing pulses to be higher among those that adopted CA than those who had not adopted it. Income from pulse production was also higher among CA adopters than non adopters. Women were able to increase their income and there were less food shortages because of the early harvest. The study concluded that, as it relates to pulses, CA adopters are more food secure than non-CA adopters. Some of the factors that contributed to food security included CA training, access to seeds, early preparation of land, and crop rotation (Nyanga, 2012).

The importance of joint adoption of soil and water conservation was examined in a study in Chile for food security. Natural, social and financial factors were evaluated to see how they impact adoption decisions relating to water and soil conservation. The study concluded that adoption is a function of farm size, the production system, access to credit, and government incentives and recommended that incentives should be provided to jointly promote the adoption of water conservation and soil conservation (Jara-Rojas et al., 2013).

The impact of conservation tillage, crop diversification, and modern seed adoption was examined in Ethiopia to evaluate its impact on household income, agrochemical use, and demand for labor. When adopton of sustainable agricultural practices (SAPs) is combined, the effects on production and food security are expected to be greater. The study found that income levels are highest when SAP's are adopted in combination, conservation tillage increases the need to apply pesticides, and that labor demand and women's workload increase when SAP's are adopted. It therefore suggested that stakeholders and policy makers promoting these technologies should be aware of the benefitsIt in terms of food security and household income but also need to keep in mind the gender related outcomes (Teklewold et al., 2013).

CA Adoption and Gender

CA offers many benefits for women including reduced labor and time owing to decreased tasks of raking/gathering of crop residue, weeding, and fetching irrigation water, which allows extra time for personal leisure and non-farm chores. Among the challenges to adoption by women are unequal knowledge between the genders and perceived health threats from herbicide use (Chiong-Javier et al, 2013).

A study on gender-based constrains and opportunities for the adoption of CA by smallholders farmers was conducted in two villages in Northern Mindanao, Philippines. The study used a livelihoods framework to explore gender dimensions such as assess to assets, agricultural practices, and knowledge and perceptions of conservation and food security. It found that men and women do not have the same access to assets, particularly relating to land and training. Labor is divided by gender with men working mainly on the farm while women work in the home. Men and women were found to share knowledge on soil quality and perceived the local soil to be degraded. Topography also appeared to influence gender roles, perceptions of the soil, and agricultural practices. Among the constraints to gender based CA adoption identified by the study are land ownership, access to capital, and training. A key opportunity for adoption is the acknolwledgement that soils and landscapes are degrading and that they need to act to prevent long-term damage. Other opportunities for adoption include conveying the benefits of reduced fertilizer use with CA and exploring the interdependence of farm and household decision making (Parks et al, 2014).

The gendered labor impacts of CA practices in remote farming communities in 3 tribal villages in Nepal were evaluated using face-to-face interviews and surveys to quantify labor distribution and household decision making. Results from the study show women bearing a disproportionate burden of on-farm labor. Despite this, women indicated they have limited control over decision making on adoption of new practices. The study concluded that technologies requiring additional labor by women who are already overburdened might be unsustainable and that gender-sensitive solutions are important to improving livelihoods (Halbrendt et al., 2014).

Socio-economic factors impacting adoption of CA by women farmers was evaluated in a study in Mallawi. The study found that availability of farm labor, access to CA training, farm size, access to information, education, age, access to farm inputs, membership in farmers groups and Extension worker visits result in higher CA adoption. Among the suggestions to improve adoption are greater access to Extension workers to reduce the knowledge gap, subsidizing input prices, improving access to credit, and leveraging farmers' groups to dissiminate information on new technologies (Chisenga, 2015).

Conclusion

CA has been shown to improve soil fertility by preserving soil organic matter, improving water infiltration and water holding capacity, encouraging soil aggregation, preventing soil erosion, and encouraging biodiversity. In improving soil fertility, it produces higher and more sustainable crop yields which are important for food security in developing countries. CA also improves sequestration of carbon in soils and reduces fossil fuel use from conventional agriculture, thereby lowering greenhouse gas emissions which are believed to cause climate change.

There are many challenges, however, to the adoption of CA in developing countries including the perception that soil cultivation improves yields, the availability of affordable locally produced seeders, local knowledge and expertise, and the perception that weeds, pests, and diseases might increase with CA. These can be overcome through education, adaptation of CA to local environments, partnerships with the private and public sectors to manufacture affordable seeders, and participatory research and demonstrations that improve awareness.

Gender presents opportunities and challenges for CA use in developing countries. Since CA requires less labor and time, it allows women to focus more on non-farm chores and leisure activities. However, land ownership, credit, access to information, and traditional decision making roles impede adoption. Gender-based interventions that improve CA adoption can help empower women and produce better health and nutrition outcomes, particularly with smallholder farmers growing crops that are high in nutritional value.

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