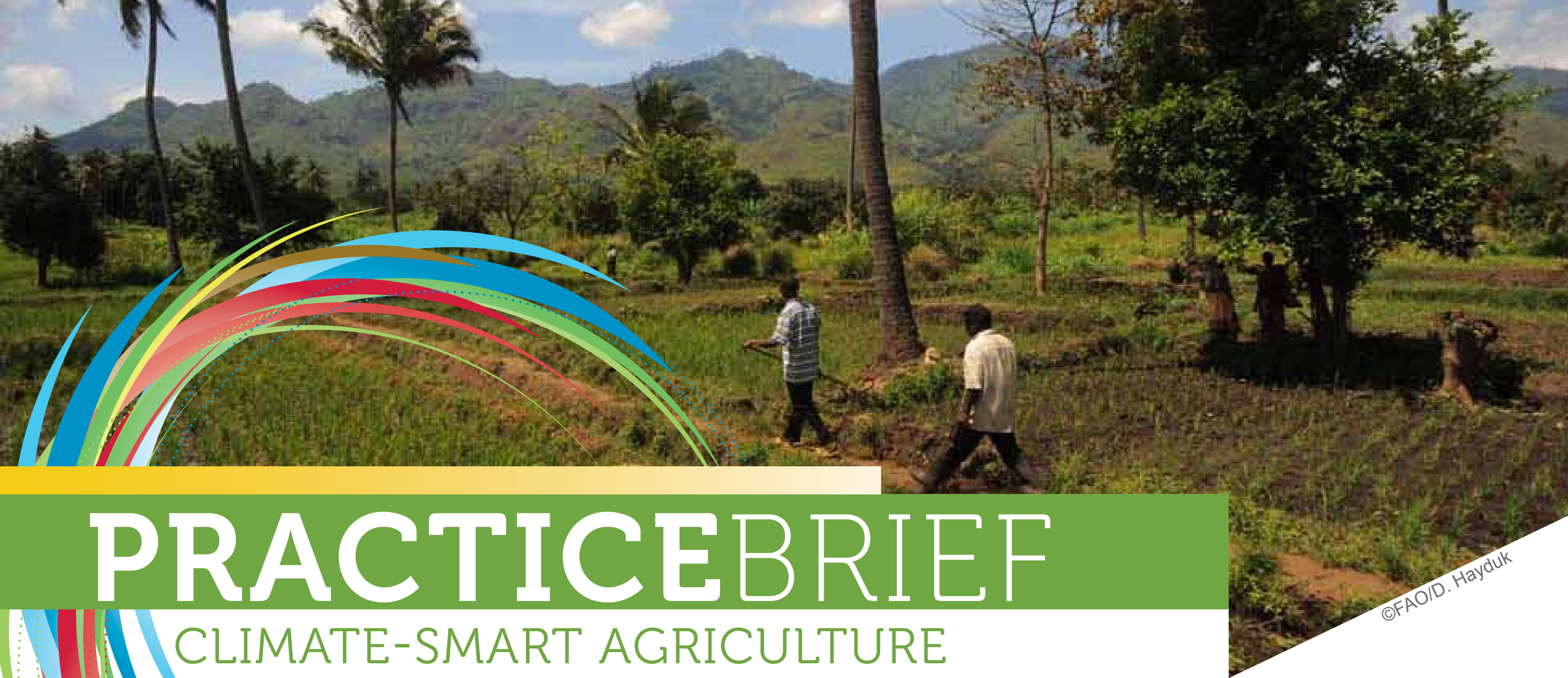

PRACTICEBRIEF
CLIMATE-SMART AGRICULTURE
SEPTEMBER 2014

Conservation agriculture

Implementation guidance for policymakers and investors

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OVERVIEW OF CONSERVATION AGRICULTURE

Conservation agriculture is an approach to agricultural management based on three principles:

1. **Minimum soil disturbance**

Zero tillage is ideal, but the system may involve controlled tillage in which no more than 20 to 25% of the soil surface is disturbed.

2. **Retention of crop residues or other soil surface cover**

Many definitions of CA use 30% permanent organic soil cover as the minimum, but the ideal level of soil cover is site-specific.

3. **Use of crop rotations**

Crop rotation helps reduce build-up of weeds, pests and diseases. Where farmers do not have enough land to rotate crops, intercropping can be used. Legumes are recommended as rotational crops for their nitrogen-fixing functions.

The idea of minimizing soil disturbance was introduced in the 1930s as a soil conservation system to counter the Dust Bowl in the United States, but the term "conservation agriculture" was not coined until the 1990s. Only recently has CA been promoted on the basis of its climate adaptation and mitigation benefits. CA is now widespread in parts of the Americas, as well as Australia. In the tropics, Brazil has the

KEY MESSAGES

1 Conservation agriculture (CA) can increase resilience to climate change and has the potential to contribute to climate change mitigation.

2 The benefits of CA are highly site-specific.

3 Innovative approaches are needed to overcome barriers for uptake of CA by smallholders.

Food and Agriculture Organization of the United Nations
CGIAR
RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security
CCAFS
CIMMYT International Maize and Wheat Improvement Center

TABLE 1

Conservation agriculture* by country as percent of arable land. *(Source: FAO Conservation Agriculture Program and FAO AQUASTAT, 2014)*

Country	Year of report	Area under CA (1000 ha)	CA as % of arable land*
Argentina	2011	27000	71.0%
Paraguay	2013	3000	68.0%
Uruguay	2013	1072	61.0%
Brazil	2012	31811	43.8%
Canada	2013	18313	39.9%
Australia	2014	17695	37.6%
USA	2009	35613	22.5%
Chile	2008	180	13.8%
Zimbabwe	2013	332	8.3%
Colombia	2011	127	8.0%
Spain	2013	792	6.4%
China	2013	6670	6.3%
Zambia	2011	200	5.6%
Mozambique	2011	152	2.7%
Malawi	2013	65	1.7%
India	2013	1500	1.0%
Kenya	2011	33	0.6%
Tanzania	2011	25	0.2%
Mexico	2011	41	0.2%

*Conservation agriculture defined here as disturbed soil <25% of cropped area combined with ground cover >30%. Arable land is land under temporary crops and meadows or fallow less than 5 years.

longest experience with CA, where the principles have been practiced since the 1970s and CA now covers over 30 million hectares. CA spread from Brazil to other South American countries, and is widely practiced in Paraguay and Uruguay as well (Table 1). African farmers have adopted CA in the last 15 years, but at slower rates. Little data is available on adoption in Asian countries.

BENEFITS OF CA

Stable yields. The water- and soil-conserving effects of CA help to stabilize yields against weather extremes. Often, CA increases average yields in the long term.

Drought buffering. CA increases soil water content by increasing infiltration and reducing runoff and evaporation. Increased infiltration improves water use efficiency and buffers crops against drought. Mulch cover also buffers the soil against temperature extremes. For example, in rainfed semi-arid highlands of Mexico, soil water content during dry periods was 10-20 mm higher in maize fields under CA than in those with conventional tillage and residue removal. Infiltration was on average 24-38 mm per ha greater on CA fields in southern Africa as compared to conventionally tilled plots.

CAN CA MITIGATE CLIMATE CHANGE?

Conservation agriculture practices—no-till in particular—have been promoted for their potential to mitigate climate change. The potential for no-till alone to mitigate climate change by sequestering carbon may be less than previously thought, but other aspects of CA have mitigation potential.

Recent studies have found that there is sometimes a small (on the order of 0.3 Mg C per ha per year) net accumulation of organic carbon in soil under no-till conditions compared with conventional tillage. This is less than earlier figures, for several reasons. No-till usually increases the concentration of organic matter near the soil surface. However, some of the observed increase is a redistribution of organic carbon, not a net accumulation– extra organic carbon occurs near the surface but not always in deeper soil. In addition, previously used soil sampling methods tend to exaggerate the effect. Apparent soil organic carbon increases calculated on an 'equal depth' basis may actually be 50% less or nonexistent when correctly calculated on an 'equal mass' basis. Consequently, the climate change mitigation achievable from converting to no-till agriculture is likely to be overstated.

Combining no-till with residue retention increases the potential for carbon sequestration by increasing biomass inputs to the soil. Permanent soil cover with crop residues or mulch provides a constant source of fresh organic material, some of which is converted into stable carbon fractions that remain in the soil for millennia. Residue cover also protects the soil from erosion by wind and water. Rotating with a leguminous crop helps balance the carbon-to-nitrogen ratio of crop residues, which allows nitrogen from decaying surface residues to be released slowly and serve as a source for the following crop.

Increasing soil carbon only mitigates climate change if it represents an additional net transfer of carbon from atmosphere to land. In the case of adding crop residues, this balance depends on the alternate fate of the residue material. For example, if crop residues would otherwise be used as animal bedding that would be composted and applied to fields, an increase in SOC from crop residues does not necessarily imply a mitigation benefit over the alternative. Where crop residues are often burned, such as in the Indo-Gangetic Plain, residue retention presents a mitigation opportunity.

Other changes associated with uptake of CA, such as reduced machinery use, reduced fuel use, and direct seeding of rice instead of continuous flooding, also represent mitigation opportunities.

Further reading: Verhulst et al. 2012, Powlson et al. 2011, Powlson et al. 2014

Reduced field preparation costs. CA reduces costs associated with tillage, whether manual or by machinery. In mechanized rice-wheat systems in India, field operational costs were 15% lower under CA. In manual maize systems in Malawi, CA fields required 20% less labor than conventional ridge and furrow fields. The reduction in field preparations with CA also allows timelier planting, which supports successful harvests.

Reduced soil erosion: Reducing tillage and maintaining soil cover with crop residues can reduce erosion by up to 80%. CA also generally increases soil organic matter in topsoil, as well as soil biological activity and biodiversity.

Climate change mitigation. Under certain conditions, CA may contribute to climate change mitigation through carbon sequestration and reduced GHG emissions, but climate change adaptation rather than mitigation should be the main policy driver for its promotion.

CHALLENGES TO CA ADOPTION

Though CA practices can provide multiple benefits, experience shows several common constraints to its adoption.

Appropriate soil type. Wetlands and soils that have poor drainage are generally challenging for CA. Heavy mulch can slow drying and cause disease problems, and increased water infiltration can exacerbate drainage problems.

Sufficient availability of crop residues or other mulch. If crop yields are very low (i.e. areas of less than 500 mm rainfall in Africa), there may be insufficient quantity of residues to effectively practice CA. The need for crop residues as livestock feed is also a common constraint to CA practice. See *Making more milk and leaving more residues* below.

FIGURE 2
Labor intensive land preparation by a farmer in Lundazi, Eastern Zambia. In the background is a field under CA, with minimum soil disturbance, less labor and reduced soil degradation.
Photo: Thierfelder, CIMMYT

Affordable access to fertilizer and herbicides. In some cases, appropriate use of fertilizers as a complement to legume residues is necessary when initiating CA to increase crop yields and available quantity of crop residues. Nitrogen inputs also help avoid yield penalties with CA, as large carbon inputs to the soil in the form of mulch can promote nitrogen immobilization by microorganisms, making it unavailable for crops.

Weed control. Weeds are a major challenge in smallholder cropping systems. Eliminating tillage sometimes increases weed pressure in the early years of CA adoption, but weeds decrease over time if controlled well. Many adaptations of CA use herbicides to control weeds.

Delayed yield benefits. While CA sometimes increases yields in the long term, farmers may need to wait 3 to 7 years to see yield increases. It takes time for farmers to gain experience with CA, and the improvement of soil structure and fertility is a slow process. More immediate benefits are likely to be related to savings in labor or other costs. As with other long-term investments in sustainability, insecure land tenure presents an additional challenge for practicing CA.

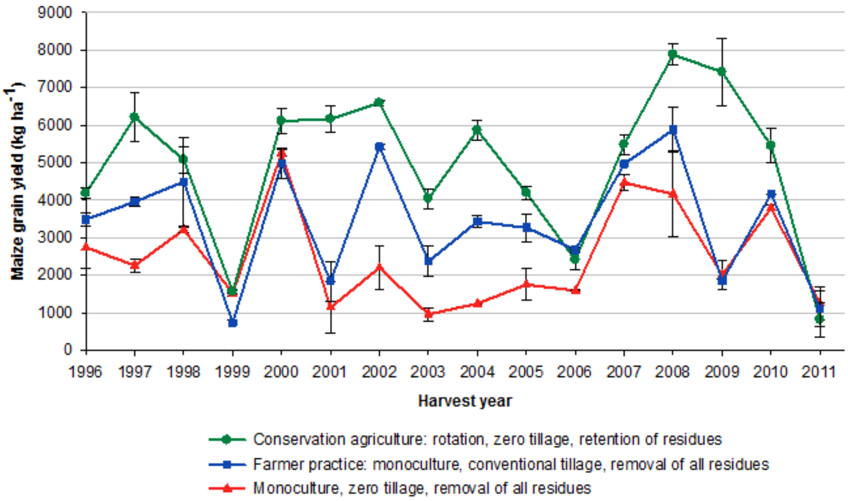

FIGURE 2
Maize yields in a long-term CA experiment in El Batán, Mexico. A drought in 2009 demonstrated the water-efficiency and yield stabilizing benefits of CA. *(Figure from Govaerts et al. 2012)*

LOCAL EXPERIENCES WITH CA

Changes in yields and soil carbon under CA depend on soil characteristics, climate, initial yield levels, and how CA principles are adapted to particular farming systems. Research results from Mexico, India, Malawi and Zambia, give an idea of what effects can be expected.

MEXICO: MORE CARBON, RESIDUES CRITICAL

Researchers at CIMMYT have conducted long-term rain-fed experiments with CA at their research station in El Batán, located in the semi-arid, subtropical highlands of Central Mexico. This CA research involved a maize-wheat rotation with no tillage and retention of all residues, in contrast to the conventional practice of continuous wheat or maize with heavy tillage before planting and removal of all crop residues for fodder. Appropriate herbicides and fertilizers were used in all treatments at the same level (Figure 2). All field operations were mechanized.

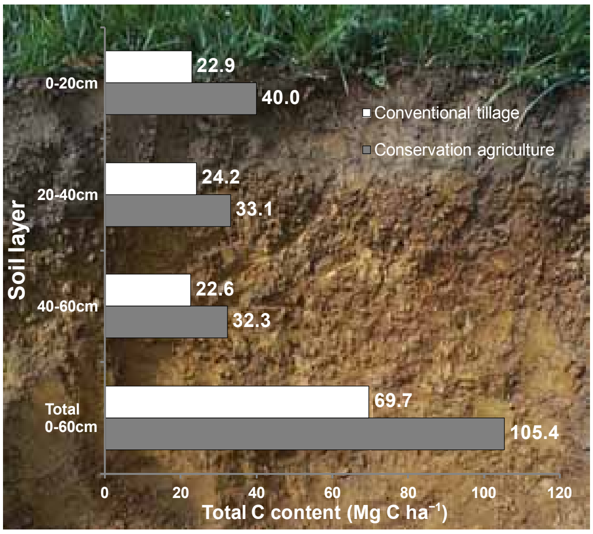

FIGURE 3
The effect of zero-till with residue retention and wheat–maize crop rotation (CA) and conventional tillage with crop removal and continuous maize (CT) on total soil C content in El Batán, Mexico. *(Data from Dendooven et al. 2012)*

Average maize grain yields from 1997 to 2009 were 50% greater under CA than under continuous maize with conventional tillage and residue removal: an average yield benefit of 1.8 tons per ha. Yields were also more stable: the drought-buffering benefit of CA was particularly apparent in 2009, an unusually dry year (Figure 2). Yield benefits became apparent only after about 5 years. This long-term trial also demonstrated the importance of the crop rotation and residue retention principles of CA. In semi-arid environments, zero-tillage can have the counterintuitive effect of degrading soils and reducing yields when residues are not retained.

Carbon stocks in the 0-60 cm soil layer were 50% higher (36 Mg C per ha) after 18 years under CA than those under continuous maize with conventional tillage and residue removal (Figure 3). There was no significant difference in CH4 and N2O emissions between CA and the conventional treatment.

INDIA: FASTER PLANTING, LESS FUEL

The most common cropping system in the Ingo-Gangetic Plain of India is a rice-wheat rotation, which generally requires intensive tillage before rice is planted. However, farmers in the Northwest Indo-Gangetic Plain have begun adopting a zero-tillage system for the wheat crop. Wheat planting is done with a tractor-drawn zero-till seed drill that plants seeds directly into unplowed fields, sometimes applying fertilizer at the same time, which eliminates the need for multiple tractor passes. Zero-till thus reduces the turnaround time between rice and wheat crops and allows timelier planting of wheat. On-farm trials have shown yield gains between 1% and 15% (0.05 and 0.63 tons per ha), due to timelier planting and decreased emergence of an herbicide-resistant weed that is a particular problem in the area, even though other weeds were more abundant.

Long-term effects of zero-till on soil carbon have not yet been evaluated in the Ingo-Gangetic Plain, and soil carbon gains are unlikely, as the rice crop is still intensively tilled, and crop residuesare generally burned or fed to animals. Researchers are working on options to reduce the need for intensive land preparation for rice, thereby bringing both rice and wheat under zero-tillage.

Further reading: Erenstein and Laxmi 2008, Jat et al. 2014, Saharawat et al. 2010

MALAWI: POSITIVE YIELD TRENDS

While manually dug planting basins have been promoted in rainfed maize systems of Malawi, farmers prefer the use of a pointed stick for planting maize directly into crop residues. This method is closer to the traditional method of planting with hand hoes. Because most farmers do not have enough land for crop rotations, some use an edible grain legume intercrop between the maize rows.

In on-farm experiments with rainfed maize at four sites in Malawi, CA out-yielded the conventional ridge and furrow system (Figure 4). Over the seven years of the experiments, the yield benefits of the two CA treatments were initially variable and occasionally negative, but the long-term trend was toward positive and increasing yield benefits, likely due to higher water infiltration rates and greater water conservation under CA. The legume intercrop did not seem to provide an additional yield benefit, but neither did there seem to be competition with the maize crop.

Unlike the expriments at research stations in Mexico and Zambia, researchers found no differences in carbon stocks between the CA and farmer practice treatments in Malawi.

Further reading: Thierfelder et al. 2013, Ngwira et al. 2012

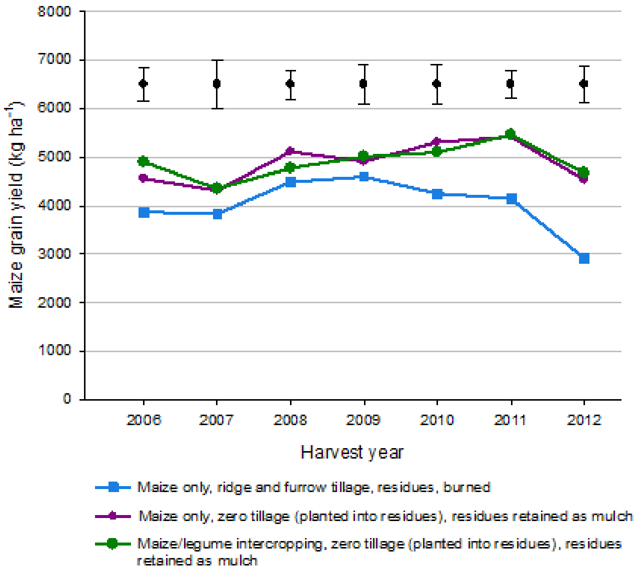

FIGURE 4
Maize yields in a CA experiment in farmers' fields in Malawi. *(Data reflects average of Malula, Chipeni, Mwansambo, and Zidyana sites from Thierfelder et al. 2013)*

ZAMBIA: LARGER YIELDS, BUT DIFFICULTIES WITH INTERCROPPING

A variety of CA methods are practiced in Zambia. Smallholder farmers often dig permanent, narrow planting basins with a specialized hoe, reducing soil disturbance to 10% of the field. Farmers also use animal traction rippers and in some cases animal traction direct seeders, originally imported from Brazil. In other areas, farmers plant seeds into crop residues by hand with pointed sticks. Maize is mostly rotated or intercropped with grain legumes or cotton under CA.

In a multi-site, multi-practice comparison of CA with conventional farming practices in Zambia, the yield benefits of CA emerged only after several years. In on-farm experiments, animal-traction CA methods with legume rotation had 75-91% higher maize yields (a yield benefit of over 3 tons per ha) after six cropping seasons. However, intercropping was not as successful as crop rotation: maize yields in the maize-cowpea intercrop were significantly lower than the maize-cowpea rotation because the intercrop made weed control difficult.

On-station experiments showed that CA treatments increased water infiltration and soil moisture as well as soil carbon to the 30 cm level. The CA treatment with maize-cotton rotation had 32 Mg C per ha after 6 years, compared to 23 Mg C per ha in the conventional ploughed treatment. There was no difference in soil carbon in on-farm experiments, likely due to farmers' difficulty retaining adequate residues in the field.

Further reading: Thierfelder et al. 2013

OVERCOMING CHALLENGES TO CA ADOPTION

Existing CA technologies are not universally applicable, but innovative thinking in the promotion of CA can help expand the conditions where CA is possible. Two case studies provide examples.

INNOVATING ON THE FARM

Though challenges still exist to full CA adoption in the Indo-Gangetic Plain of South Asia, the area is benefitting from substantial adoption of zero-till wheat production. As of a 2004 study, 34.5% of surveyed rice-wheat farmers in India's Haryana state were practicing zero tillage in their wheat crop. This success is due largely to the emergence of local innovation systems involving researchers, innovative farmers, state and local government and commercial firms.

FIGURE 5
Participants in a CIMMYT workshop in India examine a zero tillage seeder. The left-hand tank contains small-grain seed, and the right-hand tank contains fertilizer, which is applied in the same pass as the seed.
Photo: CIMMYT

Impetus for zero-till originally came from concern over accelerating soil erosion. However, adoption depended on the availability of adequate planting equipment. In the early 1990s, member organizations of the Rice-Wheat Consortium for the Indo-Gangetic Plain introduced the zero-till seed drill originally developed in Australia: a tractor-mounted implement that allows farmers to plant seeds and apply fertilizer directly into untilled soil. After several years of participatory research with farmers, farmer demand for the implements grew. The private sector saw market opportunities, and several manufacturers became involved. As more seed drills were manufactured, state and local governments provided subsidies for their purchase and helped set up village demonstration stations.

Several factors were critical to adoption of zero-till in Haryana. Most importantly, the practice provided immediate demonstrable benefits for farmers: shorter turnaround time between rice and wheat crops, reduced pressure from a persistent, herbicide-resistant weed and savings in fuel and labor. Institutional support, in the forms of equipment subsidies and research and extension activities, also helped facilitate adoption. Village demonstration systems, established by government researchers, were critical to overcoming initial skepticism about the possibility of growing wheat without intensive tillage.

LESS LABOR FOR WHOM? UNDERSTANDING GENDER DIMENSIONS OF CA

CA can reduce labor and drudgery on the farm. However, some changes associated with a shift to CA practices affect men and women differently, and consideration of these is necessary to avoid adverse impacts from CA adoption.

Experiences from Malawi, Tanzania and Zambia have shown that CA generally decreases labor requirements for land preparation and weeding, especially when herbicides are used. This is a benefit for women and children, who are generally responsible for mid-season weeding. However, as farmers often hire off-farm labor for this activity, it can also eliminate an income source for landless women and men.

Significant changes in crop rotations also have gender-related impacts. Cash crops such as cotton are generally the domain of men, and adding these to a crop rotation may increase men's control over farming income. In contrast, leguminous crops such as groundnuts and beans are often cultivated by women, whose crops and corresponding incomes have been shown to contribute more to household food security than men's.

A recent analysis by socio-economists at CIMMYT provides guidance for considering the differing impacts on men and women associated with adoption of CA. Table 2 provides examples of questions specific to CA that can help illuminate how experiences might be different for women and men. In the implementation phase, learning and extension should take a gender-transformative approach that addresses gender relations within meetings and field demonstrations. Such approaches can have positive effects, not only for the uptake of CA but also on the relationships between men and women, their roles, and access to resources.

Further reading: Beuchelt and Badstue 2013, Milder et al. 2011

Table 2. Examples of guiding questions to explore potential effects of CA on women and men in smallholder agricultural systems. *(Selection from Beuchelt & Badstue 2013)*

Categories	Questions
Food security and nutrition diversity	Will yield increase or crop diversification improve nutrition? How? Will household members benefit equally?
	Does anyone depend on crop residues? Is there a risk that livestock farmers will be negatively affected if residues are retained for mulching?
	Will food or cash crops be grown? If cash crops are used, who controls the income and is it allocated to household food and health expenditure?
Health	Is there a risk that herbicide use may lead to health hazards? How? Who will be affected?
Access to information and technology	Do extension services target women and men equally? Are extension services gender-responsive? Do they consider women's special needs?
Resources and labor	Who will benefit from reduced drudgery due to mechanization and/or reduced tilling?
	Is there a risk that labor requirements to obtain alternative livestock feed or fuel will increase if residue availability is reduced? Who will be affected by this?
Income, marketing and value chains	Who if anybody is affected when herbicides/mechanization replaces labor? Women or men? Do they have alternative income possibilities?

Challenges remain in terms of the equitability of zero-till technology. Adoption of zero-till has been higher among larger, more commercial farmers. While the technology is theoretically available to smallholders via zero-till service providers, they have been slower to adopt CA. This may be due to lack of knowledge or differential benefits for small and large farmers, and it highlights the importance of considering intra-community differences when adapting CA in a region.

Further reading: Erenstein et al. 2012, Erenstein and Farooq 2009

MAKING MORE MILK AND LEAVING MORE RESIDUES

Leaving crop residues in the field is one of the best opportunities for sub-Saharan African farmers to maintain land in a productive state, as other organic materials (such as manure) are often scarce or too bulky to transport to fields. However, competition between using crop residues as mulch and feeding them to livestock is a major cause for the slow adoption of CA in sub-Saharan Africa.

There is a potential solution: to reduce livestock demand for crop residues by promoting use of more energy-dense feed rations for animals. An analysis of mixed crop-livestock farms in Western Kenya and Ethiopia's Rift Valley showed that by closing the maize yield gap and replacing some maize residues with napier grass, soya bean meal, and molasses in the diets of dairy cattle, most farmers would be able to retain at least 1 ton per ha of crop residues in their fields. A second benefit would be increased livestock productivity.

Intensifying livestock productivity in this manner is most appropriate for market-oriented farmers who can afford to pay for the inputs and have incentives for higher productivity. In western Kenya, for example, there is a strong market for milk products, providing farmers an incentive to increase productivity and profitability by shifting to high-yielding breeds that are fed high-energy fodders and feed supplements.

This example highlights the need to focus on farming systems rather than single practices when promoting CA, especially where there are competing demands for crop residues. It also demonstrates that factors at multiple scales—such as farm-level economics and regional markets—will determine the success of CA. Making CA practices possible may depend on first addressing infrastructural issues.

Further reading: Baudron et al. 2013

IMPLICATIONS FOR CLIMATE-SMART AGRICULTURE INITIATIVES

Mitigation-adaptation synergies are possible. CA has been shown to increase water productivity in dry areas, and can help buffer against the decreasing and more erratic rainfall likely under future climate change. Contributions to climate change mitigation through soil carbon sequestration are also possible, and depend on increasing inputs of organic matter to the soil.

Anticipate delayed benefits. In most cases, yield benefits with CA can take several years to emerge. Farmers are more likely to adopt CA—and continue the practices—when they can see other benefits such as reduced fuel or labour use. Pairing CA promotion with fertilizer can help provide an immediate yield benefit and increase crop residues as long as it does not become a "payment" for continued practice of CA.

Consider capacities, resources and regional contexts. Targeting CA promotion effectively requires examining factors at multiple scales: farm, village and region. Capacities and resources of farmers, village land tenure patterns and regional infrastructure such as roads and markets can all determine the success of CA.

Be flexible. CA practices are a means to an end, not the end in themselves. The particular technologies involved in CA differ markedly between countries, and even regions within a country. Sometimes a particular practice (e.g. crop rotation) may be dropped altogether. Policies to scale up CA should not be overly prescriptive, as local adaptation by farmers is necessary and desired.

Look beyond the crops. Some opportunities—such as associating support for CA with efforts to increase livestock productivity—are not immediately obvious. Adaptation to climate change often requires shifts in entire farming systems, and CA practices may be just one piece of the puzzle.

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PRACTICE BRIEFS ON CSA

This series of briefs summarizes findings from CCAFS and CGIAR research on climate-smart agricultural practices. The intent of these briefs is to provide practical, operational information on climate-smart agricultural practices to help guide climate investment in smallholder agriculture.

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