Climate Smart Agriculture:
A Synthesis of Empirical Evidence of Food Security and
Mitigation Benefits from Improved Cropland Management.

By

Giacomo Branca, Nancy McCarthy, Leslie Lipper and Maria Christina Jolejole

Working paper

October 2011
Acknowledgments

Authors would like to thank Richard Conant (Colorado State University), Marja-Liisa Tapio-Bistrom (FAO) and Andreas Wilkes (ICRAF) for having read and commented a previous version of this paper.

This research paper is part of the Mitigation of Climate Change in Agriculture (MICCA) Programme, FAO, Rome funded by the Government of Finland.
Table of contents

Abstract..................................................................................................................... 4
1. Introduction........................................................................................................... 5
2. Materials and methods........................................................................................... 6
   2.1 Dataset............................................................................................................. 6
   2.2 Study designs................................................................................................... 9
   2.3 Literature review and empirical analysis ....................................................... 11
3. Results .................................................................................................................12
   3.1 Global trends from the literature review ......................................................... 12
   3.2 Evidence from the empirical analysis.............................................................. 18
   3.3 Synergies between food security and climate change mitigation.................... 22
4. Conclusions..........................................................................................................25
5. References............................................................................................................27
Abstract

Meeting the food demand of a global population expected to reach 9.1 billion in 2050 and over 10 billion by end of the century will require major changes in agricultural production systems. Improving cropland management is key to increase crop productivity without further degrading soil and water resources. At the same time, sustainable agriculture has the potential to deliver co-benefits in the form of reduced GHG emissions and increased carbon sequestration therefore contributing to climate change mitigation. The paper synthesizes the results of a literature review reporting the evidence base of different sustainable land management practices aimed at increasing and stabilizing crop productivity in developing countries. It is shown that soil and climate characteristics are key in interpreting the impact on crop yields and mitigation of different agricultural practices and that technology options which are most promising in enhancing food security at smallholder level are also effective on increasing system resilience in dry areas and mitigating climate change in humid areas.
1. Introduction

Agriculture is the most important economic sector of many developing countries. Agricultural production systems are expected to produce food for a global population that will amount to 9.1 billion people in 2050 and over 10 billion by end of the century (UNFPA 2011). In order to secure and maintain food security agricultural systems need to be transformed to increase the productive capacity and stability of smallholder agricultural production. However, there is a question of which technologies and practices are most appropriate to reach this objective and considerable discussion about the inadequacy of the dominant model used for intensification so far, relying on increased use of capital inputs such as a fertilizer and pesticides. The generation of unacceptable levels of environmental damage and problems of economic feasibility are cited as key problems with this model (Tillman et al. 2002; IAASTD 2009; FAO 2010a). Greater attention is thus being given to alternative means of intensification, particularly the adoption of sustainable land management (SLM) technologies1. Key benefits of these technologies are increasing food production without further depleting soil and water resources (World Bank 2006) restoring soil fertility (IFAD 2011; Lal 1997) increasing the resilience of farming systems to climatic risk and improving their capacity to sequester carbon and mitigate climate change (FAO 2009; FAO 2010c).

SLM technologies can generate both private and public benefits and thus constitute a potentially important means of generating “win-win” solutions to addressing poverty and food insecurity as well as environmental issues. In terms of private benefits to farmers, by increasing and conserving natural capital (including soil organic matter, various forms of biodiversity, water resources) SLM can generate productivity increases, cost decreases and higher stability of production (Pretty 2008; 2011). SLM practices contribute to improving soil fertility and structure, adding high amounts of biomass to the soil, causing minimal soil disturbance, conserving soil and water, enhancing activity and diversity of soil fauna, and strengthening mechanisms of elemental cycling (Woodfine 2008). This in turn translates into better plant nutrient content, increased water retention capacity and better soil structure, potentially leading to higher yields and greater resilience, thus contributing to enhance food security and rural livelihoods (FAO 2009).

At the same time, widespread adoption of SLM has the potential to generate significant public environmental goods in the form of improved watershed functioning, biodiversity conservation and mitigation of climate change. The technical potential for mitigation from agriculture by 2030 is estimated to be between 4,500 (Caldeira et al. 2004) and 6,000 Mt CO₂e/year (Smith et al. 2008), which can be reached by reducing GHG emissions – of which agriculture is an important source representing 14% of the global total – and increasing soil carbon sequestration –

---

1 According to the UN Earth Summit of 1992, SLM is “the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions”. SLM comprises four main categories of land management technologies: improved cropland management, improved pasture and grazing management, restoration of degraded land, and management of organic soils.
which constitutes 89% of agriculture technical mitigation potential (IPCC 2007)\(^2\). Many SLM technologies can increase the levels of soil organic matter, of which carbon is the main component, therefore delivering significant CC mitigation co-benefits in the form of reduced GHG emissions and increased carbon (C) sequestration\(^3\). Improving productivity would also reduce the need for additional land conversion to agriculture, which on its own represents almost as much GHG emissions as those directly generated from agriculture activities (Cerri et al. 2007, Houghton 1999, Lal 2004).

Despite the capacity to generate both public and private benefits the adoption of sustainable land management has been relatively low globally (FAO 2010a). Thus there is considerable interest in understanding better the benefits, costs and barriers to adoption of these practices. The goal of this present work is to synthesize the evidence base on the yield impacts (e.g. private benefits) of a range of improved cropland management options, known to have high potential for sequestering soil carbon and thus contributing to climate change mitigation (e.g. public benefits). By assessing the impact of adopting such practices on the level of food production, the paper also highlights the state of knowledge on where synergies between food security and CC mitigation in croplands are most likely to be found.

To fully realize these synergies, we also need a better understanding of the costs and barriers faced by households when deciding to adopt SLM practices. In a separate companion piece, we consider in more detail household-level studies of adoption of sustainable land management practices, focusing on the costs and barriers to adoption by farmers and the institutional changes and policy frameworks needed to reduce transactions costs and barriers to adoption (McCarthy, 2011).

The paper is structured as follows: section 2 describes data and analytical methods used in this study (literature review and empirical analysis), section 3 reports main results, which are then discussed in section 4.

2. Materials and methods

2.1 Dataset

The present study is based on a review of the existing literature showing the impact of selected sustainable cropland management mitigation options on the productivity (average yield) of crops\(^4\). We compiled data from the literature published in English, Spanish and Portuguese, considering the following set of technologies as reported in

---

\(^2\) To a lesser extent, improvements in rice management and livestock can reduce CH\(_4\) emissions, providing an additional 9% of mitigation potential. Adopting measures in crop management could reduce N\(_2\)O emissions from soils, representing the remaining 2% of agriculture’s mitigation potential.

\(^3\) The SOC content is likely to reach its maximum 5 to 20 years after adoption of SLM practices and remain similar, under continuous use of SLM practices and similar environmental conditions. The actual rate of SOC sequestration in an agricultural system depends on soil texture, profile characteristics and climate, ranging from 0 to 0.15 t C/ha/year in dry and warm regions and 0.10 to 1 t C/ha/year in humid and cool climates.

\(^4\) Grasslands are also a potentially important resource for carbon sequestration. However, the evidence on benefits to grasslands management in terms of both carbon sequestration and livestock productivity is more scarce than for the cropland, though c.f. Abberton et al., 2010, Lipper et al., 2007 for a review of empirical evidence on productivity and Conant et. al. 2001 for a review on carbon sequestration effects. This paper will focus only on cropland, while acknowledging the potential role of grasslands.
IPCC 2007: improved agronomic practices, integrated nutrient management, tillage
and residue management, water management and agroforestry (see table 1).

Table 1 – Sustainable cropland management practices considered in the analysis

<table>
<thead>
<tr>
<th>Management Practices</th>
<th>Details of the Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agronomy</td>
<td>Use of cover crops</td>
</tr>
<tr>
<td></td>
<td>Improved crop or fallow rotations</td>
</tr>
<tr>
<td></td>
<td>Improved crop varieties</td>
</tr>
<tr>
<td></td>
<td>Use of legumes in crop rotations</td>
</tr>
<tr>
<td>Integrated nutrient management</td>
<td>Increased efficiency of Nitrogen fertilizer</td>
</tr>
<tr>
<td></td>
<td>Organic fertilization (use of compost, animal and green manure)</td>
</tr>
<tr>
<td>Tillage and residue management</td>
<td>Incorporation of crop residues</td>
</tr>
<tr>
<td></td>
<td>Reduced/minimum/zero tillage</td>
</tr>
<tr>
<td>Water management</td>
<td>Irrigation</td>
</tr>
<tr>
<td></td>
<td>Bunds/zai, tied ridge system</td>
</tr>
<tr>
<td></td>
<td>Terraces, contour farming</td>
</tr>
<tr>
<td></td>
<td>Water harvesting</td>
</tr>
<tr>
<td>Agroforestry</td>
<td>Live barriers, fences</td>
</tr>
<tr>
<td></td>
<td>Crops on tree-land</td>
</tr>
<tr>
<td></td>
<td>Trees on cropland</td>
</tr>
</tbody>
</table>

Source: IPCC 2007

In order to be included in the analysis, studies had to report: the specific improved cropland management practice (or group of practices) adopted; the crop on which the practices have been implemented; and the corresponding change in crop yield. Reporting of variability data (min-max or range, variance or standard deviation) was preferred but not essential. Only studies reporting empirical results from wider implementation at farm level of the selected technologies in developing countries were taken into account. Thus, publications reporting model estimations or results of plot experiments in research stations or on-farm field trials and studies related to documented cases in developed countries were not considered. Studies which do not report any quantitative impact of the SLM practice on the yields, but only an overall indication of such impact (i.e. if positive or negative) were also excluded. Reports of projects implementing a set of different practices (technology package) were excluded as well since it was not possible to isolate the impact of the specific practice on crop productivity.

The main data source was publicly available published peer reviewed studies. Literature searches (mainly in English, but also in Spanish, Portuguese and, limitedly, French) were conducted through the FAO and the University of Illinois libraries as well as through search engines such as Google scholar. The following electronic databases have been consulted: CAB Abstracts, Science Direct, Science Magazine Online, ProQuest, Economist Intelligence Unit, World Bank publications, OECD publications, CIRAD (Centre de coopération internationale en recherche agronomique pour le développement) library and the World Overview of Conservation Approaches and Technologies (WOCAT) technology database (Wocat 2011). Specifically, the WOCAT database has been used by extracting case studies from the questionnaire of technologies, selecting cases which report the effects of the
practices on average yields (quantitative data). Also, the following journals have been systematically checked: No-till farming systems; Agriculture, Ecosystems and Environment; Agro forestry Systems; Soil and Tillage Research; Soil Science; Agricultural Systems. Additional information has been collected consulting the Global Farmer Field School Network and Resource Centre (FFSnet)\(^5\), the FAO database on proven agricultural technologies for smallholders\(^6\) (TECA) and the FAO Investment Centre (TCI) electronic library of project documents\(^7\).

Keywords used in the search were, among others: sustainable farming/SLM/improved agronomic practices/tillage management/water management/agro forestry/pasture management & crop yields. Key words for the search in Portuguese were: rotação de culturas/cobertura do solo/pousio/variedades melhoradas/cultivo minimo/plantio direto/incorporação de resíduos/cordão vegetado/cordão de pedra/patamar de pera/reflorestamento conservacionista/estercos/adubacao organica/adubacao verde & productividade. Key words for the search in Spanish were: cultivos de cobertura/rotación de cultivo/variedades mejoradas/labranza cero/sebes vivas/cercas vivas/agroforesteria o agrosilvicultura/estiércol/suministros o abonos organicos&cosechas o rendimientos. Key words for the search in French were: stratégie amélioration de la fertilité/rotations, successions et associations cultural/gestion de l’eau/plantes fourrageres et de couverture/paillage/haie vive antiérosive/productivité.

When a relevant study was found, papers which were cited by the study, as well as papers which cited the study itself were checked, in order to obtain as complete set of papers as possible. For each case-study, the following information is reported in the database: detailed description of the practice(s) adopted, crop(s), location (geography, climate), information about land use history, and yield variation with respect to previous conventional agricultural practices.

Overall, 217 observations from about 160 publications were included in the database for the current study\(^8\). The database covers 5 main management practices (agronomy, integrated nutrient management, tillage and residue management, water management, agro forestry) applied in 3 regions (Asia and Pacific, Latin America and Sub-Saharan

---

\(^5\) Unfortunately, we could not find useful quantitative data from this source of information. In fact, as shown in a recent study which reviewed 25 impact evaluations, largely from unpublished sources (van den Ban & Hawkins 1996), in assessing the results Farmer Field School (FFS) activities no agreement as yet exists as to what to measure and how to measure it. Nevertheless, almost unanimously, studies have demonstrated notable increases in rice, cotton and vegetable yields (Braun et al. 2006) consequent to the implementation of FFS.

\(^6\) I.e. a technology for which there is evidence that the technology has been used or adopted by target beneficiaries (farmers), especially in rural areas and that it can be easily reproduced, shows maturity by successful application in projects, the information that is available is a public good and has been developed with a participatory approach, contributes to the increase in yields by making sustainable use of natural resources (FAO 2011).

\(^7\) We examined reports such as: Staff Appraisal Report (SAR), Project Appraisal Document (PAD) and Completion Report (ICR). Unfortunately, due to a complicated and long consultation procedure, it was possible to extract only a limited amount of information. Also, in many cases, project documents provided only qualitative information or reported the impact of the whole technology package, without providing the productivity effect of the single management practices adopted.

\(^8\) The number of observations (data points) does not coincide with the number of publications for two reasons: if the publication reports a separate analysis for different countries or for more than one crop types, then the corresponding results have been considered as separate cases in the database; in some cases one observation results from more than one publications (e.g. data reported in Wocat database of technologies).
Africa), 41 countries (Bangladesh, Benin, Bolivia, Botswana, Brazil, Burkina, Cameroon, China, Colombia, Dominican Republic, DR Congo, El Salvador, Ethiopia, Ghana, Ghana, Guatemala, Honduras, India, Indonesia, Kazakhstan, Kenya, Malawi, Mexico, Morocco, Mozambique, Nepal, Niger, Nigeria, Pakistan, Paraguay, Peru, Philippines, Rwanda, Senegal, South Africa, Sri Lanka, Tanzania, Togo, Uganda, Vietnam, Zambia, Zimbabwe) and mainly over cereals (maize, wheat, sorghum, millet, teff) (see tables 2 and 3).

Table 2 – Dataset description: number of observations by management practice

<table>
<thead>
<tr>
<th>Management practice</th>
<th>Cereals</th>
<th>Other crops</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agronomy</td>
<td>28</td>
<td>10</td>
<td>38</td>
</tr>
<tr>
<td>Integrated nutrient management</td>
<td>24</td>
<td>7</td>
<td>31</td>
</tr>
<tr>
<td>Tillage and residue management</td>
<td>55</td>
<td>15</td>
<td>70</td>
</tr>
<tr>
<td>Water management</td>
<td>44</td>
<td>8</td>
<td>52</td>
</tr>
<tr>
<td>Agroforestry</td>
<td>20</td>
<td>6</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>171</td>
<td>46</td>
<td>217</td>
</tr>
</tbody>
</table>

Table 3 – Dataset description: number of observations by geographical area

<table>
<thead>
<tr>
<th>Region</th>
<th>Cereals</th>
<th>Other crops</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia and Pacific</td>
<td>49</td>
<td>10</td>
<td>59</td>
</tr>
<tr>
<td>Latin America</td>
<td>32</td>
<td>15</td>
<td>47</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>90</td>
<td>21</td>
<td>111</td>
</tr>
<tr>
<td>Total</td>
<td>171</td>
<td>46</td>
<td>217</td>
</tr>
</tbody>
</table>

2.2 Study designs
The studies used in the current review are essentially journal articles and reports of academic research, edited books and book sections, and project reports. Although seemingly a large number of studies are available on the topic, since many articles citing evidence from others – the number of original field studies is considerably more limited. However, the search has been expanded using the World Overview of Conservation Approaches and Technologies (Wocat 2011) database which contains a full range of different case studies documented from all over the world, comprising datasets on 380 technologies from over 40 countries and reporting original field data as well as grey literature (thesis, manuscripts and other unpublished work).

Most publications in the database make reference to original project data and report findings from projects aimed at promoting the adoption of improved cropland practices in a specific area and implemented by local institutions, often in cooperation with scientists (E.g. Altieri 2001, Edwards 2000, Erenstein et al. 2007, Garrity 2002, Hine & Pretty 2008, Jagger & Pender 2000, Kassie et al. 2008; Kaumbutho & Kienzle 2008; Pender 2007; Place et al. 2005; Pretty 1999; Scialabba & Hattam 2002; Sharma 2000; Shetto et al. 2007; Sorrenson 1997; Verchot et al. 2007). Most of these studies report results of observations over a limited number of years. However, some also report results of long-term observations: e.g. Sorrenson (1997) analyzed the
profitability of Conservation Agriculture on farms in two regions of Paraguay over 10 years.

Some publications report empirical results measured in other studies when building a model (e.g. Dutilly-Diane et al. 2003), while some others are a literature review: Lal (1987) basically reviews all advances in management technologies that have proven to be successful within ecological constraints of Africa by looking at past studies and literature; Parrot and Marsden (2002) and Rist (2000) generated information by a desk-based literature review, supplemented by a semi-structured survey of organic organisations, NGOs and academics and a selected number of face-to-face and telephone interviews; Pender (2007) reviews the literature on agricultural technology options in South and East Asia, drawing conclusions concerning technology strategies to reduce poverty among poor farmers in less-favored areas of this region; Derpsch et al. (2010) report and comment on results from previous studies on tillage management.

Only in a limited number of cases have results of research experiments been included, specifically in the case of long-term or worldwide experiments or when a relatively high number of farmers have been involved; e.g. Govaerts et al. (2007) report the results of a long-term experiment started in 1991 (to 2007) under rainfed conditions in the volcanic highlands of central Mexico, where crop rotations maize/wheat, zero tillage and residue management practices have been successfully tested; Hossain et al. (2003) assessed the contributions of international research centres to rice productivity gains in the developing countries of Asia and Latin America over the period 1965-99, through a questionnaire and in-depth interviews; Rockstrom et al. (2009) conducted on-farm trials over 1999-2003 in 8 different locations at 11 experimental sites, engaging varying numbers of farmers at each site.

Unfortunately, in most cases the publications reviewed do not explain clearly how the information on the effect of the SLM practices on the yields were collected. Only a limited number of studies used proper impact analysis to document the effect of the introduction of the new technologies. For example, in the study from CIAT (2008) – aimed at estimating the impacts of new bean varieties released in eastern, central and southern Africa – the Pan-Africa Bean Research Alliance (PABRA) coordinated a set of impact studies: field research was conducted between 2004 and 2006 in Kivu province of DR Congo, Ethiopia, western Kenya, Malawi, northern Tanzania, Rwanda, and Uganda and data for the country studies was obtained through sample surveys covering 2,476 farm households. Place et al. (2005) combined qualitative and quantitative analysis: quantitative measures from surveys, enumerator ratings and farmer self-assessments and qualitative research methods. Stoll (undated) reported impacts of programs and projects promoting SLM technologies. Some studies report the results of surveys conducted among farmers: e.g. Ekboir et al. (2002) asked an open-ended question on the 3 most important changes that no-till brought to farming activities and a majority of farmers (62%) mentioned higher yields; Erenstein et al. (2007) used community level surveys to compare yields from smallholders under conventional tillage (high intensive agriculture) and zero tillage in Zimbabwe; Franzel et al. (2004) used questionnaires to document the results of other report results of farm-led trials conducted after researcher-led trials.

Most studies report results from single cases in a specific area of a country, and with reference to a particular climate. However, some studies are a global review of results from various countries: e.g. Derpsch & Friedrich (2009) compare conservation
agriculture systems with conventional tillage systems in Latin America, Africa and Asia; Hine & Pretty (2008) – which is by far the largest study examining sustainable agriculture initiatives in developing countries – comprises the analysis of 286 projects covering 37 million hectares in 57 countries; Pretty (1999) examines a typology of 8 technology improvements that are currently in use in 45 sustainable agriculture projects over 17 countries, finding that some 730,000 households have substantially improved food production thanks to cereal yield increases. Also, some studies report results under different climatic conditions: e.g. Kassie et al. (2008) use 2 sets of plot level data for their empirical analysis in Ethiopia, one from a low rainfall region (Tigray region - 500 farm households, 100 villages, 50 peasant associations and 1,797 plots) and another from a high rainfall region (Amhara region - 435 farm households, 98 villages, 49 peasant associations and about 11,434 plots).

In order to isolate the production effects of the improved cropland management technologies, in many cases the results have been compared with control areas where the practices have not been implemented (e.g. Erenstein et al. 2007; Franzel et al. 2004; Hellin and Haigh 2002; Hödtke et al. (undated); Li et al. 2008). In other cases, the long term trends in crop yields have been modelled for several alternative technology options and compared to crops produced under conventional management practices, on the basis of extensive farm-experiments (e.g. Garrity 2002, Nelson et al 1998).

In almost all cases included in the literature database, publications have analyzed the results of peasant farming projects which deal with small-size farms (ranging from less than 1 ha to about 1-2 ha). Only a few cases report results of projects involving medium-large scale farms: e.g. Alvarez & Flores (1998) in Honduras; Fileccia (2008) in Kazakhstan; and Sorrenson (1997) in Paraguay.

2.3 Literature review and empirical analysis

We have analysed the effect of adopting improved cropland management technologies on crop productivity through a traditional literature review – examining the publications collected as described above – complemented by the analysis of empirical evidence, using the results from the individual studies contained in the database of publications. The basic assumption underlying the empirical analysis is that each study result is one observation that can be thought of as one data point in a larger dataset containing all available observations (Arnqvist and Wooster 1995, Gurevich and Hedges 1999). A single publication might contribute more than once to the empirical analysis if a separate study was done for different countries or if more than one crop type was studied9. Most of the studies did not report any measure of variance for the crop yields resulting from the implementation of the improved practices. Thus, only effects on the average yield have been considered.

Since the main goal of the empirical analysis was to determine whether the implementation of various improved cropland management practices elicited quantitatively different responses in crop yields, we considered the % change of average yields with respect to the corresponding yield obtained under conventional agriculture in the same geographical area and under the same climate conditions. We also tested whether there are significant differences in mean response among various

---

9 See also footnote n.8 above in the text.
categories of cropland management technologies (range, standard deviation and coefficient of variation).

Per each management practice (agronomy, integrated nutrient management, tillage and residue management, water management, agroforestry) a crop (or group of crops) is selected and the % variation of yield with respect to conventional agricultural practices by agro climatic conditions (dry/humid) is examined. Some of the studies report the change in crop yields in absolute terms (t/ha), while others report data in % yield change due to the introduction of the improved practices. In order to make the results comparable, all data have been transformed in % change with respect to average yield (using the approximate average yield for the specific crop and country and under the prevailing climate characteristics of project area, when available).

3. Results

This section presents the evidence base of the impact of selected improved cropland management options on crop yields as a result of the literature review (section 3.1) and of the quantitative analysis of the empirical evidence (section 3.2).

3.1 Global trends from the literature review

The main benefit of implementing improved cropland management practices is expected to be higher and more stable yields, increased system resilience, and therefore enhanced livelihoods and food security and reduced production risk (Conant 2010, Vallis et al. 1996, Pan et al. 2006, Woodfine 2009, Thomas 2008).

In this next section, we summarize findings from a global literature review on yield effects of the adoption of specific improved crop management practices. To the extent possible, we distinguish between agro-ecological and farming system type, as well as long run vs. short run effects. However, the analysis of these factors is highly constrained by the availability of information in the literature cited.

Use of cover crops is reported to lead to higher yields due to decreased on-farm erosion and nutrient leaching, and reduced grain losses due to pest attacks. For example: Kaumbutho et al. (2007) showed that maize yield increased from 1.2 to 1.8-2.0 t/ha in Kenya with the use of mucuna (Velvet Bean) cover crop; Olaye et al., (2007) showed that there was a significant yield loss of about 31.4%-42.4% in the long run and 36.7-48.5% in the short run for continuous maize planting compared to maize cropped using different cover crop types (Cajanus spp. – e.g. Pigeon pea – and mucuna); Pretty (2000) showed that farmers who adopted mucuna cover cropping benefitted from higher yields of maize with less labour input for weeding (maize following mucuna yields 3–4 t/ha without application of nitrogen fertiliser, similar to yields normally obtained with recommended levels of fertilisation at 130 kgN/ha); Altieri (2001) reported that maize yields in Brazil increased by 20-250% with the use of cover crops.

Crop rotations and intercropping designed to ensure differential nutrient uptake and use (e.g. between crops, such as millet and sorghum and Nitrogen-fixing crops, such as groundnuts, beans and cowpeas), will enhance soil fertility, reduce reliance on chemical fertilizers, and enrich nutrient supply to subsequent crops (Conant 2010), leading to increased crop yields (Woodfine 2009). For example, Hine and Pretty (2008) showed that in the North Rift and Western regions of Kenya maize yields increased to 3.4 t/ha (71% increase in yields) and bean yields to 258 kg/ha (158%
increase in yields); Hodtke et al. (undated), as cited by Parrot and Marsden (2002), report that, in Brazil, intercropping maize with legumes led to increases in both grain yield and total nitrogen content by 100%.

Increased crop yields after a fallow period has been widely reported (Agboola 1980; Hamid et al. 1984; Saleen and Otsyina 1986; Prinz 1987; Palm et al. 1988, Conant 2010), although the magnitude of yield increment after each successive fallow is variable and bare fallow may increase soil erosion risk.

The use of improved crop varieties is expected to increase average yields because of the greater seed diversity of the same crop. For example, Pretty (2000) showed that introduction of new varieties of crops (vegetables) and trees (fruits) increases yields in Ethiopia by 60%; the International Centre for Tropical Agriculture (CIAT 2008) showed that the average yield increase due to introduction of new bean varieties in seven African countries was 44% in 2004-05, although the gains varied widely across countries, ranging from 2% in Malawi to 137% in western Kenya.

Adopting organic fertilization (compost and animal manure) is widely found to have positive effects on the yields. For example, Hine and Pretty (2008) showed that maize yields increased 100% (from 2 to 4 t/ha) in Kenya; Parrot and Marsden (2002) showed that millet yield increased by 75-195% (from 0.3 to 0.6-1 t/ha) and groundnut by 100-200% (from 0.3 to 0.6-0.9 t/ha) in Senegal; and Scialabba and Hattam (2002) showed that potato yield increased by 250-375% (from 4 to 10-15 t/ha) in Bolivia. Altieri (2001) quotes several examples from Latin America where adoption of organic fertilization and composting led to increases in maize/wheat yields between 20-250% (Brazil, Guatemala and Honduras) and in coffee yield by 150% (in Mexico); Edwards (2000) showed that in the Tigray province of Ethiopia composting led to yield increases compared to chemically fertilized plots: barley (+9%), wheat (+20%), maize (+7%), teff (+107%), and finger millet (+3%); Rist (2000), as cited in Parrott and Marsden (2002), reports that farmers in Bolivia increased potato yields by 20% using organic fertilizers. Also, enhancing inputs of nitrogen through nitrogen-fixing plants that are not harvested (green manure) is key in maximizing production and ensuring long-term sustainability of agricultural systems (Fageria 2007, Hansen et al. 2007).

For example, Kwesiga et al. (2003) showed that in Zambia, including Sesbania sesban (an indigenous Nitrogen-fixing tree) fallow in rotation led to increases in yield for maize with respect to continuous cropping. Maize yield increased from 6.75 to 7.16 and 7.57 t/ha following 1, 2 and 3 years fallow, showing that short leguminous fallow rotations of 1-3 years have a potential in increasing maize yield even without fertilizers thanks to the Nitrogen fixation capacity and the mineralization of the below ground root system.

Increasing the proportion of nutrients that are retained in the soil (e.g. through mulching and limiting nutrient leaching) is also expected to have positive effects on crop yields (Smolikowski et al. 1997; Conant 2010; Silvertown et al. 2006). For example, Lal (1987) reported yield increases by incorporating residue mulch of rice husks (about 6 t/ha) on different crops (from 3.0 to 3.7 t/ha on maize, 0.6 to 1.1 t/ha on cowpea, 0.6 to 0.8 t/ha on soybean, 16.4 to 28.3 t/ha on cassava and 10.7 to 17.9 t/ha on yam. Also, soil water contents are generally higher under mulch cover (Unger et al. 1991; Arshad et al. 1997; Barros & Hanks 1993, Scopel et al. 2004).

---

10 New varieties were planted on 49% of total bean acreage in 2004-05, but the proportion varied across countries (DR Congo-Kivu 68%, N. Tanzania 56%, Malawi 68%, Rwanda 43%, and Uganda 31%).
Tillage systems (which adopt no-tillage, minimum tillage and crop residue management) provide opportunities for increasing soil water retention. Therefore crop yields are often higher than under conventional tillage (Derpsch & Friedrich 2009), especially in semi-arid and dry sub-humid agro-ecosystems. For example, substantial increases in rain use efficiency with implementation of conservation tillage practices in Sub-Saharan Africa are reported by Rockstrom et al. (2009). Studies examining maize production in semi-arid Mexico produced similar results (Scopel et al. 2005). Also, in semi-arid areas, no-tillage benefits seem to be higher on severely degraded soils because of low organic matter contents and poor physical conditions (Acharya et al. 1998).

There is also evidence of yield and soil improvements from humid tropical and temperate agro-ecosystems (e.g., Rasmussen, 1999; Diaz-Zorita et al., 2002; Bronick and Lal, 2005), where primarily minimum and zero-tillage practices are applied. In semi-arid sub-Saharan Africa documented success with minimum tillage practices is limited and scattered, largely in relation to certain development projects, e.g. in Tanzania and Zambia (Rockstrom and Jonsson, 1999), even though significant success has been reported from commercial farms (Oldreive, 1993). Conservation farming success in Africa remains concentrated to more humid environments where many studies report positive effects on crop yields compared to traditional tillage management: e.g. Hine and Pretty (2008) report increases in maize yields (+34%) and soya (+11%) in Argentina; Hine and Pretty (2008) record increases in maize (+67%, from 3 to 5t/ha) in 10 yrs and soya (+68%, from 2.8 to 4.7 t/ha) yields in Brazil (Paraná and Rio Grande do Sul) and again maize (+47%), soya (+83%), and wheat (+82%) in Brazil (Santa Catarina).

Proper water management can help capture more rainfall (Vohland & Barry 2009), making more water available to crops, and using water more efficiently (Rockstrom & Barron 2007), which are crucially important for increased agricultural production (Conant 2010, Rockstrom et al. 2010). Bunds/Zai and Tied Ridge Systems generate higher yields particularly where increased soil moisture is a key constraint (Lal 1987). Terraces and contour farming practices can increase yields due to reduced soil and water erosion and increased soil quality: Altieri (2001) showed that restoration of Incan terraces has led to 150% increase in a range of upland crops; Shively (1999) finds that contour hedgerows can improve maize yields up to 15% compared with conventional practices on hillside farms in the Philippines; Dutilly-Diane et al (2003) reported an increase millet yields from 150-300 kg/ha to 400 (poor rainfall) and 700-1000 kg/ha (good rainfall) in Burkina Faso; and from 130 to 480 kg/ha in Niger but also note that bunds lead to increased yields in the low and medium-rainfall areas, but lower yields in the high rainfall area (which had exceptionally high rainfall the year of the survey). Dosteus (2011) reports that building excavated terraces (bench/fanya juu11) in the Uluguru mountains in Tanzania has improved soil composition: for example, soil testing results have shown that the average moisture level in areas with terraces/ fanya juu is higher than in areas without structures (1.6% vs 0.3%) and average soil compaction is lower than in areas with no terraces (1.05 km/m² vs 3.05 km/m²). Consequently, crop performance in areas with interventions has improved in terms of crop growth rate and yields: maize and beans yields harvested on excavated structures increased 3 times. Also, farmers were able to introduce high value crops

11 A Fanya juu (“throw it upwards” in Kiswahili) terrace comprises embankments (bunds) which are constructed by digging ditches and heaping the soil on the upper side to form the bunds which are usually stabilized with grass strips (Wocat, 2007).
like tomato, cabbage and spices (Dosteus 2011). Posthumus (2005) showed that in Peru yields obtained with bench terraces are higher than yields without terraces for maize in Pachuca (640 Kg/ha versus 408 Kg/ha) and for potato in Piuray-Ccorimarca (3,933 kg/ha versus 850 Kg/ha). However, it is also found that the yield increase is nullified by the amount of area lost (20%) due to the terracing, which makes it necessary to fully exploit the terraces (e.g. cultivation of a second crop during the dry season, use of organic fertilizers, or use of irrigation) in order to counterbalance the production loss (Posthumus 2005).

Water harvesting techniques (e.g. run-off collection techniques, water storage tank construction, use of devices for lifting and conveying water, microcatchment water conservation with film mulching) also increase yields: Parrott and Marsden (2002) showed that water harvesting in Senegal changes the yields of millet and peanuts by 75%-195% and 75%-165% respectively and that water conservation techniques resulted in 50% increase in productivity in eastern and central Kenya; Pretty (2000) report that cereal yields went up more than 100% in Zimbabwe thanks to the implementation of water harvesting technology.

Agroforestry refers to land use practices in which woody perennials are deliberately integrated with agricultural crops, varying from very simple and sparse to very complex and dense systems. It embraces a wide range of practices (e.g. farming with trees on contours, intercropping, multiple cropping, bush and tree fallows, establishing shelter belts and riparian zones/buffer strips with woody species etc.) which can improve land productivity providing a favourable micro-climate, permanent cover, improved soil structure and organic carbon content, increased infiltration and enhanced fertility (WOCAT 2011) reducing the need for mineral fertilizers (Schroth & Sinclair 2003, Garrity 2004). For example, Sharma (2000) as cited by Parrott and Marsden (2002) reports yield increases of 175% on farms in Nepal; Soto-Pinto (2000) studied outputs from shade grown coffee production in Mexico and found that shaded groves had yields 23-38% higher; Verchot (2007) reported an increase in maize yields from 0.7 to 1.5-2 t/ha in Malawi. Use of live fences is also expected to increase yields (e.g. Ellis-Jones and Mason (1999) reports increased from 13.5 t/ha to 31.7 t/ha of cassava yields) although results are controversial: e.g. Hellin and Haigh (undated) reports no difference in yields from adoption of live barriers/fences. A summary of these findings is reported in table 4.

Last, while we do not present detailed results relating to pasture management, it is worth noting that SLM practices on grasslands can have a positive impact on food security by livestock yields. Research has documented that improved pasture management by improving vegetation community structure (e.g. seeding fodder grasses or legumes with higher productivity and deeper roots) can lead to higher livestock yields due to greater availability of better quality forage with potential increased returns per unit of livestock (Sleugh et al. 2000, Hussain 2007). Adopting improved grazing management (stocking rate management, rotational grazing, enclosures to allow degraded pasture to recuperate) has also the potential to increase livestock yields. For example, Derner (2008) showed that average daily gains (kg/head/day) decreased with increasing stocking rate and grazing pressure: heavy stocking rates reduced average daily gain by 16% and 12% compared to light and moderate stocking rates, respectively. Haan (2007) reported that grazing cattle return to the pasture over 80% of Phosphorus and other nutrients consumed in forage (Berry et al. 2001), and these nutrients become available to support forage growth and livestock productivity (Bakker et al. 2004). However, as noted above, for the most
part there is very limited evidence on changes in livestock productivity from various management options, and even the extent to which there is documented overgrazing (c.f. the review in Vetter, 2009) particularly in semi-arid regions. Thus, we do not delve into these issues further here.

Table 4: Impact of improved cropland management practices on crop yields. Summary of global trends

<table>
<thead>
<tr>
<th>Practices</th>
<th>Details of the practices</th>
<th>Impacts on Crop Yields</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover Crops</td>
<td>Higher yields due to reduced on-farm erosion and reduced nutrient leaching. E.g. Kaumbutho et al. (2007); Olaye, et al., (2007); Pretty (2000); Ahieri (2001)</td>
<td></td>
</tr>
<tr>
<td>Crop rotations</td>
<td>Higher yields when cropped, due to increased soil fertility. E.g. Kwesiga et al. (2003)</td>
<td></td>
</tr>
<tr>
<td>Improved Varieties</td>
<td>Increased crop yield. E.g. Pretty (2000); CIAT African Coordination Kawanda Ag Research Institute (2005); Hine and Pretty (2008)</td>
<td></td>
</tr>
<tr>
<td>Use of legumes in the rotation</td>
<td>Higher yields due to increased N in soil. E.g. Hine and Pretty (2008); Hodtke, et al (undated), as cited by Parrot and Marsden (2002);</td>
<td></td>
</tr>
<tr>
<td>Increased Efficiency of N Fertilizer; organic fertilization; legumes and green manure; compost; animal manure.</td>
<td>Higher yields through increased soil fertility and more efficient use of N fertilizer. E.g. Hine and Pretty (2008); Parrot and Marsden (2002); Scialabba and Hattam (2002); Ahieri (2001); Edwards (2000); Rat (2000), as cited in Parrott and Marsden</td>
<td></td>
</tr>
<tr>
<td>Incorporation of Residues</td>
<td>Higher yields through increased soil fertility, increased water holding capacity. E.g. Lal (1987)</td>
<td></td>
</tr>
<tr>
<td>Reduced/Zero Tillage</td>
<td>Higher yields over long run, particularly where increased soil moisture is valuable. E.g. Hine and Pretty (2008)</td>
<td></td>
</tr>
<tr>
<td>Band/Zai, Tied Ridge System</td>
<td>Higher yields, particularly where increased soil moisture is key constraint. E.g. Lal (1987), Kasie (2008)</td>
<td></td>
</tr>
<tr>
<td>Terraces, contour farming</td>
<td>Higher yields due to reduced soil and water erosion, increased soil quality. E.g. Shively (1999); Ahieri (2001); Dutilly-Diane et al (2003); Posthumus (2005)</td>
<td></td>
</tr>
<tr>
<td>Water harvesting</td>
<td>Higher yields. E.g. Parrot and Marsden (2002); Parrot and Marsden (2002); Pretty (2000)</td>
<td></td>
</tr>
<tr>
<td>Live Barriers/Fence</td>
<td>Higher yields. E.g.; Hellin and Haigh (-); Ellis-Jones and Mason (1999)</td>
<td></td>
</tr>
<tr>
<td>Various agroforestry practices</td>
<td>Potentially greater food production, particularly if undertaken on marginal/less productive land within the cropping system. Greater yields on adjacent croplands from reduced erosion in medium-long term, better rainwater management; and where tree cash crops improves food accessibility. E.g.; Sharma (2000) as cited by Parrott and Marsden (2002); Soto-Pinto (2000); Verchot et al (2007)</td>
<td></td>
</tr>
</tbody>
</table>

Table 4 summarizes the results of the review by major category of practice. There are three important trends that emerge from this analysis related to the potential of these practices to be widely adopted and benefit smallholder farmers as well as the global community.

First, the practices can be adopted in a wide range of different combinations, and this matters very much for impacts on yields as well as externalities across different locations. It depends very much on the entire package that is adopted in terms of yield effects. Table 5 exhibits the range of practices in different systems for on
location in Brazil – indicating the range of farm effects realized. FAO 2010 and Bassi 2009 provide other examples. This issue of packaging and combining practices is clearly key to obtaining desired results from SLM adoption and creates difficulties in generating comparisons across sites and combinations of technologies.

Table 5: Impact of improved cropland management technology packages on crop yields. An example from Brazil

<table>
<thead>
<tr>
<th>Activity</th>
<th>Area</th>
<th>Specific practices</th>
<th>Average productivity increase (%)</th>
<th>Average Farm Net Income increase (%)</th>
<th>Project time horizon (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Millet, soybeans, coffee, oranges</td>
<td>S.Paulo</td>
<td>Contour cropping, summer and winter rotation crops, minimum tillage, IPM</td>
<td>50.3</td>
<td>40.7</td>
<td>10</td>
</tr>
<tr>
<td>Maize and other grains, beans, banana, cassava</td>
<td>S.Caterina</td>
<td>Conservation agriculture and agro-forestry</td>
<td>205.0</td>
<td>161.0</td>
<td>15</td>
</tr>
<tr>
<td>Cotton, maize, pastures</td>
<td>S.Paulo</td>
<td>Terracing, minimum tillage, agro-forestry, integrated nutrient management</td>
<td>45.5</td>
<td>69.3</td>
<td>5-7</td>
</tr>
<tr>
<td>Maize and other grains</td>
<td>Parana</td>
<td>Vegetative contours, reduced tillage, terracing, integrated nutrient management</td>
<td>81.7</td>
<td>104.0</td>
<td>7</td>
</tr>
</tbody>
</table>

Source of data: FAO-Technical Cooperation Department

A second major issue that arises is the timing of yield effects; short run vs. long run. In many of these studies, yield benefits emerge only over time: for several options, short-term impacts may be negative depending on underlying agro-ecological conditions, previous land use patterns, and current land use and management practices. Yield variability can also increase in the short term where changes in activities require new knowledge and experience, and farmers unfamiliar with such systems require a period to successfully adopt the practice (e.g. fertilizer application or the construction of water retention structures where incidence and severity of both droughts and floods are expected to increase in the future) (McCarthy et. al. forthcoming; FAO 2009). Long-term impacts are expected to be positive for increasing both the average and stability of production levels. For instance, crop and grassland restoration projects often take land out of production for a significant period of time, reducing cultivated or grazing land available in the short-run, but leading to overall increases in productivity and stability in the long-run (FAO 2009).

Giller et. al. 2009 presents data from several field studies of conservation agriculture adoption indicating a significant lag in yield effects. They also emphasize the importance of specific site characteristics in influencing yield effects and timing. In areas where soil moisture is a key constraint on yields, conservation agriculture can have very immediate yield benefits. However in humid areas on water-logged soils the same practices could lead to yield decreases.
A final general finding from this analysis is that there are relatively few studies that report decreases or lack of yield effects. Giller et al. 2009 do report a few for the case of conservation agriculture, but in general agronomic studies on the adoption of sustainable land management practices report yield benefits. This finding can lead to two different conclusions: one is that sustainable land management does indeed have yield benefits across a wide range of practices, agro-ecologies and farming systems. The second is that studies where sustainable land management did not generate any yield benefit or actually reduced benefits are much less likely to be published and thus a bias exists in the literature in terms of our understanding of SLM impacts on yield. This latter conclusion is only speculation and not based on any evidence, but may be important to keep in mind as a possibility when assessing the overall conclusions from the literature.

### 3.2 Evidence from the empirical analysis

The empirical analysis focuses on the effect of the adoption of improved cropland management practices on the yields of cereals, as for the other crops the number of observations was too limited to be statistically significant (see tables 2 and 3 above). Our analysis clearly shows that improved cropland management increased cereal productivity. Figure 2 reports the average global marginal increase in cereal productivity with respect to average yield under conventional agriculture (in %). However, not all categories of practices had the same impact on average yield increases (and on the variability among the average) as shown in figure 1.
The data in figure 1 were further analysed in relation to the predominant climate and the geographical area where the practices were adopted\textsuperscript{12}. The impact of the adoption of SLM practices was tested in dry and humid areas. Results show that agronomy practices, integrated nutrient and water management are more effective at increasing crop yields in humid than in dry areas. On the other hand, the marginal yield increase observed under tillage management and agro-forestry practices is higher in dry areas (table 6).

These results highlight the key role of water as determinant of crop productivity. For example, in more humid areas, effective water management through terracing and other soil and water conservation measures will have the effect of reducing soil erosion, therefore increasing soil organic matter and nutrient availability in the root zone.

In drier environments, practices that allow plants to make better use of the limited amount of water available result to be most productive. Reduced/zero tillage (often in combination with mulching) will in fact increase water availability to plants improving the capacity of the soil surface to intercept rainfall (by affecting the hydraulic conductivity of the topsoil, soil roughness, and soil surface porosity), reducing direct evaporation and increasing water storage (Scopel et al. 2001). Agro-forestry controls runoff and soil erosion, thereby reducing losses of water, and increase water use efficiency from crops and trees, which could be improved if used in combination with water harvesting techniques.

However, it is worth noting that the marginal yield increase shown in table 6 is only referring to the yield change compared with yields under conventional techniques used before SLM adoption on the same fields and that the change could follow different patterns over the subsequent years, depending on several factors (crops, agro ecological conditions, previous land use, SLM practice type). Also, the sample

\textsuperscript{12} We also tested if the size of the farm is a variable with some effects on the average yields. As mentioned, most observations reported in the sample refer to smallholders. However, we have isolated the effect of the practices on the yields of the few medium-large farms of the sample, and the farm size was found not to be a factor affecting the yields.
variability should be considered, as the range of yield changes for agronomy and agro-forestry practices in dry areas, and for nutrient and water management in humid areas are significant (see figures 3 and 4).

Table 6. Impact of other SLM practices on cereal yields: summary of global trends

<table>
<thead>
<tr>
<th>Management practice</th>
<th>Average marginal yield increase with respect to conventional agriculture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dry</td>
</tr>
<tr>
<td>Agronomy</td>
<td>116</td>
</tr>
<tr>
<td>Integrated nutrient management</td>
<td>72</td>
</tr>
<tr>
<td>Tillage and residue management</td>
<td>122</td>
</tr>
<tr>
<td>Water management</td>
<td>92</td>
</tr>
<tr>
<td>Agroforestry</td>
<td>81</td>
</tr>
</tbody>
</table>

Figure 3. Effect of improved cropland management practices: average % marginal increase of cereal yields in dry areas with respect to conventional agriculture (95% confidence intervals are shown and numbers of observations are in parenthesis)

Figure 4. Effect of improved cropland management practices: average % marginal increase of cereal yields in humid areas with respect to conventional agriculture (95% confidence intervals are shown and numbers of observations are in parenthesis)
Differences in the impact of cropland management practices at regional level were also taken into account. Interestingly, the impact was higher in Sub-Saharan Africa (SSA) than in Asia for most of the practices with the exception of water management (see figure 5).

**Figure 5. Regional differences in the impact of improved agricultural practices on crop yields**

This could be explained by considering that in Asia soil capacity may have reached a productivity limit after the ‘Green Revolution’ which was based on improved crop varieties, synthetic fertilizers, pesticides, irrigation, and mechanization. There is in fact evidence, albeit largely anecdotal, of increasing production problems in those places where yield growth has been most marked. For example, evidence in South-East Asia suggest there are serious and growing threats to the sustainability of the yields of the Green Revolution lands (Pingali & Rosegrant 1998). And there is even evidence of declines in the rates of yield growth (Cassman 1999, Mann 1999, Pingali & Heisey 1999).

Crop production in Asia has increased mainly as a result of increased yields, while in SSA this happened mainly by expanding the area of land under farming (figure 6).

**Figure 6. Regional differences in the increase of agricultural production**

Source: Henao & Baanante 2006

The benefit from adopting improved practices is not therefore surprising for Asia and SSA (where there is more potential to increase crop yields). However, limited access to and affordability of fertilizers and other inputs (e.g. improved planting material) has forced African farmers to cultivate less fertile soils on more marginal lands; these in turn are generally more susceptible to degradation and have poor potential for production (Henao & Baanante 2006). Thus, there is very limited scope for further
expansion in SSA without highly detrimental impacts on natural resources (e.g. deforestation) and there is the need to increase productivity through the adoption of sustainable practices.

3.3 Synergies between food security and climate change mitigation

The literature review and the quantitative analysis of the empirical evidence have shown under which conditions improved cropland management practices can increase crop productivity therefore contributing to food security. The same practices can also deliver significant CC mitigation co-benefits in the form of reduced GHG emissions and increased C sequestration.

Improved agronomic practices have in fact the potential to generate higher inputs of C residue, leading to increased soil C storage (Follett et al. 2001): introducing rotation with N fixing crops will increase biomass production and improving land cover by avoiding use of bare fallow and using cover crops can avoid CO₂ release. Integrated nutrient management can decrease N₂O emissions on-site by reducing leaching and volatile losses, improve nitrogen (N) use efficiency through precision farming and fertilizer application timing, increase C storage (by increasing biomass and improving soil equilibrium to store more C) and improve soil fertility through manure management. In general, the use of organic manures and compost enhances soil organic carbon pool more than application of the same amount of nutrients as inorganic fertilisers, so that more soil organic carbon is reported under organic than conventional farming systems (Leiva et al. 1997).

Proper water management can enhance biomass production, increase the amount of above-ground and root biomass returned to the soil, and improve soil organic C concentration, by increasing available water in the root zone. Increasing available water in the root zone can enhance biomass production, increase the amount of above-ground and the root biomass returned to the soil and improve soil organic C sequestration potential (Kimmelshue et al. 1995).

Tillage management practices, with minimal soil disturbance and incorporation of crop residues decrease soil C losses through enhanced decomposition and reduced erosion. Systems that retain crop residues tend to increase soil C because these residues are the precursors of soil organic matter. For example, conservation tillage which leaves at least 30% of ground covered by crop residue mulch during seedbed preparation (Lal 1997b) increases soil organic C content when land is converted from conventional (plow-based) use. Based on average benefits of all conservation tillage systems, the C sequestration potential of adopting a conservation tillage system is about 0.15 t/ha (Lal 1997a,b). Adoption of reduced tillage may also save fossil fuels at the rate of about 8 KgC/ha/year (Lal and Bruce 1999).

Different estimates of the mitigation potential of agroforestry exist (Dixon 1995; Montagnini & Nair 2004, Palm et al. 2000; Watson et al. 2000). Agro-forestry systems can increase C storage in the vegetation and in the soil and may also reduce soil C losses stemming from erosion (Lal, 2001b; 2004b; Bruce et al., 1999; Olsson and Ardö, 2002; Paustian et al. 2004, Paustian et al. 1997, Lal and Bruce 1999, Lal

---

13 Judicious nutrient management is crucial to humification of C in the residue and to SOC sequestration. Soils under low-input and subsistence agricultural practices have low SOC content which can be improved by judicious use of inorganic fertilizers, organic amendments and strengthening nutrient recycling mechanisms (Lal and Bruce 1999).
Branca et al. 2011

2003). The standing stock of C above ground is usually higher than the equivalent land use without trees, and planting trees may also increase soil carbon sequestration (Oelbermann et al., 2004; Guo and Gifford, 2002; Mutuo et al., 2005; Paul et al., 2003). However the effects on N2O and CH4 emissions are not well known (Albrecht and Kandji, 2003).

Table 7 summarizes the annual mitigation potential in each climate region for the above described SLM options expressed in units of CO2 equivalent per hectare and per year: it shows average net mitigation through increase the soil C stocks or N2O and CH4 emissions reductions. Such estimates were derived from studies conducted in regions throughout the world, standardised using a linear mixed-effect modelling approach and integrated by results of simulation models (IPCC 2007).

### Table 7: Mitigation potential of sustainable cropland management technologies

<table>
<thead>
<tr>
<th>Climate zone</th>
<th>Management Practices</th>
<th>All GHGs (tCO2e/ha/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cool-dry</td>
<td>Improved Agronomic Practices</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>Integrated Nutrient Management</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>Tillage/Residue Management</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>Water Management</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>Agroforestry</td>
<td>0.17</td>
</tr>
<tr>
<td>Cool-moist</td>
<td>Improved Agronomic Practices</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>Integrated Nutrient Management</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>Tillage/Residue Management</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>Water Management</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td>Agroforestry</td>
<td>0.53</td>
</tr>
<tr>
<td>Warm-dry</td>
<td>Improved Agronomic Practices</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>Integrated Nutrient Management</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>Tillage/Residue Management</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td>Water Management</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td>Agroforestry</td>
<td>0.35</td>
</tr>
<tr>
<td>Warm-moist</td>
<td>Improved Agronomic Practices</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>Integrated Nutrient Management</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>Tillage/Residue Management</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>Water Management</td>
<td>1.14</td>
</tr>
<tr>
<td></td>
<td>Agroforestry</td>
<td>0.72</td>
</tr>
</tbody>
</table>

Source: IPCC 2007

Combining the results of the literature review and empirical analysis with the mitigation potential analysis from IPCC (2007) it is possible to highlight where are the synergies between food security and CC mitigation (table 8).

---

14 The mitigation potential is expressed in terms of tCO2e, which already accounts for the fact that some management options may cause other GHGs (CH4 and N2O) emissions that may partially offset the CO2 emission reductions determined by the implementation of the practice. IPCC (2007) does not reports confidence intervals the for specific mitigation coefficients of single management practices as reported in the table. 95% confidence intervals are reported only with reference to average mitigation coefficients (all practices, by region) which are not used in the present analysis. The Climatic Zones are defined based on the classification of IPCC which makes reference to : annual mean daily temperature, total annual precipitation, total annual potential evapo-transpiration (PET) and elevation (IPCC, 2006).
Table 8: Food security and CC mitigation potential of improved cropland management practices in dry and humid areas

<table>
<thead>
<tr>
<th>Management practice</th>
<th>Food security potential</th>
<th>Mitigation potential</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average marginal yield increase with respect to conventional (%/year)</td>
<td>All GHGs (change in soil C stock + emissions) (tCO2e/ha/year)</td>
</tr>
<tr>
<td>Agronomy</td>
<td>116 122 0.39 0.98</td>
<td></td>
</tr>
<tr>
<td>Integrated nutrient management</td>
<td>72 118 0.33 0.62</td>
<td></td>
</tr>
<tr>
<td>Tillage and residue management</td>
<td>122 55 0.35 0.72</td>
<td></td>
</tr>
<tr>
<td>Water management</td>
<td>92 164 1.14 1.14</td>
<td></td>
</tr>
<tr>
<td>Agroforestry</td>
<td>81 61 0.35 0.72</td>
<td></td>
</tr>
</tbody>
</table>

Figures 6 highlights that in dry areas the impact of the majority of the practices is more relevant in terms of increased food security than in the form of CC mitigation (with the only exception of water management which can deliver significant mitigation co-benefits also in dry areas). On the other hand, in humid areas, there is evidence of the synergies between increased crop productivity (food security potential) and CC mitigation.

Figure 6: Synergies between food security and CC mitigation for improved cropland management practices in humid and dry areas
4. Conclusions

We looked at changes in smallholder agriculture aimed at promoting food security through the adoption of improved cropland management practices and investigated under which conditions we can expect highest mitigation co-benefits. Main conclusions are summarised in what follows.

- Most practices (agronomy, integrated nutrient management, tillage/residue management, agro forestry) show significant CC mitigation potential in humid areas but smaller mitigation co-benefits in dry lands. Only water management is found to be effective in delivering significant food security benefits and mitigation co-benefits both in dry and humid areas. However in dry areas, the marginal benefit to food security from SLM is high – and thus the marginal contribution of mitigation (soil carbon sequestration) is high. This has important implications for the potential and means of capturing synergies between mitigation and food security. The higher “productivity” (e.g. t/ha emissions reduction) in humid areas provides an economic basis for supporting higher transactions costs in mitigation crediting programs – which is key to accessing many forms of mitigation finance. However dry lands offer another type of potential, large numbers of producers and areas where small incremental improvements in management of water resources and soil fertility lead to large productivity gains. Implemented over a large enough scale gives significant mitigation benefits, however also requires crediting mechanisms designed for these circumstances.

- Geographic differences influence the magnitude of crop productivity increases in response to the adoption of the improved practices. Specifically, SLM practices seem to be more effective at increasing crop yields in low fertility and drier areas of SSA than in other regions of the world (especially in Asia where the Green Revolution seems to have reached a productivity limit of soils). On the contrary, differences in farm size are not found to be a factor determining the impact on the yields. However, most publications cited here conducted the analysis at smallholders’ level (only a very small number of observations refer to medium and large-scale farming) and it is difficult to derive conclusions of general validity on the relationship between farm size and yield effects.

- The validity of our results differs across the technologies considered. Data on tillage and residue management as well water management practices show less variability and more consistent results than those related to other technologies. For example, agronomy practices and integrated nutrient management show a relatively high variability in the results as they constitute heterogeneous technology packages and include practices which are significantly different in terms of soil fertility and overall agronomic effects (e.g. use of cover crops, which is often associated with tillage in CA systems, very much differ from crop rotations and use of improved crop varieties; and the use of organic fertilization techniques and green manure very much differ from technologies aimed at increasing N efficiency). Also, the effect of agro forestry practices on the yields of the crops is not well documented and sometimes controversial.
• The results of the analysis may be biased by the limited number of crops and agro-environmental conditions considered in the studies reviewed. Most studies focus on cereals (especially maize and wheat) and there are only a few examples of positive effects on other food crops like roots and tubers (e.g. cassava, potato) and legumes (e.g. beans, soybeans). Also, the studies consulted refer mainly to warm dry and warm humid areas and other climates are much less represented (e.g. only a few studies are conducted in mountain areas and refer to cool climates).

• The results of the analysis may also be biased by the absence of studies reporting negative yield responses in the literature reviewed. This may be explained by the fact that the analysis has considered only studies reporting empirical results from wider implementation at farm level of the selected technologies in developing countries. It is plausible to expect that only technologies that have been proven to be successful were implemented at wide scale. Therefore, it may be interesting to expand the analysis considering also results of plot experiments in research stations or on-farm field trials. This would give a more balanced picture, in particular as concerns the quantification of the short-term yield losses. Additionally, a quantitative analysis of experimental data would enable more analysis of factors involved, especially if there is experimental data which combined research on crop productivity with CC research.

• More research is needed. First, the review should be expanded (e.g. exploring grey literature, national surveys and project reports) in order to: increase the number of observations and the type of crops analyzed, therefore improving the statistical significance of the empirical analysis; refine the analysis reporting results at the level of single practices instead of group of practices (e.g. analyzing the use of cover crops and the adoption of crop rotations instead of focusing on the “agronomy” package, or better examining the yield effect of organic fertilization techniques); and improve evidence across different agro-ecological zones and land use systems. Second, there is the need to compare this analysis with the literature which looks at the establishment, maintenance and opportunity costs of SLM adoption in order to highlight the trade-offs of SLM implementation (e.g. see Antle et al. 2007, McCarthy 2011, Ringius 2002, Tennigkeit & Wilkes 2008, Tschakert 2004). Third, it would be interesting to replicate the same analysis focusing on grassland productivity, sustainable grazing and pasture management and livestock production. Fourth, the analysis reported in the paper groups specific practices into five categories and presents results for those categories. However, there may be some types of specific practice that are worthy of further analysis, and some of these may cut across categories. For example, the use of leguminous crops in agronomy, nutrient management and agroforestry may lead to higher average yields than treatments using other crop types.
5. References


Aquino, P. (1988). The adoption of bed planting of wheat in the Yaqui valley, Sonora, Mexico, CIMMYT, Mexico, D.F. *Wheat Special report*


Branca et al. 2011


FAO (1987). Overview of the Economic Impact of Conservation Agriculture in South America and the implications for Policy, Rome, FAO.


FAO (2006). Legume Fooder Production in Rice fields for or increased milk yields. Rome, FAO.


FAO (2009). Food Security and Agricultural Mitigation in Developing Countries: Options for Capturing Synergies. Rome, FAO.


FAO/WOCAT (2009). SLM in Practice. promoting Knowledge on Sustainable Land Management for Action in Sub-Saharan Africa Roma, FAO.


development goals." Agroforestry Systems 61(1): 5-17(13).


Liniger, H. P., R. Mekdaschi Studer, C. Hauert, M. Gurtner (2011). Sustainable Land


Mejia Marcacuzco, A. P. (undated). Folleto de divulgación: Andenes, construcción y mantenimiento, Instituto de Estudios Peruanos. DESCO.


Branca et al. 2011

Coopération Internationale de Recherche Agronomique pour le Développement, FAO.


Pender, J., B. Gebremedhin (2007). "Determinants of Agricultural and Land


Sorrenson, W. J. (1997). Economics of No-till Compared to traditional cultivation systems on small farms in Paraguay. Soil Conservation Project, MAG-GTZ.


Verchot, L. (2007). Opportunities for Climate Change Mitigation in Agriculture and Investment Requirements to Take Advantage of These Opportunities, UNFCCC Secretariat Financial and Technical Support Programme.


Xianmo, Z., Ed. (1989). The soil and agriculture of the Loess Plateau. Beijing City,
China, Agriculture Press.