

Knowledge assessment and sharing on sustainable agriculture

Synthesis Report

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The KASSA Consortium assembled 28 contractors from 18 countries.

KASSA has been implemented through four regional "platforms": Europe, the Mediterranean, Asia and Latin America.

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I.

Introduction

Wherever agriculture is practiced, it affects – and is affected by – human society. Agriculture provides food and fiber and therefore influences public health and nutrition. It employs labour and absorbs investment capital. It modifies biodiversity, soil health and the quantity and quality of water resources. Not infrequently, it is a factor in environmental pollution. Given its importance, agriculture often is subjected to political debate and scrutiny and is governed and shaped by a multitude of policies. In the past, its rustic beauty has inspired painters and poets. At present, however, its sustainability is in question – and some people fear that the impacts of agriculture on society may become increasingly detrimental.

In response to such concerns, the notion of sustainable agriculture has emerged. Over past decades this notion has been interpreted and operationalized in many ways (e.g., conservation agriculture, direct-sowing, conservation tillage, no-till, resource-conserving technologies). Practices associated with conservation/ sustainable agriculture have begun to take hold in a number of places, including Australia, North America, the southern cone of South America, the Indo-Gangetic Plains of South Asia and, recently, China. Under the proper conditions, these practices can improve food security, generate employment, slash production costs, conserve soil, improve water productivity, reduce pollution and lower the emission of greenhouse gases. Understandably, they have become an item of widespread interest, not least in Europe.

What is KASSA?

Unfortunately, information on the theory and practice of sustainable agriculture is widely scattered. Even its practitioners and champions typically have limited knowledge of the successes and failures experienced by others. Around the world, many lessons have been learned on how to transform agriculture and improve its sustainability. A systematic effort is needed to pull together and synthesize these lessons, for the benefit of all.

The KASSA project (Knowledge Assessment and Sharing on Sustainable Agriculture) aims to do just this. Specifically, it aims to build up a comprehensive knowledge base on the international experience in sustainable agriculture – its practices, approaches, systems, conditions and challenges – in support of European stakeholders, among them farmers and professionals, researchers and policymakers, as they pursue their activities, functions and offices at local, regional, national, European and even global levels.

The information made available through KASSA is meant to:

- Highlight major social, cultural, technical and economic issues directly related to the sustainability of agriculture;
- Facilitate learning from past successes and failures on conservation agriculture;
- Identify gaps in our knowledge and understanding of sustainable agriculture;

- Define major research questions to be addressed in order to facilitate a wider use of sustainable/ conservation agriculture;
- Identify the scope for collaboration with potential stakeholders in this research;
- Define capacity-building opportunities and needs for strengthening sustainability research in Europe as well as in developing countries.

The KASSA project was implemented through an iterative process. This process began with the development of comprehensive inventories on experiences with sustainable agriculture in four different regions or "platforms" (Asia, Europe, Latin America, and Mediterranean)¹. It continued with a comparative critical analysis across platforms and the refinement of findings, and concluded with a final synthesis (the subject of this paper) to be shared with the global community. An external panel of experts has critically appraised and validated KASSA results. The prospects for sustainable agriculture in Europe have been an important theme in a closing international conference.

It should be noted that a major aim of KASSA is to provide information and analysis useful in the on-going debate within Europe on the subject of conservation agriculture. KASSA results are intended to help:

- Provide reliable and practical information on new technologies that are effective in fostering agricultural sustainability and environmental preservation;
- Present an updated, state-of-the-art view of sustainable agriculture in Europe and other countries and form a reference database useful for land-use modelling;
- Increase awareness on sustainable agriculture among European NGOs, farmer organizations, extension workers and the private sector – and increase their capacity for sustainable agriculture initiatives;
- Reinforce the capacity of the European Research Area to play an effective role as interface between societal needs and policy requirements;
- Provide information relevant to the sustainable agriculture policy debate within Europe.

Hence, KASSA contributes to the work programme of the FP6 sub-priority 6.3 Global Change and Ecosystem. More specifically, KASSA results will be of benefit to research areas: I- Impacts and mechanisms of greenhouse gas emissions and carbon sinks; II- Water cycle, including soil-related aspects; III- Biodiversity and Ecosystems; IV- Mechanisms of desertification; V- Sustainable land management and, to complementary researches dealing with risk assessment, environmental quality.

Summary of principal KASSA objectives, work plans and deliverables

The overall objective of KASSA is fairly straightforward:

"... to build up a comprehensive knowledge base assembling international experience on sustainable agriculture and emphasizing pathways, conditions and

¹ At some point, it would be interesting and useful to complement KASSA findings with information on experiences with sustainable agriculture from other countries, including Australia, China and central Asia, eastern and southern Africa, Canada and the US.

challenges to be considered by European stakeholders (farmers, researchers and policymakers) in order to improve agricultural sustainability in Europe".

KASSA has been implemented through a progressive and highly-structured process of knowledge generation, sharing, cross-checking and refinement. Activity has been divided into a sequence of "Work Packages" Some work packages were conducted independently by each of the four regional "platforms" (Asia, Europe, Latin America, and Mediterranean). Others brought the four platforms together for comparative analysis and other forms of joint activity. Still other work packages focus on information management, and platform and central coordination. Each work package has produced/ will produce a clearly defined "deliverable", typically in the form of a written report. KASSA work packages are as follows:

Table 1. A description of KASSA work packages.

<p>Work Package 1.1 - Comprehensive inventory and assessment of existing knowledge on sustainable agriculture.</p> <p>In this work package, each platform developed an inventory of past and on-going studies (and their corresponding results) relevant to sustainable agriculture and drawn from the platform's particular region. This inventory was then subjected to critical analysis and synthesis. Factors considered for each study included:</p> <ul style="list-style-type: none"> • Prevailing agroclimatic conditions and the characteristics of the cropping patterns and technologies being studied; • The research approach used; • Information regarding the effect of new practices on biological, physical and chemical processes; • Socioeconomic and environmental consequences of the new technologies; • The conditions governing technology extrapolation; • Reasons underpinning observed success or failure. 	<p>Work Package 2.1 – Validating the output of Work Package 1.1.</p> <p>For each platform, a three-day meeting was held to validate the content and conclusions of Work Package 1.1, the “comprehensive inventory and assessment” report developed for that platform.</p> <p>Each meeting involved a small number of representatives from participating institutions from the platform in question. With four platforms forming the basis of the KASSA project, it is clear that this work package featured four separate meetings.</p>
<p>Work Package 1.2 - Learning from other platforms' reports.</p> <p>This work package marked the beginnings of cross-platform critical analysis. Each platform team was given the opportunity to review, assess and critically appraise the “comprehensive inventory and assessment” reports developed <i>for the other three platforms</i>.</p> <p>Each team therefore was able to engage in debate on the performance of specific technologies and approaches, the conditions under which each was most successful, constraints and obstacles to success, ways in which these obstacles were overcome, how the transition was managed from conventional to conservation agriculture, the policy interventions that proved to be necessary, and the impacts</p>	<p>Work Package 2.2 – Validating the output of Work Package 1.2.</p> <p>For each platform, a three-day meeting was held to validate the content and conclusions of Work Package 1.2 – the summary what had been learned by this platform team by scrutinizing reports from the other three platforms.</p> <p>Each meeting involved a small number of representatives from participating institutions from the platform in question. Once again, four separate meetings were held,</p>

that were generated – as reported by other platform teams. Cross-platform analysis of this kind helped identify gaps in information that must be filled to achieve a better understanding of sustainable agriculture and how it can successfully introduced under the conditions of each platform.	one for each platform.
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<p><i>Work Package 1.3 - Refining platforms' findings.</i></p> <p>This work package built on the results of all prior work packages. Each platform team developed specific proposals for fostering widespread use of sustainable agriculture practices in their own region. In doing so, they took account of their own validated inventory of conservation agriculture research activities and results (work packages 1.1 and 2.1), and the validated summary of what they learned by scrutinizing similar reports from other platform teams (work packages 2.1 and 2.2).</p> <p>The proposals developed by each platform team covered:</p> <ul style="list-style-type: none"> • Alternative technologies and approaches in support of sustainable agriculture, and ways of adapting them to local conditions and accelerating their widespread adoption; • The agroclimatic and socioeconomic conditions in which specific conservation agriculture technologies are most likely to be attractive to farm families; • Socioeconomic and environmental impacts – and externalities – that are to be expected in the event of widespread adoption of particular technologies; • Further research needed to develop or adapt technologies, to identify extrapolation domains, or to anticipate the consequences of adoption. 	<p><i>Work Package 2.3 – Validating the output of Work Package 1.3.</i></p> <p>Work package 2.3 is analogous to work packages 2.1 and 2.2. Just as they validated the outcomes of work packages 1.1 and 2.1, this particular work package aimed to validate the proposals emanating from work package 1.3. It did so through another set of meetings of representatives from participating institutions from the platform in question.</p> <p>The deliberations from each meeting were recorded and summarized and forwarded to the central KASSA coordination unit for inclusion in an overall KASSA synthesis document.</p>
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<p><i>Work Package 3 - Discussion, synthesis and validation of KASSA results.</i></p> <p>With this work package, the various findings and reports from all platforms were finally brought together and submitted to the Central Coordination Unit. These reports served as sources for the development of a single synthesis document (the subject of this paper) and are being made available on the KASSA website for open discussion. This synthesis has been submitted to the KASSA Steering Committee for final discussion and validation.</p>
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<p><i>Work Package 4 – The KASSA international conference.</i></p> <p>The KASSA international conference has been a culminating event, placing a capstone and bringing to closure all prior KASSA activity. Conference participants included members of the platform teams, the KASSA Central Coordination Unit and Steering Committee, invited resource people from those countries involved in the KASSA endeavour, and representatives from the European Union.</p> <p>A main objective of the conference was to summarize and assess the points listed below, with</p>

special attention to application within Europe.

- Lessons learned from past research on sustainable agriculture in diverse climatic zones;
- An assessment of the agroclimatic and socioeconomic conditions most closely associated with successful application of particular sustainable agriculture practices;
- The outlook or prospects for sustainable agriculture in different parts of the world;
- Obstacles and constraints to the adoption of conservation agriculture;
- Ways to overcome these obstacles and constraints (including ways to overcome barriers related to markets and policies). Ways and the means of facilitating the shift from conventional to sustainable agriculture;
- Research needed to accelerate the development and use of conservation agriculture practices;

A proposed agenda, listing research activities, topics and approaches in support of sustainable agriculture within Europe and around the world.

Work Package 5 - KASSA website and related multimedia services.

This work package, being implemented by the Central Coordination Unit, aims to create a website and related multimedia services to facilitate the exchange of knowledge and experiences among KASSA members, and to share all of this with external stakeholders and partners, among them researchers, extension workers, teachers, students, farmers, representatives of civil society, and policymakers. These information services provide a mechanism for sharing and continuously updating KASSA project results, suggestions from sustainable agriculture practitioners, and relevant documents and information on sustainable agriculture (including slideshows, displays, PDF files, theses and dissertations, photographs, and videos). It should be noted that English is used as the official operating language of the KASSA website, for which reason all reports and material for the website and database should be provided in English. Consortium partners are encouraged to translate all suitable material into their own languages to allow and encourage their further use in countries where English is not the language of choice. When technically possible, translated material will be displayed directly in the KASSA website.

Work Package 6 - KASSA database and implementation methodology.

This work package is implemented by the Central Coordination Unit and draws on the skills of individuals knowledgeable in the area of database development and decision support systems. The database includes information on biophysical, socioeconomic and agronomic factors, and is designed to be used in support of economic and policy analysis, environmental analysis, and mathematical modelling. It can support analysis at multiple scales and time factors and includes both quantitative and qualitative information.

Work Packages 7.1 to 7.4 - Coordination of the European, Mediterranean, Asian and Latin American platforms, respectively.

Work Package 8 - Central Coordination of KASSA.

Steps in the development of KASSA

From the beginning, the project has been designed around an eighteen month time frame. To achieve this, the execution of successive work packages has followed a rather tight schedule. The first activity, Work Package 1.1 ("Comprehensive inventory and assessment of existing knowledge on sustainable agriculture") was scheduled to be carried out over a period of six months, ending in February or March, 2005. There were some delays in bringing this work package to closure by the established deadline. Despite this, accelerated activity in Work Packages 1.2 and 1.3 ("Learning from other platform's reports" and "Refining platform findings") led to their completion by the scheduled date of August – September of 2005. Further steps (Work Package 3 and Work Package 4) were implemented in scheduled timeframe.

II.

Agricultural systems and their sustainability

1. Sustainable agriculture and conservation agriculture

The principal interest of KASSA is in sustainable agriculture. This is abundantly clear from the very meaning of the KASSA acronym: "Knowledge Assessment and Sharing on Sustainable Agriculture". However, in the absence of a universally accepted and clearly understood definition of "sustainable agriculture", some limits need to be imposed.

It has been argued, for example, that genetically modified organisms can play important roles in strategies aiming to improve the sustainability of agricultural systems. Whether or not this is true, the KASSA project does not take account of GM crops. The reason is simple – much of the relevant information is privately held and controlled by tightly framed confidentiality agreements and is, therefore, not in the public domain.

It has also been argued that the only truly sustainable agriculture is that based on organic principles. Given the imbalance between the KASSA "platforms" regarding the results of past research on organic farming and in order to avoid duplication of effort and overlap with other ongoing EU funded projects, KASSA at this point defers to the judgment of those projects with a specific focus on organic farming.

In assessing and sharing knowledge on sustainable agriculture, KASSA tends to focus on what has come to known as "conservation agriculture" (typically defined as agriculture using minimum or no tillage, crop residues for soil cover, direct sowing of crops into these residues, and rotations for disease control and for fostering agroecosystem health).

There are two reasons for this focus. First, conservation agriculture practices have proven to be remarkably effective in reducing soil erosion, improving water productivity, reducing production costs, and improving farm incomes. There is ample evidence – from Argentina, Australia, Brazil, Canada, China, India, Paraguay and the US – to support this assertion. Second, in several instances conservation agriculture has grown to cover very large areas, has benefited very large numbers of farmers, and has generated non-trivial "positive externalities" of value to other members of society. It offers very substantial economic benefits to those farmers who use it – and very real hope for a major transformation of global agriculture in the direction of enhanced sustainability.

2. Conservation agriculture in rainfed and irrigated systems

The principles of conservation agriculture can be operationalized over an immense range of agroecosystems and water management regimes. They are not restricted to the high-rainfall, non-irrigated conditions where they were first taken up by farmers (in the US and Brazil). Conservation agriculture practices have enough "plasticity" such that they can be shaped and

adapted to fit conditions of high or low rainfall, large or small farm sizes, or rainfed or irrigated water regimes.

In the KASSA project, information on rainfed conservation agriculture was obtained by the European, Latin American and Mediterranean platforms. There was a nice contrast between the latter two. The Latin American platform largely focused on multiple cropping in high-rainfall environments, where the control of soil erosion is supremely important. In contrast, the Mediterranean platform tended to focus more on mixed crop – pastoral – tree systems under low-rainfall conditions, with a high priority given to water productivity and conservation.

Information on irrigated conservation agriculture was the principle focus of the Asian platform, with occasional references to it by the Latin American and Mediterranean platforms. The Asian platform, drawing on information from Vietnam as well as from the Indo-Gangetic Plains, described the unique situation of conservation agriculture in agroecosystems based on puddled rice culture, with recurring transitions between aerobic and anaerobic growing conditions. In contrast, irrigated systems described in Latin America (especially those located in the tropics) were more often devoted to horticultural crops.

3. Characterizing systems

The KASSA project assembled information on agricultural sustainability in four different climatic conditions - temperate, Mediterranean, tropical, and subtropical. In the sections that follow, agroecosystems in each climatic category will be described and, for each one, a selection of economic, social, environmental and ecological processes, problems and issues will be discussed and summarized.

3.1. Temperate systems

Although some temperate climate agroecosystems may be found in the southern reaches of Latin America, virtually all of those for which information was assembled in the KASSA project are located in northern Europe. Information was obtained for systems in the following countries: Czech Republic, Denmark, Estonia, France, Germany, Norway, Ukraine and the United Kingdom. While figures were not provided on the spatial incidence or area of coverage of different farming or cropping systems, the agricultural activities most frequently mentioned were winter wheat, winter barley, maize, sugar beet, rapeseed, potatoes and – for the United Kingdom in particular – livestock production. Water for agriculture was not normally perceived as a limiting factor, because precipitation (rain and snowfall) is generally adequate and well-distributed – unlike most other regions covered by KASSA.

Ecological and environmental issues vary across the countries for which information was gathered. Soil erosion was a ubiquitous concern, largely through water erosion but also – in the Czech Republic and the Ukraine – through wind erosion. Soil crusting was noted as a problem in loamy soils of northern Europe, and poor drainage and "pebble rising" (soil inversion bringing deeply buried stones to the surface) in parts of France and the Ukraine.

A number of issues specifically related to ecological processes and the environment were also mentioned. These include biodiversity and how it is affected by agriculture; soil organic matter content, the carbon cycle and greenhouse gas emissions; the leaching of nutrients

(especially nitrogen); and the processes whereby pesticides, heavy metals and organic materials may become air and water pollutants. Understandably, water pollution concerns tend to be greatest in those areas where rainfall is high, evaporation low, water tables elevated, drainage poor, and where sizeable levels of inputs are used in agriculture.

Economic and social issues for temperate northern European agroecosystems include the need to reduce production costs, improve competitiveness, comply with evolving CAP (Common Agricultural Policy) regulations and policies, preserve cultural landscapes, and insure the supply to consumers of safe, high-quality, nutritious food products.

3.2. Mediterranean systems

Mediterranean climates are found in south-eastern and Western Australia and small areas in North and South America as well as in countries surrounding the Mediterranean itself. The KASSA project assembled information from Spain, Morocco, Italy and Greece, with occasional references to Tunisia and France.

Mediterranean climates are distinctly different from those in temperate, subtropical or tropical areas. Rainfall is usually distributed into two periods, autumn/ early winter and spring, with relatively dry winters and summers. It tends to be in the range of 250-700 mm annually, is variable and erratic, and is often concentrated in high-volume, high-intensity storms. Drought is endemic and unpredictable. Coastal areas enjoy relatively stable temperatures and, when irrigated, these areas can support the production of a wide variety of crops. At greater distances from coastal areas, the climate becomes continental (cold winters and hot summers). Soils in the Mediterranean region typically have medium to poor fertility. They often have calcareous horizons close to the surface that limit water-holding capacity and root development. Not infrequently, they are stony, saline or alkaline. They are characterized by low levels of organic matter, partly because limited rainfall restricts biomass production, and partly as a legacy of more than 2000 years of human continual cultivation.

The most important crops in Mediterranean areas are winter cereals, especially wheat and barley. Where there is adequate soil moisture during summer months, tree crops (olives, almonds, nuts) and vineyards may accompany winter cereals. The presence of irrigation allows the cultivation of fruit trees, e.g., apples, peaches, pears, and citrus. Other crops may include grain legumes (peas, faba bean, lentils, chickpea); forage legumes (alfalfa, vetches); and a miscellany of others (sunflower, potatoes, sugar beet, cotton). Multiple cropping is not possible without irrigation. In fact, long bare fallow periods of up to 18 months (to accumulate soil moisture) are traditional "dry farming" practices in some areas. Recently, however, continuous cultivation of adapted crop rotations has become more common. Some areas are devoted to grazing of livestock (cattle, sheep, goats) on dryland permanent pastures. Crop-livestock interactions are crucial: livestock graze on the stubble of barley and wheat fields and in many situations straw is baled and used for livestock feeding and bedding.

Ecological and environmental issues are different in dryland and irrigated areas. In the drylands, the main problems are water scarcity and land degradation/soil erosion associated with lack of soil cover, frequent soil tillage, high rainfall intensity, and overgrazing of livestock. Stubble burning and lack of organic residue incorporation exacerbate these problems. The ultimate issue, of course, is the stark prospect of irreversible desertification.

In irrigated lands, important issues include excessive and inefficient water and chemical use, resulting in environmental pollution and, in places, further salinization of agricultural lands. Pollution may also arise from excessive applications of manures and organic slurries.

An important social and economic issue lies in the marked differences in agricultural activity between southern and northern Mediterranean countries. Relative to southern countries, agriculture in the north is more advanced. Driven by more rapid processes of economic growth, the proportion of the population in northern Mediterranean countries that are still directly engaged in agriculture is relatively low, while new technologies have led to substantial increases in agricultural labour productivity. Apart from this, social and economic issues are similar to those in temperate climates – the need to reduce production costs, improve competitiveness, and (for European Mediterranean countries) comply with evolving CAP regulations and policies.

3.3. Tropical systems

Tropical climate agroecosystems featured in the KASSA project are largely located in Latin America – specifically the lowlands of Bolivia, the "Cerrados" of Brazil, and irrigated horticultural systems in eastern Brazil. There were also a few references to southern Vietnam. Most of these areas are located in the humid tropics. Information from lowland Bolivia was obtained from the vicinity of Santa Cruz, where it is not uncommon to receive rainfall in excess of 1500 mm per year. Information for the Cerrados of Brazil was obtained from the central plateau, between 10 and 20°S latitude, with rainfall of 1200 - 2000 mm per year received over an 8-10 month period.

Agroecosystems vary considerably across these locations. In the Bolivian lowlands, wheat-soybean rotations (and numerous other rotations involving soybean, wheat, rice, maize, sugar cane, cotton, sunflower and sesame) may be found. In irrigated systems in tropical eastern Brazil, major crops include tomato, bell pepper, lettuce, and broccoli. In southern Vietnam, triple-cropped rice systems predominate. And in the rapidly evolving Cerrados of Brazil, a previous sorghum monocropping system is giving way to a rotation of a commercial crop (sorghum, rice or maize) followed by cereals (maize, millet, sorghum) that are intercropped with a forage species (*Brachiaria*, *Stylosanthes* or *Cajanus*).

Ecological and environmental issues for these tropical areas were not described in detail by platform teams. Some reference was made to weed competition in the high rainfall areas of the Bolivian lowlands and to vegetable diseases in tropical eastern Brazil, while the Cerrados are known to be affected by acid soils. It may be that environmental issues were not highlighted simply because, in the relevant areas, population densities are low and topographies are flat. In a similar vein, social and economic issues received little attention. It should be noted, however, that in these areas, farm sizes tend to be large (especially in the Cerrados) and poverty less of a problem than in most other parts of the developing world.

3.4. Subtropical systems – irrigated

Any description of the subtropical climate agroecosystems assessed by KASSA must make a clear distinction between those that are irrigated and those that are rainfed. There is literally a world of difference between the two. The former are concentrated in the northern hemisphere, particularly in South and East Asia, are characterized by seasonal monsoon

rainfall patterns, and are based on flooded rice culture on relatively flat land forms. The latter are concentrated in the southern hemisphere, particularly in southern Brazil and surrounding areas, are characterized by high levels of evenly distributed rainfall, and feature a range of crops grown on undulating hillside land forms. (Rainfed subtropical systems for hillsides in northern Vietnam were also studied).

The irrigated systems for which information was assembled by KASSA include those in the Indo-Gangetic Plains and in the irrigated river plains of northern Vietnam.

It is difficult to overstate the importance of rice-wheat systems in the Indo-Gangetic Plains. They are a major source of foodgrains for hundreds of millions of rural and urban poor in South Asia. They are the backbone of national food security for the countries located in the Plains. They directly or indirectly provide employment for most inhabitants of the Plains. They have major effects on the availability and quality of water resources for rural and urban areas. Any threat to the long-term productivity of these systems is taken very seriously indeed by policymakers in the region, and by scientists and research managers in the region and around the world. Principal agroecosystems in the Indo-Gangetic Plains include rice-wheat (monsoon rice followed in sequence by cool season wheat), rice-rice, rice-fallow, cotton-wheat, and an assortment of other systems with rotations with legumes, pulses, sugarcane and maize.

The ecological and environmental issues in the Indo-Gangetic Plains have recently received a great deal of attention. In the western transects, issues include groundwater depletion, poor drainage and soil salinization, water pollution from nitrogen fertilizers, air pollution from the burning of rice straw and other residues, low levels of agrobiodiversity, and a gradual but unrelenting depletion of soil fertility (including depletion of micronutrients, e.g., zinc). Water scarcity and aquatic ecosystem destruction are also problems. In the eastern transects, issues include seasonal flooding and arsenic contamination of groundwater.

Social and economic issues and problems in the Indo-Gangetic Plains are bewildering in their number and complexity. The central issue is that of poverty. Of the three quarters of a billion people living in the Plains, about a third of them lives in absolute poverty, with incomes of less than one US dollar per day. As usual, poverty opens the door to other problems: hunger, malnutrition, and disease.

Irrigated agroecosystems in northern Vietnam are extraordinarily intensive, with two rice crops and an additional winter crop all sown and harvested in a single calendar year. The cropping calendar is so tight that a 24 hour turnaround between one crop and the next is not uncommon and the winter crop, e.g., maize, may require transplanting. These systems are central to addressing the issue of food security in the context of a rapidly increasing population. Land productivity must continue to increase (note that per capita agricultural land availability fell from 1318 m² in 1980 to 914 m² in 2003). At present, however, yields are said to have reached a plateau. It is clear that new sources of productivity growth must be identified. But the Vietnamese are very aware that this must be achieved in ways that preserve the resource base.

3.5. Subtropical systems – rainfed

The principal subtropical rainfed systems for which information was gathered are those of southern Brazil and central Argentina² – in the very heart of the conservation agriculture revolution in Latin America. In these areas, abundant and evenly-distributed rainfall makes it possible to grow two – and at times even three – crops per year. Principal crops include maize, soybean, wheat, oats, and common beans.

Until a few decades ago, however, much of this region was devoted to extensive pasture for livestock. It was only in the 1960s that government policies in Brazil began to promote a shift from livestock-based farming systems to crop-based systems. Farmers responded by taking up the crops being promoted – especially soybean. Soon, however, a crisis emerged in the form of a disquieting increase in soil erosion and land degradation. In some instances, erosion so reduced productivity that farmers were unable to repay bank loans. The causes of this crisis were fairly obvious – a deadly combination of farmers’ tillage practices, hilly and rolling land forms, the erodibility of local soils, and high levels of rainfall. Conservation agriculture emerged as a response to this crisis. The story of how this happened is a fascinating one, and will be summarized in a later section. In more recent times, nitrate contamination of soils has become a source of concern.

Most social and economic issues in southern Brazil focus on equity. There is a great diversity among farmers in regard to farm size, ethnic background, and the source of farm power (mechanical or animal traction). It is felt important that all farm families should have access to conservation agriculture practices, regardless of farm size or ethnic origin.

In Argentina, the focus for information gathering was the Central Area. Little information was obtained regarding ecological and environmental issues that were important at the time that the first small-scale conservation agriculture trials were begun. The social and economic subject that was most highlighted in the case of Argentina was the leading role of farmers and farmer organizations in fostering the shift to conservation agriculture.

Finally, KASSA obtained information on one additional kind of subtropical rainfed system – the hillside systems of northern Vietnam. In many ways, these are very different from the South American systems described above. Slopes are typically steeper, population pressure on resources is more intense, and generalized issues of poverty are of greater importance. Paradoxically, cropping intensity is actually lower! Often, a single crop of upland rice (or maize) is grown during the monsoon season (May to October-November), with some cropping of vegetables, fodder and pulses near the homestead. Livestock are allowed to graze on crop residues. Sometimes these systems employ shifting cultivation, where a particular field is used for a few years until soil fertility has declined and weed pressure has increased. At that time, the field is abandoned and the farm family moves to a new field. These Vietnamese hillside systems, like their South American counterparts, suffer from soil erosion and land degradation that threaten system sustainability.

² Some of the areas in Argentina discussed in this and following sections are actually located in temperate climates. Given their many similarities with neighbouring areas in southern Brazil, however, experiences in conservation agriculture in Argentina and southern Brazil will be assessed together.

3.6. Climatic conditions, agroecosystems and platforms – a summary

It may be seen from the above that some KASSA platforms assembled information for more than one agroecosystem, often in more than one climatic zone. Table 2, summarizes the contribution of different platforms to the study of different systems.

4. Assessing systems for sustainability

The KASSA project brings together information on the sustainability of selected agroecosystems, found in four different climatic areas, as studied by four different platform teams. The above sections described some of these agroecosystems. This section focuses on the notion of sustainability and how it was assessed in KASSA.

Perhaps it is best not to attempt a detailed description of the countless attempts that have been made to define and operationalize the notions of sustainability and sustainable productivity. Despite these efforts, only limited progress has been made in our ability to answer certain seemingly straightforward questions regarding sustainability, e.g., is system A more sustainable than system B? If so, by what percent? Has the sustainability of system A increased over time? If so, by what percent? Is the sustainability of system A increasing faster than the sustainability of system B? If so, by how much?

Within the context of the KASSA project, sustainable agriculture is defined as a kind of agriculture that "ensures social and economic viability, food security and safety while conserving and even improving local and global basic resources and the environment".

Beyond this official KASSA project definition, the notion of sustainability was used by platform teams in at least five distinct but interrelated ways:

- Sustainability as continuity – the ability of an agroecosystem to preserve its productive capacity for an indefinite period;
- Sustainability as resilience – the ability of an agroecosystem to flexibly adapt to changing circumstances and still remain productive;
- Sustainable intensification – the continuous enhancement of the productivity of an agroecosystem in ways that do not threaten its long-term productive capacity or resilience;
- Sustainability as resource conservation – management of an agroecosystem in ways that conserve land and water resources;
- Sustainability for public health and welfare – management of an agroecosystem in ways that avoid processes of pollution that could threaten public health or food safety.

Table 2. The contribution of KASSA platforms to the study of different agroecosystems in four different climates.

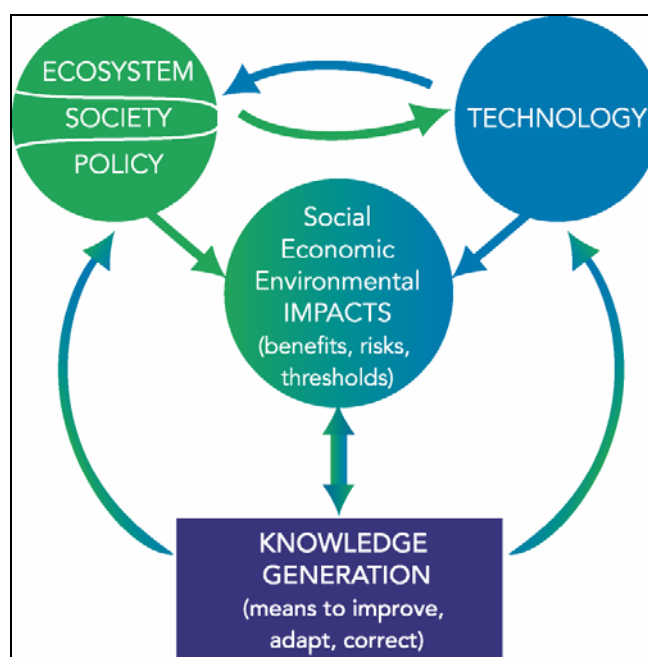
Climate	Asian Platform	European Platform	Latin American Platform	Mediterranean Platform
Temperate	None	<ul style="list-style-type: none"> • Agroecosystems in temperate northern Europe 	None	None
Mediterranean	None	None	None	<ul style="list-style-type: none"> • Water-scarce rainfed agroecosystems • Irrigated, intensive systems, including fruit trees
Tropical	<ul style="list-style-type: none"> • Rice systems in the lowlands of southern Vietnam (occasional references) 	None	<ul style="list-style-type: none"> • Wheat-soybean and related systems in lowland tropical Bolivia • Crop – pasture systems in the Cerrados of Brazil • Irrigated horticultural systems in eastern Brazil 	None
Subtropical irrigated	<ul style="list-style-type: none"> • Rice-wheat and related systems in the Indo-Gangetic Plains • Intensive rice-based systems in the river valleys of northern Vietnam 	None	None	None
Subtropical rainfed	<ul style="list-style-type: none"> • Sloping land systems on hillsides in northern Vietnam 	None	<ul style="list-style-type: none"> • Multiple-cropping in high rainfall environments in southern Brazil and central Argentina 	None

4.1. Pillars of sustainability

To be successful in fostering sustainability, the techniques of conservation agriculture must come into widespread use. Success hinges on achieving generalized, voluntary adoption of effective practices by large numbers of farmers. This means that these practices must be attractive to farm families, providing them with adequate levels of on-farm near-term benefits. Simultaneously, of course, these same practices must be effective in generating adequate levels of favourable and desirable social, economic and environmental impacts, where benefits out-weigh costs, and the risk of unanticipated negative consequences is low.

The process of developing conservation agriculture practices for a specific region or agroecosystem is guided and influenced by existing ecosystem, social and policy circumstances; the availability of effective conservation agriculture technologies; and the extent to which a dynamic innovation system is functioning. Innovation systems generate knowledge helpful in improving, correcting and adapting conservation agriculture practices. The interactions among these "pillars of sustainability" – "ecosystem, society and policy", "knowledge generation", "technology" and "social, economic and environmental impacts", is shown in Figure 1.

Figure 1. The pillars of sustainability



4.2. Applying sustainability pillars to the ecosystems of interest

The pillars of sustainability (figure 1) are applicable to all agroecosystem of interest. For each system, an assessment is made of ecosystem characteristics and social and policy circumstances; the nature and effectiveness of innovation systems; how all of these have affected the development of suitable technologies; the extent to which these technologies have been adopted by farmers; social, economic and environmental impacts of adoption – and ways forward to further accelerate conservation agriculture development and adoption.

IIIa.

KASSA research results – Conservation agriculture in systems of interest

KASSA platform teams have accomplished much of what was expected of them. They have assembled inventories and assessed the existing knowledge on sustainable agriculture in their areas of concern. They have scrutinized the inventories and assessments of other platform teams and have compared them with their own. Lastly, they have taken the opportunity to refine their conclusions.

In the sections that follow, the findings of the four platform teams will be synthesized and summarized. First, conservation agriculture practices will be listed and described (and the extent of their adoption noted) for the agroecosystems and climatic conditions that have been studied. An assessment will be made of various driving forces and constraints that have influenced the pace of development and adoption of conservation agriculture. Opportunities for the further development of conservation agriculture for the relevant agroecosystems will then be identified. Finally, the scientific knowledge acquired regarding the impacts of conservation agriculture on agroecosystems of interest will be summarized.

1. Agroecosystems in temperate northern Europe

In northern European agroecosystems, there has been negligible adoption of conservation agriculture – at least in the broad, comprehensive sense of no-till combined with surface cover and innovative crop rotations. There has been some adoption of minimum tillage without mulch, principally in Germany and Eastern Europe, where it is said to cover more than 15% of agricultural area. Even here, however, minimum tillage for winter crops is typically followed by full tillage for the subsequent spring crop. The European platform team summed things up with this terse comment: "It appears that No Tillage is very little used in Europe. There is a large diversity of situations between the countries, which also implies diversity in the practices used" [sic].

Research on conservation agriculture for European agroecosystems has been more basic and strategic than adaptive. There has not been a strong research focus on participatory interaction with farmers to design conservation agriculture practices. Rather, research has compared the performance of different practices in contrasting soil and climate conditions, examined ways to reduce pollution derived from agriculture, fostered the development of organic farming practices, and assessed long-term consequences of technologies (e.g., on soil physics) through long-term stationary field experiments.

2. Mediterranean dryland and irrigated agroecosystems

In Mediterranean agroecosystems, the use of conservation agriculture is not widespread. Where adoption has occurred, however, impacts are said to have been favourable and significant. Adoption in European Mediterranean countries has been greater than in North African countries. Cropping systems where some conservation agriculture practices are used are said to include winter cereals in rotation with legumes, sunflower and canola; and no-tillage and cover crops between rows of perennial crops such as olives, nuts and grapes. Information on levels of adoption, however, was not provided by the platform team.

In the Mediterranean dryland areas, "the main problems are water scarcity and land degradation/soil erosion associated with lack of soil cover, high rainfall intensity, and overgrazing of livestock". It is not surprising, then, that attention has been paid to technologies for soil and water conservation in dryland areas, most of them also aiming to facilitate the introduction of conservation agriculture practices, especially no-till.

In the past, research has been conducted on ways to increase the production and optimize the management of crop residues; establish cover crops between rows of tree crops (olives, nuts, grapes); increase fertilizer use efficiency; and increase crop diversification and improve weed control through the introduction of new crop rotations. The Mediterranean platform team listed some further technologies that might be relevant – although they were unable to find published research on these practices for the Mediterranean area. These include management of crop/livestock interactions and fertilizer use to optimize the production and allocation of crop residues; germplasm to increase production of crop residues; and drought-tolerant germplasm with better transpiration and water use efficiencies.

In Mediterranean irrigated areas "important issues include excessive and inefficient water and chemical use, resulting in environmental pollution and, in places, further salinization of agricultural lands. Pollution may also arise from excessive applications of manures and organic slurries". Related areas of technology development have included cover crops between rows of fruit trees; practices to optimize irrigation system management to conserve water, energy and soil quality; and practices to increase fertilizer use efficiency. Information on the extent of adoption of such practices, however, was not provided.

3. Wheat-soybean and related systems in lowland tropical Bolivia

There has been substantial adoption of one conservation agriculture practice – no-till – in the lowland humid tropics of Bolivia, near Santa Cruz. This practice is principally used for annual crops (soybeans, wheat, rice, maize, sugar cane, cotton, sunflower, and sesame). Slightly more than half of the 1.6 million ha of cultivated area in Santa Cruz Department is sown using no-till. In most of this no-till area, however, there is little or no complementary use of cover crops, or of new crop rotations driven by the principles of conservation agriculture. Adoption rates are higher for larger farmers, though many small farmers have also come to use no-till. No-till implements are either purchased from Brazil or manufactured locally (based, however, on Brazilian designs).

Research on conservation agriculture technologies began in the 1980s, largely through farmer initiative. Research and development activity has emphasized participatory action research with farmers to develop workable no-till practices.

4. Tropical crop – pasture systems in the Cerrados of Brazil

A good deal of innovative research has been conducted on conservation agriculture practices for the Cerrados of Brazil. Several ingenious systems have emerged from this. Although reports from the Latin American platform team did not indicate the extent to which these technologies have been adopted. Technologies include the following:

- Systems with two annual crops in succession under continuous direct seeding, the second crop is said to play the role of a "nutrient pump". These systems do not require high rainfall levels to be successful.
- Systems with three crops per year, all under continuous direct seeding, consisting of a commercial crop (sorghum, rice, maize) followed by a cereal (maize, millet, sorghum) that is intercropped with a forage species (*Brachiaria*, *Stylosanthes*, *Cajanus*). The latter are seen as "nutrient pumps" producing large amounts of biomass in the dry season which then can be grazed or used as green manure. Because *Brachiaria sp.* is very efficient forages for cattle, farmers may choose to convert their area into pasture or to remain with grain production for another year. These systems are most appropriate for areas with high rainfall or with irrigation.

These technologies are replacing systems based on a single crop of sorghum or soybean. In the latter case, new rotational systems featuring no-till soybean are replacing intensive-till soybean monocropping (in which other crops before or after soybeans were difficult to grow because of the brevity of the rainy season). Initially, conventional-till soybean out-yielded no-till soybean. The no-till system began to catch up and then out-yield the conventional system only when green manure cover crops were combined with the no-till practice.

5. Irrigated horticultural systems in tropical eastern Brazil

Tomato, bell pepper, cauliflower, lettuce, pumpkins, broccoli, cabbage and water melon are among the horticultural crops grown under irrigation, in rainfed conditions, or in greenhouses, in such locations as Guairá, SP; Rio Verde, GO; Varjão de Minas, MG; Itupeva, SP; and Teresópolis, RJ. Technologies are being developed for growing these crops in mulch systems based on black oat straw, maize stover, or residues from *Crotalaria juncea*, amaranth, millet, or forage sorghum.

A number of benefits have been observed, among them: the elimination of raindrop splash, cleaner and better quality products from improved soil temperature regimes, higher crop longevity from deeper root systems – and higher yields with less water use. Platform teams did not provide, however, information on the extent to which these practices are being commercially used by farmers.

6. Rice-wheat and related systems in the Indo-Gangetic Plains

Conservation agriculture practices, in this region referred to as "resource conserving technologies" or RCTs, have over the past eight years or so begun to revolutionize irrigated agriculture in South Asia. The practice that has most widely adopted is zero tillage wheat after puddled rice. Area under this technology now exceeds 2 million ha, up from virtually zero in the late 1990s. The swift adoption of this practice is an indication of its very high levels of near-term profitability to farmers – achieved through cost reductions as well as yield gains.

Although research and development continues on crop residue management, mulches for soil cover, and new rotations based on green manures, adoption of these practices is not yet widespread. Farmer experimentation with and adoption of diversification crops does, however, continue apace – taking advantage of "space" in the cropping calendar made possible through wheat zero tillage (No-till reduces turnaround time between rice harvest and sowing of the following crop, sometimes making it possible to establish a third crop after wheat harvest, or between rice and wheat). These crops include potato, mungbean, and other pulses and legumes.

Some early adoption is also being seen for several complementary technologies, among them zero till direct-sown rice, double-zero till of rice and following crops in bed and furrow systems, intercropping of wheat with other crops (e.g., sugarcane, mint) in bed and furrow systems, and laser levelling of irrigated fields – to name just a few. Apart from laser levelling, however, the area covered by these practices remains small.

Research leading to this "no-till revolution" featured a fruitful partnership among national public-sector research programs, local universities, international research centres, private sector implement manufacturers, state-level extension agencies, NGOs, and farmer groups.

7. Intensive rice-based systems in the river valleys of northern Vietnam

The development of conservation agriculture practices is just beginning in the intensively-cropped rice-based lowland agroecosystems in river valleys in northern Vietnam. As in South Asia, the search for ways to operationalize the principles of conservation agriculture is complicated by the prevalence of puddled rice culture. Puddling is a practice used for creating soil conditions suitable for rice transplanting while simultaneously forming an impermeable pan to facilitate the control of irrigation water. In the process, of course, puddling destroys soil structure. As the platform team notes, "A key issue with the rice production system is how we can reconcile the current crop establishment and management practices with elements of Conservation Agriculture."

Direct dry seeding of rice and co-culturing techniques of rice with green manure crops are practices that might be explored. At present, such practices result in unacceptably low rice yields. Some "aerobic rice" practices appear promising, using bed and furrow systems developed in South Asia. Such systems might be designed so as to allow use of diversified cropping patterns, hybrid seeds, short-duration varieties, and relay cropping. The challenge is huge.

8. Multiple-cropping in high rainfall environments in southern Brazil and central Argentina

Conservation agriculture in southern Brazil and central Argentina areas is, without doubt, the quintessential model of success. This relatively well-documented example has served (and continues to serve) as an inspiration to those in other countries who seek to improve the productivity and sustainability of their own agroecosystems. Arguably, the very definition of conservation agriculture – minimal or zero soil movement, and the use of crop residues for permanent soil cover, and the introduction of new rotations – is drawn from this experience. To keep this example in context, however, it might be useful to repeat a paragraph introduced earlier:

“Until a few decades ago, however, much of [the] region was devoted to extensive pasture for livestock. It was only in the 1960s that government policies in Brazil began to promote a shift from livestock-based farming systems to crop-based systems. Farmers responded by taking up the crops being promoted – especially soybean. Soon, however, a crisis emerged in the form of a disquieting increase in soil erosion and land degradation. In some instances, erosion so reduced productivity that farmers were unable to repay bank loans. The causes of this crisis were fairly obvious – a deadly combination of farmers’ tillage practices, hilly and rolling land forms, the erodibility of local soils, and high levels of rainfall. Conservation agriculture emerged as a response to this crisis.”

It is painfully clear that, in this particular context, the three practices simply must go together. The need to control erosion is the principle driving factor. Erosion control is achieved through mulch-based soil cover. But soil cover can only be maintained by eliminating tillage. To the extent that permanent soil cover results in increased disease incidence, new rotations are required to break the disease cycle. As the platform team noted, "It has been demonstrated by many authors that the maintenance of crop residues on the soil surface has been one of the most important factors that contribute to a higher incidence of saprophytic organisms that will cause [sic] diseases in crops such as wheat, maize and soybeans. It has also been demonstrated that no-tillage must be associated with crop rotations in order to keep the inoculum potential within an acceptable level."

As long as conservation agriculture principles are observed, the precise way in which they are implemented can vary from one region to another or even from one farm to another within a region. No-till drills in southern Brazil are drawn by large tractors, small tractors, and draft animals. Soil cover may be based on maize stover, oat straw, ryegrass, vetch, or others. Rotations are shaped according to locally-relevant market opportunities and requirements for disease control. Nonetheless, in this environment, all three components of conservation agriculture are usually present.

From its very beginning, the development of conservation agriculture in this region has been led by farmers and farmer organizations, private implement manufacturers, and foreign experts, with local research institutions and universities joining the partnership some years later. It is an example of an innovation system at its most dynamic.

Adoption information for conservation agriculture in southern Brazil and neighbouring areas is important. The area covered by conservation agriculture in Brazil (whole country) is estimated at more than 24 million ha. Conservation

agriculture in Argentina (whole country) covers more than 18 million ha. The adoption of conservation agriculture in this region has generated immense impacts, both regionally and globally.

9. Sloping land systems on hillsides in subtropical northern Vietnam

Hillside "shifting agriculture" agroecosystems in northern Vietnam have much in common with similar systems elsewhere in the humid tropics, e.g., Central America, or other countries in Southeast Asia. The major issue in these systems is soil erosion and land degradation. In other parts of the world, erosion in hillside systems has posed problems for downstream water users, e.g., through siltation of lowland irrigation infrastructure, dam siltation, reduction in water quality for downstream water users, or damage to fisheries and aquatic ecosystems. The Asia platform team, however, did not note this as a problem in Vietnam.

Two groups of conservation agriculture technologies were examined for these systems. The first group focuses on residue management, mulching, and soil cover through:

- dry mulch (from crop residues) – already used by some Vietnamese hillside farmers in vegetable production;
- living mulch (from green manure cover crops grown together with the main crop);
- in-situ mulch (*Brachiaria* or *Mucuna* grown two to three months before crop establishment, at which time they are knocked down so that crops may be sown into the fresh residue);
- imported mulch (e.g., tree litter) – note that there is some interest in the introduction or improvement of agroforestry practices for this purpose;
- mini-terraces – but note there is some concern about terrace breakage during heavy rains, for which reason some observers suggest a continuation of "up and down" cultivation, not contour farming, with grass cover to protect drainage strips;
- "soil-cooking" – an indigenous practice aimed at rehabilitating highly degraded lands, in which dry residues are placed in shallow trenches, partly covered, then burned. It is not clear whether soil cooking holds advantages over straw retention on the soil surface.

The second group of conservation agriculture practices focuses on no-till establishment of crops after upland rice. As the platform team noted, "There seems to be an opportunity to grow a second crop as (winter wheat, fodder, and pulse crops) in the residual moisture of the preceding rice crop, using surface seeding/no-till agriculture." This may not be compatible, however, with the farmer practice of combining short-duration and long-duration rice cultivars in the same field (a risk management strategy).

These technologies are exciting and full of promise. No information was provided by platform teams, however, regarding the extent to which these practices are used by farmers.

10. Summary

Progress in developing and using conservation agriculture technologies varies substantially across agroecosystems, regions, and climates. There are instances where no conservation agriculture practices have been developed; where some practices have been developed but farmers have not yet come to use them; where farmers have come to use some components of conservation agriculture; and where all components are used by most farmers.

Variability in the development and use of conservation agriculture practices across agroecosystems is summarized in Table 3, below. Note that for half of the systems, platform teams were unable to provide information on the extent of adoption. Colour coding in Table 3 is simple – the reddish tint indicates problems, and the greenish tint indicates progress, in the pursuit of conservation agriculture. From the information provided, there appear to be three situations in which conservation agriculture is presently used by farmers.

1. Where annual cropping under conditions of high rainfall on erodible soils results in unacceptably high rates of erosion. Soil cover is introduced for erosion control, and no-till crop direct-sowing becomes necessary for crop establishment. Where permanent soil cover increases crop diseases, new rotations are introduced. This is the situation in southern Brazil and – potentially – for sloping hillside lands in Vietnam.
2. Where no-till for one or more crops in a system is introduced to advance sowing dates or reduce production costs. Erosion is not the principal issue, for which reason soil cover is not initially emphasized. Adjustments in sowing dates allow farmers to experiment with new and more diverse rotations. In the absence of disease pressure, new rotations for disease control are slow to develop. This appears to be the situation in rice-wheat systems in the Indo-Gangetic Plains, and annual crop systems in lowland tropical Bolivia.
3. Where soil cover and no-till are introduced in order to take better advantage of abundant rainfall, facilitating a move from monocropping to multiple-cropping. This appears to be the situation in the Cerrados of Brazil.

Variability in the use of conservation agriculture technologies – and their relationship to climates, regions and agroecosystems – are further explored in the next section, where “drivers” and “constraints” to conservation agriculture are discussed.

Table 3. Conservation agriculture practices across the agroecosystems of interest

	Temperate	Mediterranean		Tropical			Subtropical irrigated		Subtropical rainfed	
Conservation agriculture practices being used	Agroecosystems in temperate northern Europe	Water-scarce rainfed agroecosystems in the Mediterranean	Irrigated, intensive systems, including fruit trees	Wheat-soybean and related systems in lowland tropical Bolivia	Crop – pasture systems in the Cerrados of Brazil	Irrigated horticultural systems in eastern Brazil	Rice-wheat and related systems in the Indo-Gangetic Plains	Intensive rice-based systems in the river valleys of northern Vietnam	Multiple-cropping in high rainfall environments in southern Brazil and central Argentina	Sloping land systems on hillsides in northern Vietnam
Extent of adoption	Estimates provided	Estimates not provided	Estimates not provided	Estimates provided	Estimates in literature	Estimates not provided	Estimates provided	Estimates not provided	Estimates provided	Estimates not provided
Minimum tillage	Some adoption of <u>minimum tillage</u> without mulch, principally in Germany and Eastern Europe	<u>Reduction of intensive tillage</u> in the region begun in the 1980's, and later tentatively in North African Mediterranean countries					Sometimes, <u>minimum till</u> is used instead of complete tillage			
Zero tillage	<u>No Tillage</u> is very little used in Europe	<u>No-tillage</u> and cover crops between rows of perennial crops such as olives, nuts and grapes.		Of about 1.6 m ha of cultivated area in Santa Cruz Department, slightly more than half is <u>sown with no-till</u> .	New CA systems with 2-3 annual crops in succession under <u>continuous direct seeding</u>		<u>Zero till wheat</u> after puddled rice now covers more than 2m ha, up from zero just a few years ago	The development of conservation agriculture practices is just beginning	<u>No-till</u> covers huge areas – it is indispensable for maintaining soil cover	<u>No-till</u> establishment of crops after upland rice (however, information on adoption is missing).
Soil cover/ mulch	Some adoption of minimum tillage <u>without mulch</u> , principally in Germany and Eastern Europe	<u>No-tillage</u> and <u>cover crops</u> between rows of perennial crops such as olives, nuts and grapes.		In most of this no-till area, however, there is <u>little or no use of cover crops</u> or new crop rotations	Continuous direct seeding understood to include <u>conservation of residues</u>	Horticultural crops grown under <u>straw mulch</u>	Adoption of <u>soil cover</u> or mulch with zero till wheat not yet widespread	The development of conservation agriculture practices is just beginning	<u>Soil cover</u> is seen as essential for erosion control and is widely used by farmers	Various <u>mulch-based systems</u> (however, information on adoption is missing).
New rotations developed for conservation agriculture		Conservation agriculture not adopted on a large scale. Occasionally used for winter cereals in <u>traditional rotations</u>		In most of this no-till area, however, there is little or no use of cover crops or <u>new crop rotations</u>	<u>New CA systems</u> with 2-3 annual crops in succession, last crop as nutrient pump.		Farmers are trying and adopting diversification crops – but most rice before wheat is still puddled	The development of conservation agriculture practices is just beginning	<u>Rotations</u> are designed with an eye to market opportunities and disease control	

IIIb.

KASSA research results - Driving forces and constraints

In the course of their analysis, platform teams assembled information on drivers of conservation agriculture and constraints to its use. "Drivers" are factors that facilitate the development and use of conservation agriculture. "Constraints" are the complete opposite – they are factors that tend to discourage or inhibit its use. Each will be discussed in turn.

1. Drivers of conservation agriculture

Some of the "drivers" of conservation agriculture were said to act at the farm level, with others acting at institutional, social or policy levels.

1.1. Farm-level drivers of conservation agriculture

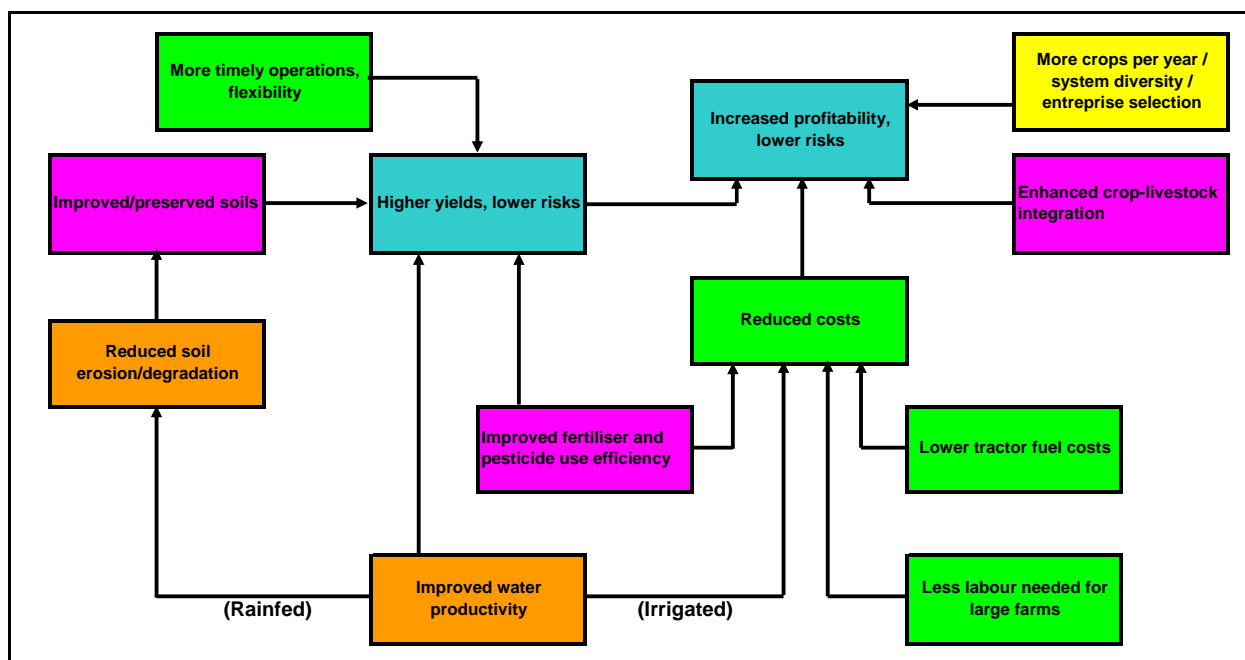
Farmers, on average and over time, tend to adopt new practices that increase near-term farm-level profitability and/ or reduce risk. Other things being equal, improved profitability depends on some combination of higher yields and/or output prices, lower costs, or improvements in "enterprise selection" (decisions on crop or livestock enterprises).

Farm-level profitability and its determinants – yields³, prices, costs, and enterprise selection – were seen as drivers of the development and use of conservation agriculture for most agroecosystems. Yields, of course, may be affected by many factors, among them resource (especially soil) quality, water availability and productivity, and the timeliness of operations, e.g., sowing. The use of no-till may reduce costs. Improvements in fertilizer and pesticide use efficiency may result in higher yields (if input levels remained unchanged) or cost savings (if input levels decline). Output prices depend on marketing margins, market performance, and policies and institutions.

Figure 2, below, shows various farm level drivers of conservation agriculture and illustrates some of their cause and effect relationships.

³ Given the high level of production (at times, over-production) of agricultural products in Europe, yields as such are perhaps of less interest there than in other platforms. Still, they are one of the several determinants of the profitability of different agricultural technologies, among them conservation agriculture.

Figure 2. Drivers of conservation agriculture – farm level



Colour coding in Figure 2 is as follows:

- blue boxes indicate desirable farm-level outcomes from conservation agriculture that, if attained, can encourage adoption
- green boxes indicate drivers shown to be operational in all platforms
- rose coloured boxes indicate drivers hypothesized to be at work in all platforms – although their effects still need to be demonstrated through long-term research.
- tan coloured boxes indicate drivers hypothesized to be at work only in specific environments (e.g., water-scarce ecosystems, erosion-prone ecosystems). The effects of these also need to be demonstrated through research.
- yellow boxes indicate drivers that depend very much on external market forces.

1.1.1. Reduced production costs

All platform teams highlighted the importance of conservation agriculture in reducing production costs, though this factor was deemed more important in some agroecosystems than others. The European platform team, for example, noted that, "For Nordic/North European countries, to reduce cost is according to our findings the most important driving force for conservation agriculture/no ploughing". The Mediterranean platform team concurred, noting that "reduction of intensive tillage in the Mediterranean region begun in the 1960's and later [tentatively] in North African Mediterranean countries . . . with variable impact and mainly driven by the necessity for a reduction in different inputs (fuel, machinery and labour) . . ."

In the Indo-Gangetic Plains, the use of no-till to establish wheat after puddled rice resulted in very substantial cost savings – especially for smallholder farmers who rent in tillage and crop establishment services. The Asian platform team noted that, "Resource conservation [sic] technologies related to tillage practices (zero/bed planting/ direct seeding etc.) on [the] one hand afford time for optimum sowing and other hand drastically reduces the consumption of fossil fuels . . . and the wear and tear of tractor parts and accessories . . .". The importance of cost saving in the

adoption of conservation agriculture was also found in southern Brazil and Bolivia, "From farmer's perspectives, the main driving forces for the adoption of CA was the savings on the use of machinery (for large-scale farmers), the reduction on labour requirements and drudgery (for small-scale farmers), erosion control and increase in yields . . . ".

Agroecosystems where cost savings were not mentioned as a driver of conservation agriculture include the lowland valleys and sloping hillsides in Vietnam, the Cerrados in Brazil, and irrigated systems in the Mediterranean and Brazil. Moreover, platform teams did not provide information on the extent to which cost savings in tillage might be offset by cost increases for fertilizers, herbicides or pesticides.

1.1.2. Reduced soil erosion and resource degradation

Another critically important driver of the adoption of conservation agriculture was erosion control and the preservation of soil quality and land productivity. This was particularly true for the sloping rainfed lands in southern Brazil, as has already been mentioned. The Latin American platform team noted the following:

"During the 70's [sic] the Brazilian agricultural policy encouraged the expansion of the agricultural frontier, the production of commodities such as soybeans and wheat, which replaced activities such as coffee and livestock. These new economic activities were implemented under conventional cultivation, combined to the high erosivity of rains and erodibility of soils, led to serious soil losses. By this time public research and institutions recommended that farmers switch to livestock production or to adopt mechanical measures for soil conservation. However, depending on the soil type . . . even mechanical measures were not effective; the production of annual crops was not recommended and supported by official institutions (research, extension and credit) in such erosion-prone areas. Such situation lead farmers to search for other alternatives, and CA were disseminated. . [sic]"

In a similar vein, the Mediterranean team noted that, ". . . one of the driving forces for evolution of CA in many of the Mediterranean platform countries has been the necessity of controlling erosion by rainfall – runoff and wind".

Soil erosion and land degradation were also mentioned as important potential drivers of conservation agriculture for temperate systems in Europe (water and wind erosion, soil crusting, pebble-raising) and sloping hillside systems in Vietnam. Land degradation is also a major concern in the Indo-Gangetic Plains – but it takes the form of soil fertility depletion, groundwater depletion, and salinization or waterlogging of fields, more than erosion as such.

1.1.3. Improved water productivity

Understandably, improved water productivity (and higher yields through improved water management) are of greatest interest in water-scarce environments. Two such environments were studied within KASSA – the rainfed Mediterranean area, and the western (drier) transects of the Indo-Gangetic Plains.

The Mediterranean platform team explained farmer interest in conservation agriculture as being partly due to its,

" . . . much better water economy and efficient water use through a higher accumulation and infiltration of water in the soil profile and lower water losses by evaporation and runoff. This is especially well appreciated by dryland farmers in areas where the water available for crop growth becomes a limiting factor in dry years."

Nonetheless, little specific data or other evidence were provided on the extent to which conservation agriculture helps conserve soil water in water-scarce ecosystems. Further research on this theme is clearly needed.

Water productivity and management, and their effects on crop yields, were found to be important in rice-wheat systems in the western Indo-Gangetic Plains. Waterlogging and salinization reduce yields in some districts, while groundwater depletion threatens the very existence of irrigated agriculture in others. The use of no-till, bed and furrow systems, laser levelling and other resource conserving practices have proven their usefulness in improving water management. Improvements in the timeliness of sowing (made possible by no-till and similar practices) can also result in improved water productivity.

The effect of water management on yields was not described as important for other agroecosystems in other climates. In many of these systems, of course, water is not scarce, e.g., temperate systems in northern Europe, and irrigated lowlands in Vietnam. In parts of the Cerrados of Brazil, there is reason to believe that the conservation of soil moisture through conservation agriculture practices allowed the introduction of double-cropping where monocropping had been the rule.

1.1.4. More flexibility and improved timeliness of operations

The ability of some conservation agriculture practices, especially no-till, to facilitate timeliness of operations, especially sowing, was highlighted in several instances. The original motivation for developing zero tillage wheat technology in the Indo-Gangetic Plains was to attain timely wheat sowing (and thereby improve yields and input use efficiency). No-till and surface seeding have also proven to be effective in fostering greater agroecosystem intensity in the hitherto "rice-fallow" areas of the eastern Indo-Gangetic Plains. In Bolivia, no-till was also described as allowing earlier sowing, resulting in higher yields.

The Mediterranean platform team noted that, "CA can offer large possibilities, particularly no-tillage systems, as flexible and early times for sowing, fertilizer application and weed control . . . yield increase (10% to 15% higher) . . . greater yield stability . . . faster crop establishment and development (e.g., better emergence observed in crops sown in autumn due to warmer soil conditions in October and November)."

1.1.5. Diversification and enterprise selection

Timeliness of sowing is often closely linked to system intensification, diversification, and enterprise selection. System diversification has been observed as an outcome of the adoption of wheat no-till in the Indo-Gangetic Plains. The Asian platform team also noted the expectation that no-till could be used in sloping upland systems in Vietnam for sowing a second crop after upland rice or maize. And the Vietnamese have made it very clear that they are counting on conservation agriculture

technologies to facilitate further intensification and diversification of lowland valley rice-based agroecosystems.

In the original example of conservation agriculture from southern Brazil, sustainable multiple-cropping was only made possible by the use of mulch-based soil cover. Perhaps the most dramatic example of conservation agriculture fostering changes in enterprise selection, however, comes from the Cerrados of Brazil, where a successful transition was made from full-till monocropping to no-till conservation agriculture multiple-cropping.

In all cases, of course, the acceptability to farmers of diversification enterprises depends very much on their farm-level profitability, which in turn is affected by markets and policy and institutional drivers.

1.1.6. A final comment – cross-checking with KASSA deliverables D2.x

In the deliverables D2.1, D2.2, D2.3 and D2.4 from KASSA work packages 1.2 and 2.2, the Mediterranean platform submitted the following table⁴. It summarizes the driving forces regarding the transformation from conventional to conservation agriculture, as proposed by the different platform teams. Farm-level driving forces are highlighted in yellow – all of them have been discussed above. Social, institutional and policy drivers are explored next.

Synthesis of major driving forces regarding shifting from conventional agriculture to Conservation Agriculture (CA)

MEDITERRANEAN PLATFORM	EUROPEAN PLATFORM	LATIN AMERICAN PLATFORM	ASIAN PLATFORM
<p>Better economy at farm level</p> <p>More flexible technical possibilities (sowing, fertiliser application, weed control, etc.)</p> <p>Greater water economy in dryland areas</p> <p>Soil protection</p> <p>Cropping diversification</p> <p>Yield increase and stability</p> <p>Greater nutrient-use efficiency (less use of fertilisers)</p>	<p>Soil erosion</p> <p>Soil crusting</p> <p>Pebble raising</p> <p>Increase OM necessity</p> <p>Higher trafficability</p> <p>Development of technologies (machinery and herbicides)</p> <p>Improvement of labour organisation</p> <p>Farmer associations promoting CA</p> <p>Costs and labour time reduction</p> <p>Yield increase/stabilisation</p> <p>Political decisions that indirectly favour CA</p> <p>Regulation measures (reduction of environmental impacts)</p> <p>Subsidies</p>	<p>Better economy (savings on machinery, labour and drudgery)</p> <p>Institutional factors (public and private sectors)</p> <p>Technical facilities (machinery, agrochemicals) (Brazil, Argentina)</p> <p>More flexible technical possibilities (e.g. sowing) (Bolivia)</p> <p>Soil erosion (Brazil, Argentina) and fertility and yield (Brazil)</p> <p>Crop x livestock integration (Brazil)</p>	<p>Institutional factors (public and private sectors)</p> <p>Population pressure</p> <p>Better economy (savings on machinery, labour and drudgery)</p> <p>Livelihood improvement (by increasing yields, crop diversification, timely planting for the rice-wheat system)</p> <p>Improvement in environmental quality (land and water resources)</p> <p>Availability of adapted machinery</p> <p>Herbicide resistance in weeds.</p>

⁴ J.L. Arrue *et al.* 2006. The Mediterranean platform comparative critical analysis. Learning from KASSA platforms' reports. Deliverable D2.2.

1.1.7. Summary

The above discussion is summarized in table 4, below, which shows the relevance of different farm-level drivers of conservation agriculture in different climates and agroecosystems. Darker shades indicate drivers of greater importance while blank cells indicate that the driver is either unimportant or that no information was provided.

Table 4. Farm-level drivers of the development and adoption of conservation agriculture, by climate and agroecosystem (Darker shades indicate drivers of greater importance. Blank cells indicate low levels of importance or lack of information).

	Temperate	Mediterranean		Tropical			Subtropical irrigated		Subtropical rainfed	
Drivers	Agroecosystems in temperate northern Europe	Water-scarce rainfed agroecosystems in the Mediterranean	Irrigated, intensive systems, including fruit trees	Wheat-soybean and related systems in lowland tropical Bolivia	Crop – pasture systems in the Cerrados of Brazil	Irrigated horticultural systems in eastern Brazil	Rice-wheat and related systems in the Indo-Gangetic Plains	Intensive rice-based systems in the river valleys of northern Vietnam	Multiple-cropping in high rainfall environments in southern Brazil and central Argentina	Sloping land systems on hillsides in northern Vietnam
Reduced costs										
• Lower tractor, fuel costs										
• Lower labour costs										
Increased yields										
• Reduced resource degradation										
• Water infiltration/savings										
• Timeliness of sowing										
Enterprise selection										
• More crops per year/diversity, flexibility										

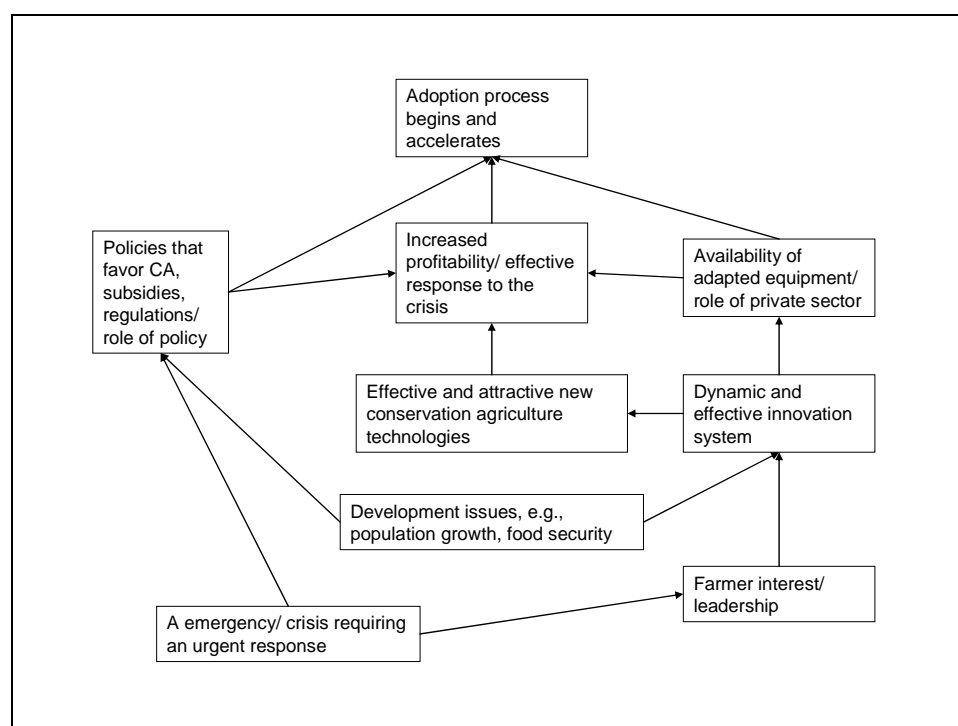
1.2. Institutional and social drivers of conservation agriculture

Farm-level drivers of conservation agriculture were not the only ones identified by KASSA platform teams. They also identified policy, institutional and social drivers. Institutional and social drivers were said to include:

- the dynamism and effectiveness of innovation systems in generating knowledge to adapt and improve conservation agriculture practices;
- the extent to which conservation agriculture implements and technical services are generally available to farmers;
- the leading role of farmers and farmer organizations in the shifting from conventional to conservation agriculture; and
- the occurrence of a “crisis”, resulting in a more rapid development of conservation agriculture practices and implements.

Figure 3 illustrates some of these drivers and ways in which they might possibly interact. Note that the effects of most of these drivers are felt through their influence on the feasibility and profitability of conservation agriculture technologies at the farm level. Not all of these drivers were actually found in all platforms.

Figure 3. Drivers of conservation agriculture – policy, institutional and social levels



1.2.1. Dynamic and effective innovation systems

Among the pillars of sustainability introduced earlier in this paper (Figure 1) is that of "knowledge generation" to "improve, adapt and correct" the design of conservation agriculture practices and implements. But knowledge generation is most effective when embedded in an innovation system that is dynamic and inclusive, one that brings in relevant stakeholders and is quick to learn. At its best, an innovation system will co-evolve with the technologies being developed – new partners will come on board as new problems are encountered or new needs are identified.

The most commonly cited example of an effective innovation system is that from southern Brazil.

"The adoption of CA by farmers is by far the most widespread in Brazil . . . Inspired by no-till production concepts emerging in the USA at the time, a handful of dynamic "farmer-researchers" started to develop own their implements and systems without initial assistance from government or researchers. Farmer associations and co-operatives, NGOs and local industry then joined suit and were later followed by the international agro-industry, governmental agencies, national and provincial agricultural research stations, universities, etc. The real CA evolution impetus, however, has remained farmer-driven in Brazil, and industry and governmental research is participatory. . . . In terms of extension, in LA, the formation of CA farmers' associations has furthered the dialogue between industry and farmers, as well as advancing adoption of CA by helping farmers overcome some of the hurdles associated with obtaining information or even funds for CA implements."

Further evidence was provided by the Latin American platform team on farmer-led innovation systems in the Cerrados area of Brazil, and in lowland tropical areas of Bolivia.

"In humid Cerrados region, diversified CA systems were developed by farmers for the large-scale grain production and to replace the inefficient tillage-based sorghum monoculture system . . . Initiatives of the farmers in no-till system were well supported by research. Institutional arrangements among various stakeholders (public/private research and extension institutions, agrochemicals companies, machinery manufacturers etc.) played a major role in development . . . of CA."

In the case of the eastern lowlands of Bolivia, it appears that no formal public sector research institutions of any kind were involved in the development and dissemination of no-till practices. Farmers' organizations arranged for the representative of an international research centre and other specialists to work with them directly.

The other major example of a dynamic innovation system is that associated with the development of no-till wheat after puddled rice in the Indo-Gangetic Plains. This example is of particular interest because it offers a sharp contrast to the Latin American innovation systems described above.

Progress with no-till wheat in this region can be traced to the collaborative research of one scientist from an international research centre, whose initiative was further developed at a local university. A private sector implement manufacturer became aware of the prototype no-till implement designed at the university, and invested in its local adaptation and re-design. However, it took a regional crisis (the emergence of herbicide tolerant weeds in wheat) for the implement to be taken up by a different

university, for use in a program of participatory action research with farmer groups on weed control issues.

Farmers, however, began to take interest in the no-till practice for reasons having little to do with weed control (i.e., cost savings), and the practice began to spontaneously spread. Adoption was further accelerated by research and extension programs launched by public sector research institutions (e.g., the Indian Council on Agricultural Research) and state-level extension services. Private sector implement companies continued to adapt and improve their no-till drills and, at the same time, accelerated their manufacture and marketing. Throughout this process, mentoring activities, support services and information exchange were facilitated by an international network (The Rice-Wheat Consortium for the Indo-Gangetic Plains), international research centres, universities and public sector research institutions.

Few other examples of innovation systems were provided from other platforms, climates or agroecosystems.

1.2.2. Ready availability of conservation agriculture implements

Many platform teams concluded that the ready availability of adapted implements for conservation agriculture, especially drills for direct-sowing into soil cover, is an important driver of the transition from conventional to conservation agriculture. In most cases, however, the development, adaptation and commercial availability of these implements was an important outcome of a dynamic innovation system, as described above.

Of course, the mirror image of a driver can be a constraint. The transition to conservation agriculture can be constrained when suitable implements are not readily available. Farmers cannot experiment with no-till direct-sowing if they have no access to implements capable of performing this operation. Note that the availability of implements may be less of an issue in systems that are less mechanized, e.g., those in Vietnam.

1.2.3. Leadership from farmers and farmer organizations

In at least four examples, individual farmers or farmer organization were responsible for taking the lead – or "driving" – the development and dissemination of conservation agriculture practices. Remarkably, all of these are in Latin America – central Argentina, southern Brazil, the Cerrados of Brazil, and lowland tropical Bolivia. In these cases, farmers struck the spark that lit the fire of innovation – and at times provided much of the fuel. But it must be noted that other entities – the private sector, NGOs, international and national public sector research institutions, universities and others – gradually came on board, joining and participating in the innovation system, and made substantial contributions to the eventual success of conservation agriculture. It would appear that farmers might best show their leadership in ways that encourage, not discourage, the participation of other partners.

Once again, the Indo-Gangetic Plains provides a contrasting example. Farmers did not lead the transition to no-till although they did make essential contributions.

In research on conservation agriculture for the sloping hillsides of Vietnam, the lack of farmer participation was seen as a problem. "In Vietnam, the presence of real

erosion-linked problems has allowed the development of various mulching technologies . . . however, in the absence of farmers' participation in research or vis-à-vis challenges to which CA can provide immediate solutions (i.e. erosion), widespread adoption . . . remains unachieved."

1.2.4. The presence of a crisis mentality

Several platform teams identified one final driver – the presence of an acute problem or crisis to which conservation agriculture was seen as a possible solution. One team noted the following: "In essence, what appears to be necessary to foment widespread CA adoption is a combination of very real and acute problems to trigger real responses, proactive and dynamic farmers with sufficient knowledge and resources, and good linkage between industry, farmers and research . . . " Another team concurred, ". . . the constraints to CA extension are often stronger than driving forces, except if there is a crisis regarding soil fertility (e.g.: hugely degraded soils, intense erosion, non availability of water resource, ...) or regarding labour requirement . . . " [sic].

The conversion of pasture land in southern Brazil to annual cropping, and the resulting crisis of soil erosion, provided a sense of urgency that drove stakeholders to take swift and effective action. In a slightly different way, the crisis of herbicide-tolerant weeds in wheat in the Indo-Gangetic Plains was the motivation for launching an emergency program of farmer experimentation with no-till – with spectacular results. It is not clear, however, the extent to which a sense of crisis led to more rapid progress in Argentina, the Cerrados of Brazil, or the lowland tropics of Bolivia.

1.3. Policy drivers of conservation agriculture

The KASSA platform teams uncovered a host of policy issues that, under the right circumstances, can foster the development and use conservation agriculture. Understandably, different platforms emphasized different policy questions. In most instances, the policies in question are capable of either driving or constraining the use of conservation agriculture – according to how they are shaped and the incentives they create.

1.3.1. Favourable macroeconomic policies

The prospects for conservation agriculture can be hugely affected by macroeconomic and economic development policies, including those that influence enterprise selection and agroecosystem diversification. The Latin American platform team noted the negative effect of national fiscal and monetary policies on the profitability of agricultural production. Some policies, they indicate, have depressed product prices, raised interest rates, restricted the availability of credit, and discouraged investment.

"The socioeconomic environment in Latin America, if not constraining to agriculture, is not really favourable. Most of the countries live under the spectre of past high inflation rates and huge public debt. In order to deal with the economic situation local governments undertake the usual orthodox policy of high interest rates to keep inflation low and attract foreign investments. In addition, since some of the biggest Latin American countries, as Argentina and Brazil for example, are

important commodity exporters, agriculture is a useful instrument for their economic policies as a foreign currency provider."

It might be further observed, however, that when conservation agriculture has a strong cost-savings element, a shift to these technologies might be one way that farmers can adapt to an unfavourable macroeconomic regime.

The Mediterranean and Asian platform teams commented on the importance of national economic development policies. The goals of such policies usually include reducing poverty, fostering food and environmental security, enhancing natural resource conservation, and improving rural livelihoods. Given the potential of conservation agriculture to help achieve these goals, it was suggested that these policies be reshaped to explicitly support conservation agriculture research and development.

1.3.2. Favourable agricultural sector policies

Sectoral policies that provide support for specific commodities, or influence the diversification of agroecosystems, may also be important as drivers of conservation agriculture. Recall that the erosion crisis in southern Brazil (and the conservation agriculture response) was initially sparked by a policy that encouraged the expansion of soybean and wheat production into areas previously devoted to cattle and coffee. (This is not meant to suggest that policies that foster unwise land use are a preferred means of encouraging the development of conservation agriculture.)

In South Asia, some countries retain food security policies that provide input subsidies (e.g., free electricity for pumping of irrigation water) and price supports for foodgrain production. These policies tend to encourage over-production of rice and wheat, reduce incentives for efficient input use, discourage the production of alternative crops and, sometimes, damage the resource base (e.g., groundwater depletion from over-pumping). Such policies can increase the difficulty of developing conservation agriculture technologies that are economically attractive to farmers. In Latin America, policies that encourage monocropping can also discourage the use of crop rotation strategies needed for disease control.

The European platform team raised the possibility of trade-offs between conflicting agricultural sector policies. For example, a policy aiming to mitigate soil erosion (achievable through conservation agriculture) might conflict with another policy discouraging the use of herbicides (often critical to the initial success of conservation agriculture practices). It is clear that in EU countries, the Common Agricultural Policy (CAP) can either foster or discourage a shift to conservation agriculture.

1.3.3. Policies affecting farm size, agrarian structure and land tenure

Some of the countries participating in KASSA were until recently managed under the soviet system. Policies and practices carried over from the soviet era can have noticeable impacts on agrarian structure, systems of land holding, farm size, and farmers' confidence and attitudes. These can encourage or discourage the adoption of conservation agriculture.

Similarly, policies that influence land ownership, tenancy rights or inheritance patterns may be important. Farmers who own land, or whose tenancy rights are

secure, are more likely to invest in conservation agriculture technologies that generate benefits over an extended period. Moreover, in some instances, larger farmers simply find conservation agriculture practices more attractive (e.g., larger farmers with larger field sizes in the UK are said to face greater risks from wind and rain-induced erosion, one of the foremost drivers for conversion to conservation agriculture). In such cases, differences in size of farm holding, even within a country, can determine where conservation agriculture is adopted. The European platform team called attention to differences in the size of holdings between East and West Germany, and land ownership differences between Scotland and England in the United Kingdom.

1.3.4. Appropriate agricultural research policies

As result of KASSA, agricultural research and extension institutions will have the opportunity to play a stronger and more effective role in fostering the use of conservation agriculture. The introduction of conservation agriculture requires many adjustments in traditional agronomic and crop management practices that research can help identify. Equally important is for research to quantify and perhaps even forecast the long term agronomic, economic, social and environmental consequences of the widespread adoption of conservation agriculture practices.

Lessons drawn for Latin American and Asian platforms suggest that research efficiency improves when close cooperation is achieved between research institutions and all other partners, in the context of a broader innovation system, using multidisciplinary approaches and systems thinking. To succeed in responding to this challenge, research institutions may need to scrutinize their internal research policies and priorities. Otherwise, research centres themselves may pose a constraint to the development and use of conservation agriculture.

Also, as suggested in the European platform report, close collaboration between research and extension workers, private sector implement manufacturers and farmers is needed for the development of no-till direct-sowing drills that are effective even when seeding into large amounts of loose residues, and no-till drills specifically designed for small scale farmers.

1.3.5. Policies for training, communication and support for farmers' initiatives

KASSA platform teams identified a large number of areas where policy interventions can provide an institutional and social setting favourable to the development of dynamic innovation systems and for the development of conservation agriculture practices. These include policies to:

- Foster partnerships between private companies, public institutions and farmers;
- Facilitate farmer access to and acquaintance with conservation agriculture technology, and farmer-to-farmer communication;
- Support networking on conservation agriculture for knowledge development and sharing;
- Promote participatory multiple-stakeholder conservation agriculture projects;
- Develop institutional mechanisms to provide support for farmers' initiatives;

- Promote conservation agriculture in educational programs;
- Provide training in conservation agriculture for farmers – but also for extension workers, research managers, scientists, teachers, donors and policymakers;
- Publicize the potential benefits of conservation agriculture to policymakers.

2. Constraints to the development of conservation agriculture

"Drivers" are factors that tend to facilitate or encourage the development and use of conservation agriculture. "Constraints" are the complete opposite – they are factors that tend to discourage or inhibit its use. Some constraints to conservation agriculture have already been introduced, e.g., unfavourable macroeconomic, agricultural sector, agrarian reform, and agricultural research policies. Platform teams identified many additional constraints, among them: agroclimatic factors (climate, soils); biological factors (weeds and pests and diseases); technology management factors (residue management, cover crops, rotations); input and cost factors (increased production costs, availability of implements); and factors associated with farmer characteristics (lack of knowledge, farmer reluctance).

2.1. Agroclimatic constraints - climate

KASSA teams identified at least two climatic circumstances that may constrain the use of conservation agriculture. The first, in northern Europe, emerges from a combination of short growing seasons, cold temperatures, high rainfall levels and poorly drained soils. When lands are flat, water is abundant and erosion rates are low, the use of soil cover for water conservation or erosion control becomes less compelling. And when soil cover and no-till result in cooler soil temperatures and delayed sowing, the use of conservation agriculture may depress yields. The European platform team concluded that, "Cold and wet sand and silt soil and heavy clay [are] difficult to cultivate without ploughing in a short season."

In contrast, the Latin American platform team submitted that in Argentina, conservation agriculture was not really suitable for some temperate sub-humid and subtropical regions where "monozonic" rainfall patterns and "deficient" water balances limit biomass production, crop development and final yield. This concern must be clarified as it appears to contradict experiences from other parts of the world where conservation agriculture is used to improve water productivity and agroecosystem profitability in water scarce environments.

2.1. Agroclimatic factors - soils

Platform teams agreed that conservation agriculture is less suitable for soils that are susceptible to compaction, and that its introduction should be partly guided by maps indicating where such soils are located. The European platform team suggested that conservation agriculture is most suitable for well-drained soils. "Reduced tillage methods are best suited to medium textured soil and well drained clay, and clay loam soils . . . heavy clay and sandy and silty soils are not good opportunity for reduced/none tillage due to compaction and poor drainage ability. [sic]" "Chernozems soils in Ukraine are ideal for CA, while solontzetic, overmoistened, gleyed, sandy and stony soils are regarded as not suited."

The Latin American team expressed concern about farmers' perceptions that compaction is "... more evident under soil moisture stress associated to high clay and low organic matter content or in soils with high silt content ..." and that "there is a need to evaluate to what extent farmers' perception corresponds to real problems of soil compaction."

The Asian platform team did not address the soil compaction issue – at least in the irrigated Indo-Gangetic Plains. Having a wider array of crop establishment practices from which to choose⁵, they have attempted to match different resource conserving technologies to different soils. In essence, they do not focus on whether a particular soil is suitable for conservation agriculture – In any event, the whole issue of compaction is hugely complicated by the opposing edaphic requirements of two different commonly-grown crops (rice and wheat). Recall that rice culture continues to use puddling to maintain standing water on the soil surface for much of the crop growing period.

2.2. Technology management – residues

The retention of crop residues for soil cover is a major component of conservation agriculture. A scarcity of residues can hinder the introduction of conservation agriculture technologies. Oddly enough, excessively high levels of residues can also serve as a constraint.

Residue scarcity emerges when biomass production is relatively low - or when the use of residues for mulch competes with their use for livestock fodder within the farm or out of the farm, i.e. sold onto the market. Residue retention becomes exceptionally difficult when traditional land use systems allow open and unrestricted grazing of livestock on crop residues after grain harvest. The Latin America platform team reported that these problems may be found in many parts of Argentina, Bolivia and Brazil, where they especially affect small scale farmers. Residue availability may be increased by introducing multipurpose cover crops, rotational grazing, the use of fodder banks, silage, etc. Most of these practices, however, are only feasible when farmers control access to the residues they produce, i.e., no open grazing. Residue management questions such as these are also relevant for rainfed Mediterranean agroecosystems.

When farmers in tropical climates produce only one crop per year, high rates of residue decomposition due to high rainfall and temperatures patterns leave soils uncovered for extended periods resulting in soil compaction problems, soil crusting and high incidence of diseases. This at times can be addressed through new rotational strategies or the introduction of adapted cover crops.

The introduction of conservation agriculture can also be constrained by excessive levels of residues. A surfeit of residues on the soil surface can make the establishment of following crops difficult to impossible, unless farmers have access to specialized no-till direct-sowing drills that can cope with high residue volumes. This constraint has been observed in northern Europe, in some parts of the Mediterranean, and (for rice straw) in the Indo-Gangetic Plains, where many farmers deal with large volumes of loose straw by simply burning it. Retention of rice straw on the soil surface tends

⁵ Direct sowing with zero-till, minimum-till or strip-till drills drawn by four wheel tractors or two wheel tractors; temporary or permanent bed and furrow systems with or without controlled traffic; surface seeding, parachute establishment of rice, direct sowing of rice, etc.

(in the absence of specialized drills) to hinder the timely sowing of the following wheat crop. Incorporating the straw tends to immobilize soil nitrogen, requiring that farmers apply additional nitrogenous fertilizers if they are to avoid a yield penalty.

Once again, soil puddling for rice culture adds further complications. Residue retention and soil puddling are mutually exclusive. Research is responding to this challenge by adapting rice culture to upland conditions, e.g., rice grown as a direct seeded crop without puddling and standing water. Highly productive aerobic rice production managed in double zero till, permanent bed and furrow systems is the vision driving much of this research.

Finally, when residue retention and no-till result in cooler soil temperatures and delayed sowing (as in northern Europe), yields may be depressed and farm income reduced.

2.3. Technology management – cover crops

Sometimes, crop residue production is inadequate to maintain soil cover. Under these conditions, specialized "cover crops" may be introduced to fill the gap. Many cover crops also serve as green manures.

In the Mediterranean platform, cover crops were described as being used between rows of perennial crops such as olives, nuts and grapes. The Asian platform team reported on substantial work done in hillside agroecosystems of northern Vietnam on "living mulch" (green manure cover crops grown together with the main crop in order to maintain soil cover) and "in-situ mulch" (cover crops grown, then knocked down by herbicide or mechanically so that the main crop may be sown into fresh residue). In the Cerrados of Brazil, cereals are sometimes intercropped with forage species that also serve as green manures and as sources of dry season soil cover.

In the European platform, there have been many experiments on cover crop management within various crop rotations, including winter and summer catch crops, intercrops and under-sown crops. However, at present, few farmers are said to use cover crops within market crop rotations, largely because they increase production costs and typically are not marketable.

The introduction of cover crops can discourage farmer use of conservation agriculture when: -i) they increase production costs without generating commensurate benefits, or -ii) when inappropriate cover crops are chosen for specific climatic zones or agroecosystems.

2.4. Technology management – rotations

Crop rotations first emerged as an important component of conservation agriculture practices in Brazil, where they played an important role in strategies for integrated weed, pest and disease management. Frequently, however, the use of rotations for these purposes is ruled out by farm-level economics. Agronomically-desirable rotation crops are often simply unprofitable because of lack of markets and low product prices. This is exacerbated when farmers have insecure land rights and the beneficial effects of rotations are only observed over extended periods.

The European platform team noted the following:

"Although much knowledge on the effects of preceding and succeeding crops in a rotation exists in scientific literature, and it is arguable that astute crop rotations are the basis of successful sustainable agriculture and CA, market pressures, caused by the changed support system of the EU and the decrease of market prices for many products, in combination with the need to boost short-term profitability, mean that few farmers actually practice agronomically ideal rotations."

In the Indo-Gangetic Plains, much effort has gone into diversifying agroecosystems that at present are restricted to continuous rice-wheat. There has been special interest in pulses and oilseeds, potatoes, and fruits and vegetables. Interestingly, it appears that zero tillage facilitates agroecosystem diversification by providing greater flexibility in sowing dates. Small farm mechanization can also encourage diversification by facilitating the transport of high-value goods to nearby markets, thus reducing marketing margins. Ultimately, however, the situation in the Indo-Gangetic Plains is the same as found elsewhere – the extent to which new rotations are adopted depends very much on their farm-level profitability.

2.5. Weeds, pests and diseases

Farmer use of conservation agriculture practices is sometimes constrained by an increase in weeds, pests or diseases associated with the new practices. The Mediterranean platform team noted that rodents and slugs become more troublesome with no-till direct-sowing. The Latin American platform team indicated that certain crops, e.g., cotton and tobacco, are rarely grown under conservation agriculture because of pest and disease issues. The use of *Mucuna* as a cover crop has been known to result in increased problems with rats – and snakes.

The European platform team cited a number of examples where conservation agriculture practices have resulted in snail problems with sugar beets, mice in grain crops, and progressively greater weed problems:

"Pressure from weeds such as Bromus or creeping thistle (Cirsium arvense) are one of the most common concerns voiced by farmers attempting RT/CA and can constrain adoption of RT and increase reversion to conventional ploughing significantly. Although special herbicides, such as glyphosate and other broadband herbicides, - the basis for successful RT/CA -, Danish experiences over a number of seasons under RT indicate that grass weeds become harder and harder to control, sometimes necessitating large glyphosate applications with minimal success."

2.6. Increased production costs

Reductions in unit production costs can be drivers of conservation agriculture. However, if the introduction of conservation agriculture leads to increased production costs, then the driver becomes a constraint. In the KASSA reports, there are several suggestions to the effect that the adoption of conservation agriculture can result in higher production costs because new, specialized implements must be purchased. This is a very partial measure, however. In the Indo-Gangetic Plains, for example, the returns to investment to wheat no-till are so large that the purchase of a no-till drill pays for itself in one or two seasons. Sound economic analysis combined with farmer assessment of technologies is needed.

The European platform team went a bit further, however. They pointed out the potential importance of social costs that do not impinge on farmer decision-making, for example, costs associated with rural unemployment if conservation agriculture reduces overall labour requirements, or costs associated with environmental pollution if conservation agriculture increases the use of pesticides.

Finally, they reminded us that the full economics of conservation agriculture can be eminently difficult to assess. A thorough economic analysis requires consideration of all costs and benefits, private or social, direct or indirect, near-term or longer-term, at the level of farm, region and watershed. Detailed quantification of these is difficult. Placing values on them is next to impossible. Some attempts at such analysis, however, would be useful to get a sense of the magnitude of the hidden costs/benefits of conservation agriculture.

2.7. Non-availability of conservation agriculture implements

There was a consensus across the European, Mediterranean, Latin American and Asian platforms that the use of conservation agriculture is constrained when suitable implements are not available. (Implement availability is less of a constraint in unmechanized agroecosystems, e.g., those in Vietnam.) Implements might include special drills for direct-sowing into mulch without seedbed preparation, harvesters with special tools for optimal straw distribution on the soil surface, and equipment for weed and pest control. Some more specialized "conservation agriculture" implements were called e.g., for harvesting potatoes⁶ with minimal soil disturbance.

Some of these implements have long been available in southern Brazil. No-till drills are becoming generally available in the Indo-Gangetic Plains. Some conservation agriculture implements are also said to be generally available in most European countries (Norway, Denmark, Germany, France, Spain, Italy) although particular implements or implements adapted to particular slopes in the Mediterranean may be difficult to find and are often rather costly. Implement availability appears to be even more of a problem in the Eastern European countries (Ukraine, Czech Republic and Estonia) studied by KASSA.

The importance of small-scale farmer access to conservation agriculture implements was raised several times, for the most part in the context of southern Brazil, Europe, and South Asia. Animal-traction no-till drills have been developed for small scale farmers in Brazil. In South Asia, the renting in by small farmers of no-till services has become customary. It remains to be seen how the situation in Europe will unfold.

2.8. Lack of subsidies and credit facilities

The transition from conventional to conservation agriculture usually requires investment in new equipment, as noted above. Subsidy and credit programs for implement purchase may serve as drivers of conservation agriculture adoption. The absence of these programs, however, may constrain adoption, especially by small-scale farmers.

⁶ There is experience of conservation agriculture in Sichuan Province in China, where potatoes are grown on the soil surface under a very thick cover of rice straw. Potato harvest does not result in any soil movement.

The Latin American platform team noted that:

"In the poorest areas agriculture is subsistence oriented without surplus production that would allow making investments for improvement of soils and crop yields. Some successful examples of programmes oriented to small-scale farmers in Brazil could be a reference for other countries. These programmes included the provision of credit at low interest rates and oriented to farmers groups. [sic]"

The Mediterranean team warned, however, that subsidies or incentives for conservation agriculture should be used to underwrite its effectiveness in fostering soil and water conservation. There is a public interest in resource conservation. Some compensation to farmers for these long-term social benefits might be in order. They further note that:

"The interest of the EU, national and local administrations and policy makers in CA are very variable and do not often respond to long-term requirements for CA systems to be developed and adopted. Current policies promoting CA in European Mediterranean countries should change towards natural resources - soil and water-conservation, yield stability, and sustainability of agricultural systems more than to increase the productivity."

Finally, the European platform team indicated that for financially-stable farms in Western Europe, external financial support for conversion to conservation agriculture is generally not necessary. Small-scale farmers, however, may need such assistance. Examples were given from eastern Germany and the Ukraine.

2.9. Lack of knowledge

Even the most perfectly adapted conservation agriculture technologies have little impact if not widely used by farmers. A lack of farmer information and knowledge regarding these technologies can be an important constraint. This was observed by the Mediterranean platform team, with respect to:

"Lack of information and technical advice about CA technologies taking into consideration site-specific social, economic and environmental aspects . . . lack of information on the time needed to reach a complete adaptation or stabilization of the CA based cropping system (transition phase) . . . [and] on crop rotations performance)."

In Bolivia, mainly in the subtropical region, the Latin American team describes a situation of contradictory and incomplete information, both for farmers and technicians.

"Rural extension is very weak, technicians are not convinced by the benefits of CA and technical messages for farmers are not clear. In the tropical area, there is also a lack of scientific information mainly for small-scale farmers. Moreover, in some regions where local languages predominates among farmers and the high unliterary also hinders the farmers' access to external information."

In Europe, the situation is very much mixed. In Denmark, the Agricultural Advisory Service (a private farmer-funded national-level organization) employs 16 specialists in the use of reduced tillage implements to assist farmers with problems. Moreover, the 288-member Danish Reduced Tillage Farmers Union shares advice and experiences of equipment over public media, such as the internet and local radio. In

France, on the other hand, the European platform team reports the presence of a lobby against some conservation agriculture practices, which is said to stifle the free exchange of information.

Although improvement is always possible, it appears that in Brazil and Argentina, information on conservation agriculture is widely available. In the Indo-Gangetic Plains, information on wheat no-till is circulating swiftly, but information on other conservation agriculture practices has not yet been widely distributed.

2.10. Agricultural research policies

It was noted above that suitable agricultural research policies can serve as drivers of conservation agriculture (e.g., research through partnerships within a broader innovation system, the use of multidisciplinary approaches and systems thinking, the reorientation of technology component development for use in conservation agriculture systems.)

In the same way, unsuitable policies can serve as constraints. In Latin America, the spread of conservation agriculture may have been slowed by conflicting messages emanating from research institutions (burn crop residues for disease control – but also retain them for mulch!), by the slow speed with which some research institutions joined the conservation agriculture innovation system, and by an unwillingness to engage in cross-disciplinary, problem-solving research using systems thinking. Similar constraints have no doubt occurred (and continue to occur) in other regions and countries.

2.11. Socio-cultural issues

Experience shows that – despite information on the effectiveness of conservation agriculture practices – farmers are often very reluctant to even try them. This appears to be a near-universal problem, occurring in the US and Europe as well as in the Punjab of Pakistan or the tropical lowlands of Bolivia. This reluctance can have its roots in tradition, culture or religion (e.g., Mennonite farmers in Bolivia) – or simply habit and peer pressure. Attitudes prejudiced against conservation agriculture are not only found among farmers – they can also be found among policymakers and, scientists and extension workers. The only way forward is to relentless provision of new information on conservation agriculture, especially when a crisis emerges for which conservation agriculture can help.

3. Drivers and constraints – a summary

KASSA platform teams tended to discuss drivers of conservation agriculture, and constraints to its use, as if they were wholly different categories. In fact, most drivers can become constraints and most constraints can become drivers. A unified list of drivers and constraints, drawn from the above discussion, is provided in Table 5. This initial list served to assess/anticipate the suitability of conservation agriculture and opportunities and challenges to its development in the regions analysed by KASSA.

Table 5. A unified list of drivers and constraints (not ranked) for conservation agriculture

Farm and market conditions	Reduced/ increased production costs
	More/ less flexibility and improved timeliness of operations
	More/ less diversification and enterprise selection
	Use/ lack of cover crops
	Use/ lack of suitable rotations for integrated pest, weed, disease control
	Suitable / scarcity or excess amounts of residues
	Weak / strong crop-livestock interactions
	Reduced/ increased soil erosion and resource degradation
	Improved/ reduced water productivity (apply to water-scarce agroecosystems)
Biophysical conditions	Favourable/ unfavourable climate
	Favourable/ unfavourable soils
Social, cultural, technological, institutional, and policy environments	Presence/ absence of a crisis mentality
	Absence/ presence of socio-cultural barriers
	Leadership/ lack of leadership from farmers and farmer organisations
	Ready availability/ lack of conservation agriculture implements
	Presence/ absence of dynamic and effective innovation system
	Availability/ lack of knowledge regarding conservation agriculture
	Presence/ absence of policies for training, communication and support for farmers' initiatives
	Policies affecting farm size, agrarian structure and land tenure
	Appropriate/ inappropriate agricultural research policies
	Favourable/ unfavourable macroeconomic policies
	Favourable/ unfavourable agricultural sector policies
	Presence/ absence of suitable subsidies and credits to facilitate conservation agriculture
Impact of conservation agriculture on health and on the environment	Reduced/ increased pressure of weeds, pests and disease
	Reduced/ increased pollutions
	Impact of conservation agriculture on human health known/ not known

Indeed, it seems relatively difficult to introduce conservation agriculture when:

- The technology is less profitable for farmers. This is generally the case when the unit production costs are increased, when the use of cover crops and agronomically sound rotations increase costs but produce few benefits; and, when pest, disease or weed problems are increased. In the absence of an integrated management strategy, increased incidence of pest, diseases or weed calls for two possibilities: *i*-increased use of pesticides which impacts farm economics and harms the environment and the food chain, and may lead to the emergence of resistance issues; and *ii*-the use of conventional technologies such as soil tillage, residue burning...
- Knowledge is lacking. Conservation agriculture technologies cannot develop and spread when farmers and technicians have little knowledge about them, or have cultural barriers that discriminate against their use. This is generally the case

where policy and governance conditions do not encourage the emergence of dynamic innovation systems for knowledge generation and sharing.

- Suitable implements are not available. Adapted and affordable implements are necessary for the success of conservation agriculture. The main countries adopting conservation agriculture have developed their own implements; it is often the result of a close collaboration between industry, farmers and research.
- Biophysical conditions are not favourable. In cold sandy and silty soils and in heavy clayey soils prone to waterlogging the use of soil cover and no-till result in cooler soil temperatures, delayed sowing, and depressed yields; this is the case in wet cold temperate regions. No-till is not suitable for soils prone to compaction. In dry lands and under rainfed conditions, shallow soils are not suitable due to their poor water holding capacity. Conservation agriculture technologies are generally unsuitable where soil cover from crop residues is either inadequate (dry lands conditions, livestock competition for biomass) or in excess (wheat straw in temperate climate, rice straw in rice-based systems).

This initial list may also be cautiously tested in other regions and, further research may help complete/improve it and assess its usefulness.

IIIc.

KASSA research results – Scientific knowledge acquired regarding conservation agriculture in ecosystems of interest

This section introduces the central theme of impacts. What happens when widespread adoption of conservation agriculture is achieved? In the sections that follow, information that was acquired during the KASSA project will be summarized with regard to the consequences of conservation agriculture adoption for production costs and livelihoods, soil and water resources, and the environment. Where widespread adoption has not occurred, some cautious inferences will be made, based on results from various research outcomes.

1. Adoption

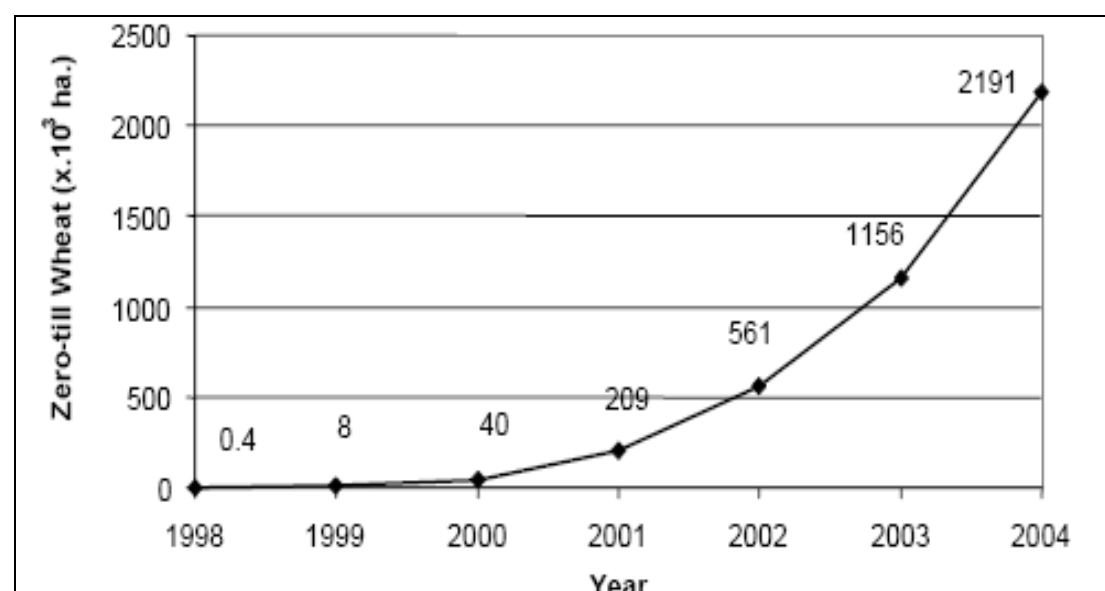
A summary of information on conservation agriculture adoption in different agroecosystems, as acquired by the KASSA project, was presented earlier. Evidence for substantial adoption of conservation agriculture components was presented for four agroecosystems: multiple cropping on undulating lands under high rainfall in southern Brazil and Argentina; crop – pasture systems in the Cerrados of Brazil; wheat – soybean and related systems in lowland Bolivia; and rice-wheat and related systems in the Indo-Gangetic Plains. The actual area covered by conservation agriculture in the first two of these examples is immense. Data from the Latin American platform team shows the very large proportion of farmed area currently covered by these practices (Reproduced below as table 6).

Table 6. Adoption of conservation agriculture in Latin America (% of farmers)

		Argentina	Bolivia	Brazil
Tropical	Small-scale	-	40	5
	Large-scale	-	80	40
Subtropical	Small-scale	0	-	50
	Large-scale	55	-	75-80
Temperate/Central humid	Large-scale	70	-	-
Temperate/Sub humid	Large-scale	50	-	-

Quantification was provided by the Asian platform team regarding the recent swift adoption of zero till wheat after rice in the Indo-Gangetic Plains (Figure 4). Perhaps the most impressive thing is that the rate of adoption continues to accelerate – it has not yet begun to flatten out, even after having passed the 2m ha mark.

Figure 4. Adoption of wheat zero till after puddled rice in the Indo-Gangetic Plains, 1998-99 to 2004-05 (m ha)



The absence of conservation agriculture adoption was confirmed for lowland and upland agroecosystems in Vietnam. Adoption levels in Mediterranean countries remain unclear. Little adoption was confirmed for northern Europe – the platform team presented a table (reproduced below as Table 7) that vividly illustrates this point.

Table 7. Number of farms and average farm size for conservation agriculture and organic farming for various countries

Country	General		Conservation Agriculture		Organic farming	
	No of Farms	ha/Farm	No of Farms	ha/Farm	No of Farms	ha/Farm
Czech Republic	-	-	-	-	-	-
Denmark	48,750	53	-	-	3,510	48
Estonia	36,859	22	-	-	810	57
France	600,000	70	-	-	-	-
Germany ³¹	420,697	44	-	-	16,476	45
Norway	55,697	19	-	-	2,484	-
Ukraine	53,000	800	-	-	-	-
UK	304,800	69	-	-	3,995 ³²	174

Other sources (not cited in platform reports) provide detailed estimates for area under no-till for different regions and countries, including some of those covered by

KASSA (Table 8)⁷. Except for possible anomalies in France and Spain, these data tend to independently confirm platform reports.

Table 8. Extent of no-tillage adoption worldwide (as summarized in Derpsch, 2005).

Country	Area under No-tillage (ha) 2004/2005
USA ¹	25.304.000
Brazil ²	23.600.000
Argentina (*) ³	18.269.000
Canada ⁴	12.522.000
Australia ⁵	9.000.000
Paraguay ⁶	1.700.000
Indo-Gangetic-Plains (**) ⁷	1.900.000
Bolivia ⁸	550.000
South Africa ⁹	300.000
Spain ¹⁰	300.000
Venezuela ¹¹	300.000
Uruguay ¹²	263.000
France ¹³	150.000
Chile ¹⁴	120.000
Colombia ¹⁵	102.000
China ¹⁶	100.000
Others (Estimate)	1.000.000
Total	95.480.000

Sources: 1) John Hassel CTIC, 2005; 2) FEBRAPDP, 2005; 3) AAPRESID, 2004; 4) Dr. Doug McKell, Soil Conserv. Council of Canada, 2004; 5) Bill Crabtree, WANTFA, 2005; 6) MAG – DEAG, Soil Conservation Program, 2005; 7) Dr. Peter Hobbs & Raj Gupta 2005; 8) Carlito Los, 2005; 9) Richard Fowler, 2003; 10) ECAF Homepage, 2005; 11) Rafael E. Perez, 2004; 12) Miguel Carballal AUSID, 2005; 13) ECAF Homepage, 2005; 14) Carlos Crovetto, 2005; 15) Fabio Leiva, 2005; 16) Li Hongwen, 2005;

(*) Preliminary information based on 40% of data collection for 03/04

(**) Includes four countries in South Asia, India, Pakistan, Bangladesh and Nepal.

⁷ Derpsch, Rolf. 2005. The extent of Conservation Agriculture adoption worldwide: Implications and impact. Keynote paper for the III World Congress of Conservation Agriculture, Nairobi, Kenya, 3-7 October, 2005.

2. Consequences of conservation agriculture adoption for production costs, income and employment

On the surface, the socioeconomic impacts of conservation agriculture appear quite straightforward. All platform teams agree that no-till reduces labour, machinery and fuel costs, and that cost reduction is a principal driving force in adoption decisions. And the mere fact of adoption seems to indicate that the practices are adequately profitable for adopting farmers. These simple statements, however, mask a good deal of complexity.

2.1. Production costs

KASSA platform teams did not provide complete data sets for comparing production costs with vs. without conservation agriculture. Rather, they provided data only for those cost categories most likely to be affected by the adoption of conservation agriculture. This partial budget approach is probably adequate to compare conventional vs. conservation agriculture technologies for similar rotations or enterprises. A more thorough analysis (not provided) would have been advisable, however, to assess costs and returns when rotations or crop mixtures are modified.

Cost categories for which information was provided include the following: equipment costs (in principle including the costs of depreciation, interest, repairs and fuel); labour costs; input costs for weed and pest control; and soil fertility management costs.

The Mediterranean platform observed simply that “. . . the general motivation of the farmers for the introduction and adoption of CA technologies has been the reduction of costs in machinery and fuel and time-saving in the operations that permit to develop other agricultural or non agricultural complementary activities . . .” The Latin American team referred to studies that “. . . have shown that conservation agriculture promotes a reduction of 46% in the total hours of equipment and machinery use due to no ploughing and harrowing. Thus a [similar] reduction in the consumption of fuel and other lubricants is also observed.” The European platform team presented estimates from several countries on fuel and labour costs for crop establishment using full tillage, reduced tillage, and no-till direct-sowing (see table reproduced below as Table 9). These estimates give a further sense of the magnitude of cost-savings to be gained.

Table 9. Fuel and labour costs for ploughing, reduced tillage and direct-seeding in Germany, Denmark and France

		Ploughing	RT	DS
Fuel consumption (L/ha)	Germany	35	14 to 25	6
	Denmark	40/50	18 to 35	
	France	Clayey soil: 75 to 105 Clay/loam soil: 26 to 38	Clayey soil: 18 to 29 Clay/loam soil: 12 to 25	12 to 24
Labour (h/ha)	Germany	2	0.8 to 1	0.4
	Denmark	2/3	1.1 to 1.7	0.8 to 1
	France	2	1.5	0.5 to 1

The Asia platform team presented information on fuel savings from no-till for the Indo-Gangetic Plains – with an unusual twist. They found that no-till reduced fuel costs for wheat crop establishment by \$36-47 per ha in Pakistan, and about \$50 per ha in Haryana State, India. But they also found that no-till led to lower fuel costs for the pumping of irrigation water. It appears that water covers a no-till laser-levelled field faster than a fully tilled field and that less water is required, at least for the first irrigation.

Note that the above data almost certainly underestimate machinery cost savings associated with a shift to conservation agriculture. Platform teams provided information on fuel costs while largely ignoring the equally important categories of depreciation, interest and repairs. Other things being equal, tractors and implements used for conservation agriculture last longer than those used for conventional agriculture, so annualized depreciation and interest costs are lower. And because they get less wear and tear, annualized costs for repairs are similarly reduced. These are the data needed to get proper estimates of returns to farmer investment in new no-till implements.

The transition to conservation agriculture affects more than just machinery costs – it can also affect input costs. An important question is the extent to which reductions in fuel and other machinery costs are offset by increased costs for herbicides, pesticides and fertilizers. Different platform teams provided different answers.

The adoption of conservation agriculture is likely to generate changes in the mixture of weeds, pests and diseases affecting crops. The Latin American team asserted that, “For weeds, insects and diseases management, crop rotations are the pillar of any IPM/IWM program; if crop rotations are not used in conservation agriculture; the reliance on chemicals is higher, resulting in higher costs and negative environmental consequences”. This assertion was supported by data from Germany (shown below in table 10) provided by the European platform. These data indicate that, for some crops, cost savings from no-till are partly (but never entirely) offset by increased herbicide costs. In contrast, the Mediterranean team simply stated that, “From a socioeconomic impact point of view, conservation agriculture implies a reduction in the cost of direct inputs”.

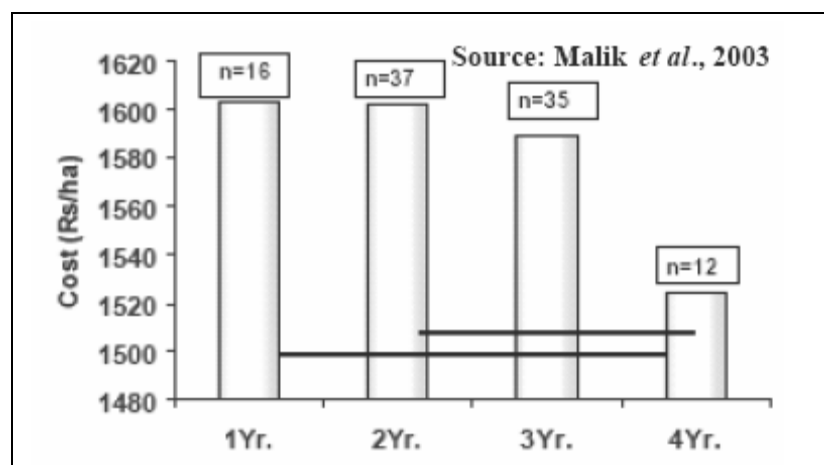
Table 10. Reduction in costs for conservation tillage and additional expenses for plant control compared to conventional plant production in different farms of the state Saxony with loess soils – Average 1994-2003

Crop	reduction of costs at soil tillage (€ / ha)	additional expenses at plant control (€ / ha)		
		herbicides	fungicides	control of slugs/ mice
winter wheat	100 – 120	+ 25	no	+ 20
winter barley	100 – 120	+ 50 bis +70	no	no
winter rye	110	no	no	no
triticale	110	+70	no	no
spring barley	110	+70	no	no
winter rape	100 – 120	+ 50 bis +70	no	+ 20 bis 40
sugar beet	100	+ 50	no	no
potatoes	250	no	no	no
corn	100 – 150	+ 50	no	no
grass for food	120	no	no	no
grass for reproduction	120	no	no	no

Agrarbericht Sachsen, 2003

Information provided by the Asia platform team, however, allows different conclusions to be drawn. They found that the adoption of wheat no-till after rice in the Indo-Gangetic Plains actually helps control a major problem weed (*Phalaris minor*). Adoption of no-till resulted in a decrease in herbicide use over time because weed germination gradually dwindled. The data used in support of this conclusion are shown in the figure 5, below.

Figure 5. Effect of zero tillage practice on investment on herbicides over four years



The adoption of conservation agriculture is likely to lead to adjustments in strategies for soil fertility management. However, it is not clear whether the new strategies will increase or reduce costs. The Latin American platform team noted that:

“Research developed under CA, in Latin American Platform, has shown that the rate, placement and timing of fertilization and soil acidity correction by limestone and consequently nutrients dynamics are altered by adoption of no-till system. Some nutrients concentrate on the surface layers, increasing the risk of loss by runoff, while others are lost by leaching. In addition, by eliminating soil tillage the availability of nutrients to plants is increased. So, the recommendation of fertilizer and limestone for different crops . . . that were developed for conventional tillage, require adjustment for rate, placement, and timing.”

This issue is further complicated by the use of green manure cover crops to modify soil fertility and, incidentally, to help control weeds. The Latin American team, citing examples from the Cerrados of Brazil, showed how green manures in crops could be used to re-establish pastures with no extra cost. The European platform, however, observed that cover crops are not used in northern Europe because of their additional expense.

It appears, then, that platform teams were unable to bring this issue to closure. Further information and more thorough analysis are needed to estimate costs and returns to soil fertility management strategies that include new rotations, green manure cover crops, and changes in rates and management of inorganic fertilizers. In some situations, new strategies may increase costs while in others production costs may go down.

There is one further complication in assessing the consequences for production costs of introducing conservation agriculture – the structure of costs actually evolves over time, particularly during the “transition period”. The European team asserted that,

“During transition period, the yields are generally lower or instable. During this time, the farmer has to learn to asses the new situations in growing crops. The costs for pesticides are often increased during this period.”

It was the Latin American team, however, that provided the most detailed commentary on this point. Unfortunately, no quantitative estimates accompanied these insightful comments.

“During the first phase of the process (improvement of tillage techniques) expenditures in chemical inputs for weed and disease control may offset gains from diminished labour and machinery demands. In the second phase (improvement of soil conditions and fertility) reduced production costs from less labour and machinery requirements may lead to an increase in farm net income obtained through higher yields. The third phase (diversification of crop pattern) should bring increased and more stable yields, higher soil fertility and a decrease in plant protection costs resulting in more gains in net farm income . . . in the fourth phase (integrated farming system) crop output and productivity would be stabilized.”

One further word of caution is in order. The discussion above was narrowly focused on direct farm-level production costs. But other costs may be important, among them environmental and social costs that do not directly impinge on farmer decision-making.

2.2. Incomes

Estimating impacts on incomes and employment is even more complicated than estimating impacts on production costs. Unfortunately, there were few references in platform reports to the effects on incomes or employment from adoption of conservation agriculture.

At the broadest level of analysis, the important question is, “whose incomes”? Widespread use of conservation agriculture could conceivably have consequences for the incomes of:

- Poor urban consumers (whose real incomes are increased when food prices go down and vice versa);
- The rural non-farm commercial and service sector (whose incomes are driven by the purchasing power of farm families);
- The rural landless poor and small-scale farmers (whose incomes often depend on on-farm employment);
- Farm families themselves.

To the extent that KASSA teams analyzed these issues, they focused largely on farm families, with some limited attention to issues of employment.

As mentioned in an earlier section on farm-level drivers of conservation agriculture, farmers, on average and over time, tend to adopt new practices that increase farm-level, near-term profitability and/ or reduce risk. Other things being equal, improved profitability depends on some combination of higher yields and/or output prices, lower costs, or improvements in “enterprise selection” (decisions on crop or livestock enterprises). Of these, production costs were discussed above. Output prices are influenced by policies, institutions, marketing margins, and aggregate supply and

demand – none of which (with the possible exception of aggregate supply) are necessarily influenced by conservation agriculture. What have we learned, then, from KASSA platform reports on the effects of conservation agriculture on crop yields and enterprise selection?

In agroecosystems in southern Brazil, the introduction of conservation agriculture had huge impacts on crop yields and enterprise selection. Without it, multiple-cropping of annual crops would have been impossible. Either soils would have swiftly degraded, resulting in large yield losses, or annual cropping would have been abandoned and lands would have reverted to pasture. If – as seems likely – net benefits per ha from annual multiple-cropping are higher than net benefits per ha from livestock management, then farm family incomes are higher than otherwise would be the case. A similar argument can be made for the Cerrados.

In the Indo-Gangetic Plains, the situation (once again) is somewhat different. Rice-wheat systems were not in imminent peril of collapse from land degradation and the adoption of no-till was spurred by cost savings, not as a last ditch effort to preserve annual cropping. But, as it happens, no-till wheat turned out to yield more than conventional till wheat, for two reasons: more timely sowing (resulting in better use of residual soil moisture, avoidance of late-season heat stress, etc.); and better stand establishment. As noted by the Asian team:

“On average, based on many monitored zero-till farmer fields in India, yields of zero-till wheat are from 2-400 kg/ha more (Malik, 2002). At \$100 per ton that works out to \$20-40 per hectare extra income. Gill and Ahmed (2003) in Pakistan showed a 500 kg increase in yield from fields they monitored.”

Understandably, this combination of lower costs and higher yields is proving irresistible to farmers.

No-till also helped foster diversification (changes in enterprise selection) by increasing flexibility in sowing dates and reducing the “downtime” between the harvest of one crop and the sowing of the next. In the eastern Plains, the introduction of no-till can facilitate the sowing of a cool-season crop after rice, in areas where it hitherto had been impossible to do so. Stronger and more detailed quantification of this process, however, is needed.

2.3. Employment

It has been seen that the introduction of conservation agriculture often saves labour costs. But whose labour is “saved”, and what alternative employment opportunities exist?

In the case of small – scale farmers in southern Brazil, the introduction of conservation agriculture improved labour productivity but reduced labour requirements in agriculture, thus encouraging farm family members to seek other employment alternatives:

“Studies indicate that only farmers who will have part of their income originated from non-agricultural activities will be economically viable . . . For instance, in the State of Paraná (Brazil), 27% of the farms have already incorporated non-agricultural activities such as home employees, hotel workers, clubs, shops, hospitals, schools, and industries for processing of agricultural products (dairy, meat, fruits).”

In northern Europe, employment issues are also seen as important.

“On the surface, reduced labour costs on the farm represent a direct financial gain to the farming business – but require alternative employment opportunities. For farmers managing large units this may well be a decisive factor in favour of conservation agriculture – but for many family farmers that operate under marginal conditions this would mean they would have to supplement their own incomes through finding alternative ways of employment in their own locality.”

Nonetheless, it is important to keep a sense of perspective. In northern Europe, agricultural employment represents only a small proportion of the total. New employment opportunities for displaced agricultural labour are determined by the overall structure of labour markets and the policies that govern them. They do not wholly depend on new employment generation within agriculture.

The consequences of conservation agriculture for employment in the Indo-Gangetic Plains appear to be more sensitive than for other agroecosystems studied by KASSA. Populations are larger, absolute poverty is more widespread, and the rural landless – who depend heavily on employment in agriculture – are more numerous. For the no-till wheat technology itself, it appears that labour displacement is minimal because many small-scale farmers rent-in tillage and establishment services from service providers. As no-till practices move into the eastern plains, however, where animal traction tillage is more common, labour displacement may become more of an issue. But at the same time, no-till has been seen to facilitate labour-intensive agroecosystem diversification. For any particular locality, it is unclear whether employment generation from diversification will exceed labour displacement.⁸

There are two new resource conserving technologies that may have more dramatic consequences for employment. These are direct-sown aerobic rice systems, and permanent bed and furrow systems with crop residue cover. Neither of these has as yet been widely adopted by farmers although participatory action research with farmers is proceeding and some early adoption is taking place.

Direct sown aerobic rice has the potential to displace rice transplanting labour. In the eastern plains, rice transplanting is often performed by women. Elsewhere, transplanting is typically performed by teams or gangs of migrant labourers who move from farm to farm offering their services. Ironically, a principal incentive for farmers to invest in direct-sown rice is a continued rise in rural wages that is now making hand transplanting very expensive. But the potential for labour displacement is clearly present, and (judging by KASSA platform reports) the issue has not been studied in detail.

In contrast, permanent bed and furrow systems with crop residue cover have the potential to generate additional employment at the largest possible scale. These systems offer many new opportunities for employment-generating system diversification, e.g., “to replace rice with extra short duration pigeon pea (ICPL 88039) or Quality Protein Maize; to enable inter-cropping of sugarcane with wheat,

⁸ In the western Indo-Gangetic Plains, those who appear to have been most harmed by the introduction of no-till wheat are larger farmers, heavily invested in conventional tillage equipment, who previously had rented out tillage and establishment services. As the demand for these services has evaporated, they are increasingly hard pressed to repay the bank loans taken out for conventional tillage implement purchase.

chickpea, or Indian-mustard; of winter maize with potatoes, peas or vegetables; and of winter wheat with mint.”⁹

3. Consequences of conservation agriculture for soil and water resources

The biophysical processes are reasonably well known whereby conservation agriculture can (in principle) increase soil organic matter and biological activity, improve soil fertility, enhance structure stability, and conserve water resources. However, there is considerable variability across platforms and agroecosystems regarding the relative importance of different issues, and whether conservation agriculture is actually being used to address them.

3.1. Water resources and water productivity

In many water-scarce environments, there are great expectations that conservation agriculture can help enhance water productivity, finally allowing the large increases in agroecosystem productivity that have long been desired. For rainfed environments, this vision has inspired work on conservation agriculture in such disparate locations as eastern and southern Africa, western China, semi-arid regions in India and Pakistan, large areas in central and western Asia, and the western highlands of Mexico. For irrigated systems, they have driven work on no-till and related technologies in the Indo-Gangetic Plains, the Yellow River basin in China, irrigated areas along the Amu Darya and Syr Darya rivers in Kazakhstan, Uzbekistan and Tajikistan, and similar environments.

Before proceeding, however, it might be useful to briefly review the concept of water productivity.

Resource productivity is an output-input relationship. In the context of water use in agriculture, water productivity is defined as agricultural output per unit of water depleted. Water productivity in agriculture depends on the product being produced, the production system and associated practices, and the biophysical environment. Crop water productivity is a measure of the ratio of crop outputs and services per unit volume of water depleted. Similarly, livestock water productivity is a measure of the ratio of livestock outputs and services per unit volume of water depleted.

The denominator of the “product/water” ratio can be expressed as total seasonal rainfall, irrigation water diverted or water depleted through evapotranspiration – whichever is most appropriate for the production system in question. Estimates of the denominator typically require a water accounting system to keep track of inflows, flow paths, processes, and outflows of water. Water depletion is estimated in similar ways regardless of whether the water is used in crop production, livestock or fisheries production, urban and industrial use, or for environmental services. In all cases, the amount of water depleted is that made unavailable for reuse, e.g., through evaporation, contamination or flow to a saline sink.

⁹ Experimentation with bed and furrow systems have also shown their potential to reduce irrigated water use by 30-40%, while improving yields, avoiding waterlogging, and reducing lodging. Within South Asia, there is a great deal of interest in the further development of these systems.

Input productivity increases in importance when the input is scarce or expensive. Labour productivity is of greatest concern when labour is scarce. Fertilizer use efficiency becomes more important when fertilizers are expensive. Similarly, water productivity is most important in water-scarce environments. In the lowlands of northern Vietnam, where farmers must struggle with problems of waterlogging and drainage, the question of water productivity is not given a high priority. In contrast, for water-scarce rainfed areas in the Mediterranean, water productivity is arguably the most important issue of all.

In the context of the KASSA project, then, what have been the impacts of conservation agriculture technologies on water productivity in agroecosystems of interest? Water scarcity is a major problem – and therefore water productivity is a critical issue – in only two of the agroecosystems studied by KASSA: rainfed systems in the Mediterranean, and irrigated systems in the Indo-Gangetic Plains.

In the Mediterranean, platform team reports note that “. . . CA in semiarid conditions reduces water loss from soil surface and enhances organic matter accumulation . . .” and that “. . . Conservation agriculture increases water infiltration into the soil and improves water use efficiency, especially in rainfed farming areas . . . Crop residue management is the basis of CA and improves soil protection, fertility and humidity . . .” To the extent that conservation agriculture reduces unproductive evaporation, or cuts back on water pollution associated with soil erosion, then water productivity is increased.

In the Indo-Gangetic Plains, issues that may affect water productivity are far more complex, potentially including groundwater management, tubewell pumping and groundwater depletion, irrigation canal system management, drainage systems and salinization, conjunctive water use and cross-basin water transfers, etc.

No-till wheat improves farm level water productivity by increasing yields while decreasing water depletion (output/ input ratio goes up). This is also true at the watershed and river-basin level of analysis when the water that is not pumped would otherwise have ended up in a saline sink. The Asian platform team presented abundant evidence regarding the even stronger improvements in water productivity that can be obtained from the use of ridge and furrow systems in the production of lowland rice and virtually any upland crop.

3.2. Soil chemistry, biology, physics and nutrient cycling

Efforts to describe the effects of conservation agriculture on soil properties quickly get entangled in the strong interactions among soil chemical, biological and physical properties. These are indeed difficult to sort out.¹⁰

Most platform teams mentioned the effects of crop residues and other sources of soil cover on soil organic matter and soil fertility. The Asian team noted their role in replenishing soil organic matter, which in turn supplies essential plant nutrients as it mineralizes. The Latin American team was somewhat more specific, observing that, “The quantity and flux of organic material produced by the agricultural production

¹⁰ This is explicitly recognized in the “soil nutrition principle” mentioned by Argentinean scientists. This principle calls for an evolutionary approach to soil fertility research that takes account of dynamic interactions among soil chemistry, soil biology, soil organic matter, structural properties, and nutrient cycling.

system governs factors such as the biological activity of the soil, the production of secondary organic compounds, aggregation of soil particles and other, less well-defined, emergent soil properties all of which contribute considerably to total soil fertility.” But there are areas in cooler climates where organic matter fluxes are so very slow that no-till can actually cause problems:

“ . . . In Nordic areas where the conditions for decomposition of accumulated plant residues on soil surface or in superficial layer is limited due to low temperature, low biological activity and anaerobic conditions, additional manipulation are needed to increase decomposition intensity.”

The Latin American team specifically claimed that no-till improves biological nitrogen fixation, “. . . it was observed, in Paraná state, that the number of *Rhizobium* and *Bradyrhizobium* cells and the accumulation of flavonoids (nodulation genes inducers) were superior under no tillage . . .” Work from Argentina is said to show a relationship between no till and an increase in microbial biomass carbon in at least two kinds of soil.

No till is also said to affect the way in which inorganic soil amendments should be managed:

“Research developed under CA, in Latin American Platform, has shown that the rate, placement and timing of fertilization and soil acidity correction by limestone and consequently nutrients dynamics are altered by adoption of no-till system. Some nutrients concentrate on the surface layers, increasing the risk of loss by runoff, while others are lost by leaching. In addition, by eliminating soil tillage the availability of nutrients to plants is increased. So, the recommendation of fertilizer and limestone for different crops used in various production models that were developed for conventional tillage, require adjustment for rate, placement, and timing.”

With regard to this issue, the European team observed that plant nutrient dynamics and availability within the soil profile can indeed be altered by conservation agriculture – usually resulting, however, in an increased demand for mineral nitrogen (at least in the initial stages of transformation from conventional to conservation agriculture).

Although conservation agriculture and no-till can affect soil organic matter and ultimately soil chemistry, these effects tends to be concentrated near the soil surface. The European team was content with merely noting that, “. . . the effects of reduced tillage on chemical properties mainly appear through the establishment of a vertical gradient of the distribution of chemical compounds”. In contrast, the Latin American team went into much more detail:

“ . . . [no till] creates a much more favourable environment on those first millimetres of the soil profile where a large amount of chemical and microbiological activity takes place . . . the stratification of SOM observed under no tillage systems associated with increased levels of soil moisture and smaller variations in temperature, due to soil cover, reflects directly upon the soil microbial community, which has its total microbial biomass and activity more concentrated in the first centimetres of the soil profile as well. For this reason the biological functioning of soils under no tillage systems is completely different of that found in soils under conventional tillage.”

Platform teams unanimously mentioned an increase soil flora and fauna as a result of the introduction of no-till. The European team stated this in vivid terms,

“The benefits of reduced tillage intensity on soil fauna seem obvious: ploughing may be regarded as an elementary catastrophe for soil fauna because of the destruction of the mulch, plant residues or cover crops that protect the soil surface and deliver food for soil organisms . . .”

Observers in Asia and Europe noted an increase in the abundance and biomass of earthworms when tillage intensity was reduced. The Asia team also noted improved biological activity and diversity in the soil, including natural predators and competitors.

With regard to soil structure and soil physics, the principal main issue is that of compaction in light textured soils and waterlogging in heavy textured soils. The European team expressed concerns that farmers may not have enough time or resources to properly monitor soil structure in their fields – especially if they hire-in private contractors to seed and harvest.

Compaction was also seen as an issue in Latin America, where the team observed that,

“Under no-till system in various agro ecological conditions, the farmer has the perception and different soil studies have shown development of compacted layer. This compacted layer, characterized by increased soil bulk density and soil resistance to penetration, and reduction of macro pores and total porosity, restricts water fluxes, air diffusion, and plant root development. Chisel ploughing has not been a solution for this problem. The use of crops in the production models that don’t add organic material higher than the decomposition rate may be the main cause of this problem under no tillage.”

In Asia, problems of soil structure and compaction are largely driven by soil puddling for lowland rice cultivation. As noted earlier, this very much limits the extent to which residues may be retained and cover crops used within crop rotations.

Finally, the platform teams called for the development of soil maps, databases and decision support systems to help match conservation agriculture practices to soil and water conditions.

4. Consequences of conservation agriculture for the environment

For some stakeholders, the use of conservation agriculture to reduce the negative consequences of agriculture on the environment is even more important than its use to improve the profitability of the farm business. For these people, there is great interest in the potential of conservation agriculture to reduce soil erosion, soil and water pollution, and greenhouse gas emissions. Here are some of the anticipated impacts of conservation agriculture on the environment, as assessed by platform teams.

4.1. Soil erosion

Erosion as a problem is most serious in the two high rainfall hillside systems: the undulating landscapes of southern Brazil and the sloping lands of northern Vietnam. There are also references to water and wind erosion as problems in the Mediterranean

agroecosystems and in northern Europe. There may more subtle processes of erosion at work in irrigated systems in the Indo-Gangetic Plains and northern Vietnam. As the Asian team noted,

"In the Indo-Gangetic Plains the soils are deep and erosion process being insidious this aspect has not deserved the desired attention. High intensity monsoon rains concentrated in a span of about 100 days cause heavy soil losses with adverse on site and off site impacts."

Southern Brazil provides the quintessential example of using soil cover to control erosion. The Latin American team observed, in reference to this area, that,

"The adoption of CA by farmers is by far the most widespread in Brazil. Here, the extensive erosion/soil degradation from widely practiced continuous summer soybean/winter wheat rotations in the 1970s and 80s initially convinced many southern Brazilian farmers to shift their production paradigm towards promoting better soil conservation . . . by keeping the soil covered with a straw layer and sowing directly with minimal soil disturbance . . . CA reduces soil erosion and the runoff of water, soil sediments and organic matter to rivers and small streams."

Even in Brazil, however, some caution is in order. Many farmers and technicians have come to the conclusion that soil cover is sufficient to control erosion; terraces and other erosion mitigation techniques have been discarded. What is often overlooked, however, is that conservation agriculture practices have resulted in a concentration of nutrients near the soil surface. And, there is evidences (Table 11) showing that intensive rainfall events can lead to unexpectedly high rates of nutrient loss at certain locations in farmers' fields.

Table 11. Chemical attributes at the original soil and at the sediments produced for intense rainfall in an area with no tillage management system, showing the enrichment of the eroded sediment.

Attributes	Concentration	
	Soil ¹	Sediment
pH in H ₂ O	6.4	6.6
Ca (mmolc/dm ³)	34.0	44.0
Mg (mmolc/dm ³)	56.0	60.0
P (mg/dm ³)	34.0	72.0
K (mg/dm ³)	270.0	609.0
Organic matter (%)	2.9	7.3

¹ From 0 to 10 cm depth. Source: Denardin *et al.* (2005).

In Argentina, Bolivia and Brazil, there are many areas that are susceptible to water and wind erosion. Here, however, it is felt unwise to rely entirely and exclusively on no-till (presumably including soil cover) for erosion control. The Latin American team observed that,

“Despite all of its admitted advantages, no-tillage needs to be supported by complementary conservationist techniques . . . every conservationist technique capable of keeping the length of the slope within boundaries where the covering of the soil doesn’t lose efficacy on the dissipation of the incident energy, will contribute greatly to diminish the water born erosion process. Some other techniques like contour planting, aerial planting, strip cropping, buffer strip among others, are good conservationist techniques to segment the slope, what is more, they proved to be a good stimulus for the stubble, assisting in that way to an effective erosion control.”

In Vietnam, soil cover has been found to be effective in controlling erosion. Strategies for achieving soil cover, however, go beyond the mere retention of crop residues to include more comprehensive and elaborate mulching strategies. These were described in a previous section. One example provided for Vietnam has to do with cassava cultivation (Table 12):

In recent times, cassava cultivation has become more popular with the farmers as it gives more profit. But the cassava cultivation leads to more soil erosion. If Cassava is intercropped with peanut/soybean, it helps to reduce soil loss and improves profitability . . . There are a number of plant species can be intercropped with cassava as live mulch to reduce the soil losses through erosion . . .”

Table 12. Effects of hedgerows on soil erosion and cassava yields in Hong Tien-Son Duong-Tuyen Quang (Nguyen The Dang et al, 2002)

Treatment	Eroded soil (t/ha)	Cassava yield (t /ha)
Control	106.0	26.3
Cassava + Tephrosia bands	15.0	28.7
Cassava + Vetiver grass bands	7.1	27.0
Cassava + Paspalum atratum bands	7.2	31.2
Cassava + Panicum maximum	6.2	27.0

For Mediterranean rainfed ecosystems, attempts to control erosion have traditionally been based on bench terracing, said to be very common in all areas. Apart from a reference to one ICARDA experiment conducted in Syria, almost all evidence reported by the Mediterranean platform team, supporting the proposition that reduced tillage can help control erosion comes from Spain. In that country, the platform team observed that:

“The development of CA is particularly necessary in erosion and desertification-prone areas. Tillage systems such as no-tillage, reduced tillage and ridge tillage are used by farmers to control erosion and to comply with soil conservation measures . . . Long fallowing (16 to 17 months), in the cereal/fallow rotation, may favour soil losses by wind erosion on agricultural soils of semiarid lands . . . [it has been shown] that reduced tillage, with chiselling as primary tillage, could be a viable alternative to conventional tillage (mouldboard ploughing) for wind erosion control. . .”.

The role of residue retention or mulching or of other conservation agriculture practices in reducing soil erosion is not clear. The evidence seems rather incomplete.

Finally, we come to northern Europe where erosion and run-off measurements – presumably from experiments – indicate that no-till results in reduced erosion during the cropping period and during the intercrop, an effect which tends to increase and become stronger over time. Reduced water run-off during the intercrop, however, only occurs when a cover crop is used. “Results on experimental stations showed that runoff was reduced by 4 times when a mustard intercrop was sown: 6.1 mm in no-till system to 1.5 mm in the system with the cover crop . . . On farms results confirm this observation: sowing a mustard intercrop permits to reduce runoff by 1.5 to 15 times from case to case . . .”

Unfortunately, as noted in an earlier section, “In the European platform, there have been many regional experiences and trials on cover crop management within various crop rotations, including winter and summer catch crops, intercrops and under-sown crops. However, at present, few farmers are said to use cover crops within market crop rotations, largely because they increase production costs and they are not marketable.”

4.2. Carbon and greenhouse gases

The relationship between conservation agriculture on the one hand, and carbon sequestration and greenhouse gas (GHG) emission on the other, is an important but controversial topic. Most of the debate focuses on the extent to which a shift from conventional to conservation agriculture affects stocks of soil organic carbon, greenhouse gas emissions from diesel fuel consumption and the burning of residues, and emissions of CO₂, N₂O, and CH₄ from soils. GHG emissions of all kinds can be combined into a single “carbon equivalent” measure, which allows sensible comparisons to be made of emissions from different systems in different locations. For the most part, however, platform teams did not adjust their estimates to carbon equivalent units.

Surprisingly, only one platform team – from Asia – mentioned a large reduction in the use of fuel by tractors and pumps (and a correspondingly large reduction in carbon equivalent emissions) attributable to a shift to no-till. They found that such reductions in emissions are very substantial, as might be expected when farmers on millions of ha go from 8-12 to merely 1-2 tractor passes over a field. It would be useful to obtain better estimates of carbon savings from “fuel not burned” for more KASSA ecosystems.

There were occasional references to carbon emissions from the burning of crop residues. Most analysts do not count these as greenhouse gas emissions, however, as a similar amount of carbon is taken from the atmosphere to produce straw and other residues during the next cycle of crop production. Residue burning does have important effects on organic matter cycling in soils, and on air pollution that affects public health.

The Latin American team discussed the effect of conservation agriculture on changes in soil organic carbon (SOC) levels. When conservation agriculture leads to permanent increases in SOC, carbon can be said to have been sequestered in the soil. The team cited several studies that measured increased SOC levels attributable to the introduction of conservation agriculture. The further noted that the effect of conservation agriculture on C stocks was especially strong “when additional cover crops, especially grasses and legumes, are used in order to increase the total

photosynthetic production during the year and provide high levels of biomass returned to the soil”. Details were provided for locations in Brazil (Table 13).

Nonetheless, the Latin American team presented some cautions:

“... assessments changes in SOC stocks for different Latin American eco-regions or different non-intensive systems are inconclusive due to high variability and small number of observations. The adoption of CA in large areas such as the Brazilian Cerrados (occupying 207 million hectares) and its impact on C sequestration needs more investigation ... Research on the potential of CA for carbon sequestration needs to include data on SOC concentration and bulk density for different layers, but at least to the depth disturbance (typically 20-40 cm), so that SOC stock and dynamics can be assessed. Larger data base of undisturbed and cultivated soils needs to be compiled to enable better assessment and modelling of SOC with land use change for major Latin American eco-regions and soil types (specially regarding clay content and mineralogy).”

Some information was gathered by KASSA teams on greenhouse gas emissions from soils. The European team noted that such information needs to be used with caution because of difficulties in measuring gas emissions, especially N₂O. They cited several studies from France and Germany comparing conventional till and no-till in which significant differences in CO₂ emissions were not found. Nevertheless, cumulated emissions over a year tend to be slightly higher in no-till than in conventional (4068±221 kgC/ha versus 3162±453 kgC/ha). These same studies showed that N₂O emissions were significantly higher in no-till systems. The gas was supposed to be produced during nitrification and not denitrification, because the ratio N₂O/N₂ remained low (1,2). However, the Latin American team reported that:

“Few results have been published regarding N₂O emissions in Brazilian tropical regions. One of them was realized in the Cerrados region ... The results demonstrated that N₂O emissions were very low (< 1 g ha⁻¹ day⁻¹) for both conventional and conservation management systems. Peaks of N₂O were observed after fertilization. N₂O is produced mainly by denitrification, which may be explained by low NO₃ levels in soils and a < 60% water filled pore space (WFPS) within the soil for the majority of the time. Low WFPS under these crops can be caused by evaporation at high temperature (more than or equal to 25°C). However, measurements of gas concentrations in soil showed that the production of N₂O is reasonably prolific (concentrations of 1 to 30 times the atmospheric concentration). This suggests that N₂O is produced but cannot diffuse to the soil surface, both because denitrification is complete and N₂ is produced or because the N₂O is nitrified before diffusing.”

No information has been brought by KASSA teams on CH₄ emissions.

Hence, it seems clear that greenhouse gas emissions from conservation agriculture systems deserve more attention in the future.

Table 13. Carbon storage rates (accumulation following conversion of a conventional tillage system to no-tillage) in Brazil regions.

Place	State ^a	Succession or dominant plant ^b	Reported soil classification	Clay (%)	Layer (cm)	Duration (yr)	Rate (t C/ha)	
Cerrados region								
Planaltina	DF	S/W	Latossol (Oxisol)	40-50	0-20	15	0.5	Corazza <i>et al.</i> , 1999
					0-40	15	0.8	
Sinop	MT	R - S/So – R/So - S/M- S/E	Latossol (Oxisol)	50-65	0-40	5	1.7	Perrin, 2003 ud
Goiânia	GO	Rice/Soybeans	Dark red Latossol		0-10	5	0.7	
Rio Verde	GO	M or S/Fallow S/M or So or Mi	Red Latossol	45-65	0-20	12	0.8	Scopel <i>et al.</i> , 2003
Planaltina	DF	M or S	Dark Red Latossol (Oxisol)	>30	0-40	16	0.4	Resck <i>et al.</i> , 2000
South region								
Londrina	PR	W/S	Oxisol		0-10	22	0.31	Machado and Silva, 2001
					0-20	22	0.25	
					0-40	22	-0.17	
Londrina	PR	S/W – S/L –M/O	Red Latossol		0-20	7	0.5-0.9	Zotarelli <i>et al.</i> , 2003
Londrina	PR	S/W/S or M/W/M or S/W/M	Oxisol Typic Haplorthox		0-10	14	0.4 ^d	Castro Filho <i>et al.</i> , 1998
					0-20		0.2 ^d	
Londrina	PR	S/W/S or M/W/M or S/W/M	Oxisol Typic Haplorthox		0-40	21	0 ^c	Corazza Filho <i>et al.</i> , 2002 Sá <i>et al.</i> , 2001
Ponta Grossa	PR	(S or M)/(O or W)	Oxisol Typic Hapludox	40-45	0-40	22	0.9	
Tibagi	PR	(S or M)/(O or W)	Oxisol Typic Hapludox	40-45	0-40	10	-0.5	Sá <i>et al.</i> , 2001
Tibagi	PR	M/W – S/O – S/O	Red Latossol (Oxisol)	40-45	0-10	22	1.0 ^d	Venzke Filho <i>et al.</i> , 2002 Siqueira Neto, 2003
Tibagi	PR	M/W-S/O-S/O	Red Latossol (Oxisol)	42	0-20	10	1.6	
Toledo	PR	S/O	Haplic Ferrasol		0-10	3	-0.68 ^d	Riezebos and Loerts, 1998
		S/O	Haplic Ferrasol		0-10	10	0.37 ^d	
Passo Fundo	RS	W/S	Oxisol		0-10	11	0.59	Machado and Silva, 2001
					0-20	11	-0.07	
					0-40	11	0.29	
Passo Fundo	RS	W/S	Red Latossol	63	0-30	13	0 ^c	Sisti <i>et al.</i> , 2004
		W/S-V/M	Typic Hapludox		0-30	13	0.4	
		W/S-O/S-V/M			0-30	13	0.7	

Passo Fundo	RS	W/S	Red Latossol Typic Hapludox	63	0-10	11	0.3	Freixo <i>et al.</i> , 2002
					0-20	11	0 ^c	
					0-30	11	0 ^c	
		W/S – W/M	Red Latossol Typic Hapludox		0-10	11	0.4	Freixo <i>et al.</i> , 2002
					0-20	11	0.2	
					0-30	11	0 ^c	
Santa Maria	RS	M and Mu/M	Ultisol	15	0-20	4	1.3	Amado <i>et al.</i> , 2001
Eldorado do Sul	RS	M/G	Podzólico Vermelho Escuro		0-17.5	5	1.4 ^d	Testa <i>et al.</i> , 1992
		M/La			0-17.5	5	0.6 ^d	
		O/M			0-17.5	5	0.2 ^d	
Eldorado do Sul	RS	O+V/M+C	Clay loam Acrisol Typic Paleudult	22	0-17.5	9	0.84	Bayer <i>et al.</i> , 2002
Eldorado do Sul	RS	O/M	Clay loam Acrisol Typic Paleudult	22	0-30	9	0.51	Bayer <i>et al.</i> , 2000b
		O+V/M+C			0-30	9	0.71	
Eldorado do Sul	RS	O+V/M+C	Clay loam Acrisol Typic Paleudult	22	0-17,5	12	1.26	Bayer <i>et al.</i> , 2000a
Lages	SC	M or S / W or O	Cambisol		0-20	8	1.0	Bayer and Bertol, 1999
Other regions								
Campinas	SP	S or C / M	Rhodic Ferralsol Typic Haplorthox	60	0-20	3	0.8 ^{de}	De Maria <i>et al.</i> , 1999
					0-20	8	0.4 ^{de}	
Sete Lagoas	MG	M/B	Dark red Latossol Typic Haplustox		0-15	10	0 ^c	Roscoe and Burman, 2003
					0-45		0 ^c	

^aPR =Paraná, RS =Rio Grande do Sul, DF = Distrito Federal, SC = Santa Catarina, SP = São Paulo, MT = Mato Grosso, GO = Goiás, MG = Minas Gerais; ^b Dominant succession: W = Wheat (*Triticum aestivum*), S = Sorghum (*Glycine max*), So = Sorghum (*Sorghum vulgaris*), R = Rice (*Oriza sativa*), E = *Eleusine coracana*, O = Oat (*Avena sativa*), V = Vetch (*Vicia sativa*), M = Maize (*Zea mays*), B = Beans (*Phaseolus vulgaris*), Mu = Mucuna (*Stizolobium cinereum*), C = cowpea (*Vigna unguiculata*), L=Lupine bean (*Lupinus angustifolius*), La = Lablab (*Dolichos lablab*), G = Guandu (*Cajanus cajan*);^c 0 means that the difference was not significant; ^d calculated using an arbitrary soil bulk density of 1.2 g cm⁻³; ^e value reported for OM, C= OM / 1.724, ud =unpublished data from Metay.

Source: Bernoux *et al.* (2005)

4.3. Soil and water pollution

Soil and water pollution linked to agricultural activities is a highly debated matter notably in Europe. Almost all of the information on the relationship between conservation agriculture on the one hand, and pollution on the other, comes from the European and Latin American teams, especially the former. Issues of concern include pesticides use, fertilizers use, water pollution from leaching and/ or run-off of pesticides, nutrients, and heavy metals and, their fate and related impacts. Here are highlights from platform reports on what was found regarding pesticides use and degradation, nutrient leaching, and heavy metals that may be traced to a shift from conventional to conservation agriculture.

4.3.1. Pesticides

Very little is known on the actual use of pesticides (products, doses and frequency of applications) in conservation agriculture systems considered within KASSA platforms. According to the European team, it is broadly accepted that no-tillage may lead to an increased use of pesticides for weed, pest and diseases control, at least during the transition period. In the long run, this is not compulsory, especially when sound crop rotations and cover crops are used. However, the simultaneous use of crop rotations and cover crops is difficult in certain conditions discussed in chapter IIIb and, no evidence of reduction in pesticides use has been provided by the Latin American platform where conservation agriculture is practised for a long time. Data provided are scarce; figures in table (10) tend to evidence an increased use of pesticides under conservation agriculture practices, while the figure (5) tend to show a decrease in the use of herbicide to control *Phalaris minor* in zero-till wheat.

The fate of pesticides is a major issue in agricultural and environmental research in western European countries, but very few researches focused on conservation agriculture systems. Results reported by the European and Latin American teams clearly indicate that the transfer of pesticides is linked to a number of parameters including: soil organic matter and biological activity, the nature of the pesticide used and, the time interval between pesticide application and rainfall events or watering in irrigated systems

As soil organic matter accumulates in the upper layer of no-tilled soils, pesticides susceptible to sorption on organic matter accumulate near the surface and show less availability to depth (or lateral) transfer. This seems to be the behaviour of glyphosate. Indeed, results from Argentina show that the amount of glyphosate leached in not-tilled soils represents 0,3-0,6% of the rate applied. Also, results extrapolated from Norwegian studies that however did not take into account different tillage systems describe increased binding and degradation of glyphosate with increasing organic matter content in upper soil layers. It was found that glyphosate degradation increases with increasing temperature and decreases with increasing soil depth due to decreasing soil organic matter content and microbial activity. The role of soil organic matter in reducing pesticides losses may be however counteracted by irrigation or heavy shower events occurring shortly after treatment application.

The retention of pesticides by the soil cover is also less documented. The Latin American team reported on experiments testing the retention of a wide range of pesticides by straw in no-till. Atrazine and sulfentrazone seem to be the less retained products.

4.3.2. Nutrient leaching and water pollution

Nutrients losses, mainly N and P pose a serious problem of water pollution in conventional agriculture. This issue is less documented in conservation agriculture. According to the European team nutrients accumulate in the upper soil layer of no-tilled soils and losses of N, P and K are significantly reduced. However, no long-term evidence has been provided to support this assertion. In conservation agriculture systems it is likely that the cycling of nutrients operates differently compared to conventional systems and water infiltration capacity is enhanced. This affects in field-level nutrients balances, leading to changes in leaching of nutrients.

4.3.3. Heavy metals

This issue is also less documented in KASSA platforms. Higher sorption rates of heavy metals under no-till were detected in German studies by different extractabilities especially of Zn and Cd. This suggests that the availability of those heavy metals for transport should be reduced under no-till or reduced-tillage, which benefit from the supply of organic C from plant residues left on the surface.

Hence, soil and water pollution in the context of conservation agriculture deserve more investigations in the future. Better indicators and decision support tools are needed for more sensible assessment of food-chain and public health risks. These tools are of great interest to help policy makers (targeted incentives and compliance) and farmers (self risk calculation).

IIIId.

KASSA research results –knowledge gaps and research needs

The KASSA project has been successful in pulling together an enormous amount of information on conservation agriculture in several agroecosystems, spread across four different platforms. The relationship between sustainability in agriculture and “conservation agriculture” has been explained, and selected agroecosystems have been described and characterized. For each system, achievements thus far in the development of conservation agriculture have been depicted; drivers and constraints have been summarized; consequences of conservation agriculture adoption have been assessed with regard to livelihoods, land and water resources, and the environment.

Platform teams have come to realize, however, that despite all of this progress, much remains to be learned. This section will integrate conclusions reached by platform teams on important gaps in our knowledge in two broad areas touching on conservation agriculture – how to facilitate its wider use and how to better understand its impacts. After this, some tentative observations will be made regarding scope for collaboration with potential stakeholders and the need for capacity-building and strengthening sustainability research in Europe – and in developing countries.

1. Identifying gaps

A commonsense definition of a “knowledge gap” is the difference between “what is known” and “what needs to be known”.

$G = N - K$, where

G = “the knowledge gap”,

N = “what needs to be known” and

K = “what is known”.

In the case of conservation agriculture, N can never be definitively defined and K can never be more than imperfectly understood, so the best we can do regarding G is to obtain a rough approximation.¹¹ A major aim of the KASSA project has been to estimate G by improving our understanding of N and K .

Knowledge gaps and research needs are simultaneously determined. For every knowledge gap, a research activity can be devised to fill it – at least in principle. For example, if a knowledge gap exists regarding the impact of conservation agriculture practices on pest carryover, a way to quantify such carryover can be designed and implemented; conclusions can be drawn on the extent to which the introduction of

¹¹ As the Latin American platform team noted, “. . . nothing is static and this is particularly true in agriculture. Once farmers move from one system to another, new dynamics are created and new questions arise. These are the new knowledge gaps that should be tackled”.

conservation agriculture (in specific circumstances) results in pest carryover (of a clearly defined nature); and decisions can be made on whether or not conservation agriculture practices need to be modified so as to avoid or manage the problem.

It is clear, of course, that there are actually two different “G’s”:

G_t = the technology development knowledge gap – what needs to be learned for more effective and rapid development of conservation agriculture technologies capable of being widely adopted;

G_i = the impact assessment knowledge gap – what remains to be learned to understand and anticipate the impacts of adoption once it is achieved.

Each platform team was asked to list important knowledge gaps relevant to the development and dissemination of conservation agriculture and the estimation of its impacts. These lists were incorporated into the respective reports for Work Package 1.3. Table 14 pulls together these various lists. Important gaps are organized by theme to enable cross-platform comparisons. G_t and G_i type gaps are listed separately.

In Table 14, it may be seen that there are many similarities – but also some differences – in how platform teams perceived conservation agriculture knowledge gaps.

1.1. Knowledge gaps in technology development

1.1.1. Weed, pest and disease management

Most teams recognized knowledge gaps concerning integrated strategies for weed, pest and disease management, including strategies for systems with puddled rice. The European and Latin American teams also emphasized the need for conservation agriculture strategies that reduce or minimize herbicide use.

1.1.2. Management of crop residues, cover crop and rotations

A wide variety of knowledge gaps were mentioned here, including how to identify cash and cover crops more tolerant to abiotic stresses (Latin America), conservation agriculture practices for additional crops (e.g., cotton and tobacco), and crop residue management when residues are either scarce (Mediterranean) or excessive (Asia).

The European team perceived many knowledge gaps in this category, including the management of cover crops and catch crops, the identification of adapted crop rotations; intercropping and cover crop performance in conservation agriculture systems; and crop residue management.

1.1.3 Crop improvement/ plant breeding

The Asian team was the one most sensitive to gaps in knowledge on crop improvement to develop crop varieties tailored for use with conservation agriculture systems. The Mediterranean team also mentioned as potentially useful the development of drought-tolerant crop varieties.

Table 19. Knowledge gaps in conservation agriculture as identified by platform teams

Research field	Items	Europe	Mediterranean	Asia	Latin America
	Technology development				
Agriculture: Sustainable production	Weed, pest and disease management	Integrated weed and pest management Strategies for reducing herbicide input	Integrated weed control practices in CA Integrated pest and disease management in CA Long term crop rotations trials for weed, pest and diseases control	Development of CA systems less dependant on external inputs Weed management in zero till rice Develop new herbicides for intercropping systems	
	Crop residues, cover crops and rotations	Management of cover crops and catch crops Adapted crop rotations Intercropping and cover crops performances in CA Crop residue management	Long term experiment in crop rotations for weed, pest and diseases control Crop diversification in CA Intercropping and cover crops performances in CA Crop residue management	Develop co-culture of green manure and cover crops for major cropping systems Introduce permanent bed systems to promote diversification Innovative crop rotations for addressing changes in weed and pest complexes	Development of cash and cover crops more tolerant to abiotic stress and compatible to different farming systems Technology development for some [additional] crops under CA, e.g., cotton, tobacco
	Crop improvement/ plant breeding	Crop breeding for CA	Crop breeding for CA	Develop cultivars with efficient nutrient translocation systems Breed germplasm for heat/drought/ waterlogging tolerance Harness tillage x germplasm interactions	Study (adaptation/breeding) of species aiming at cropping systems' diversification for different agro ecological conditions
	Organic farming	Strategies for knowledge exchange on CA and OF systems and possible joint technologies			

	Items	Europe	Mediterranean	Asia	Latin America
Agriculture: Environment and Natural resources management	Water management and erosion control	Erosion control	Irrigation systems for CA Water conservation Water and wind erosion	Introduce and train service providers on precision land levelling Introduce permanent bed systems to improve water productivity	Technology development for runoff management in CA
	Soil fertility management	Soil organic matter maintenance and accumulation	Nutrient cycling and fertilization under CA	Role of crop residues in meeting nutrient demands in micaceous and acidic soils Sensor based technologies (NDVI) for improved N management Develop practices for organic accumulation in soils	Dynamics of soil nutrients in agroecosystems and technology development for the increase of efficiency of liming and fertilization;
Agriculture; Climate; Natural resources; Modelling	Technology targeting and recommendation domains	Site specific suitability of pedoclimatic conditions for CA		Extend conservation agriculture to rainfed and irrigated areas in system crops with contrasting edaphic requirements.	
Enterprise and Industry	Implement development	Appropriate technology (machinery) Planting techniques for seeding into excessively cold, moist soils		Refine existing drilling implements for planting into loose residue conditions to prevent burning of straw	Technology development for precision agriculture

	Items	Europe	Mediterranean	Asia	Latin America
Policy Governance; Education; Socioeconomics & Institutional changes	Socioeconomics, policy and institutional change	Need for research targeting: Training, education and knowledge sharing The profitability and viability of CA; The appropriateness of local and regional policy in support of the transition to CA in Europe.	There is little research conducted to date solely on sociological and economic factors concerning the evolution and the social impact of CA systems and various authors state the need for more research into the social and economical implications of these 'new' agricultural systems.	There is a need for policy analyses to understand how conservation technologies integrate with other technologies, policy instruments and institutional arrangement that promote or deter conservation agriculture. Improve farm advisory services	
	Research management and innovation systems	The adoption of CA leads to the necessity to revise the whole management process. A better governance to generate knowledge and promote CA systems is needed.	The adoption of CA leads to the necessity to revise the whole management process. Yet, it appears that gaps in knowledge in crop and soil management under CA are still permanent in most countries. Most data are gathered from experimental plots and hence extrapolation or out-scaling stay difficult in countries where no-tillage is still at experimental or R&D stage.	Promoting CA will call for moving away from the conventional compartmentalized and hierarchical arrangement of research that generated and perfected technologies, extension that delivers it and farmers who adopt it.	
	Impact assessment				
Agriculture	Water productivity	More efficient water use	Combined water and nitrogen use efficiency under CA		
	Input use efficiency (other than water)	Plant nutrient availability, management, organic and mineral fertilization, decreased nutrient losses	Combined water and nitrogen use efficiency under CA		Dynamics of soil organic matter in agroecosystems

	Items	Europe	Mediterranean	Asia	Latin America
Agriculture; Socioeconomics	Yield improvement	Effects on yields and yield stability, particularly in dry regions and during the dry periods		Socioeconomic analysis of benefits	
Agriculture; Environment	GMOs				Impact assessment of the adoption of GM crops and CA
Environment ; Health & consumers protection	Erosion	Water and wind erosion	Soil erosion control		
	Soil and water quality, pollution	Fate and behaviour of pesticides Ground water protection Fate of heavy metals in soils under CA and impact on the food chain. Fate and behaviour of persistent organic pollutants (POP)	Soil quality indicators under CA Contamination and pollution of soil, air and water	CA practices e.g. no-tillage and surface maintained crop residues results in resource improvement gradually and benefits came about only with time. It is important that evaluation of CA takes into account its impact on the environment, and improvement in the quality of natural resources. Nitrate and agrochemical pollution of water resources	Impact assessment of the use of external inputs in CA on soil and water quality and on biodiversity Definition of soil quality indicators for different agroecosystems Studies of genesis, diagnosis, and mitigation of soil compaction in CA areas
	Biodiversity and pest carryover	Biodiversity and agronomic problems (pests like slugs etc.)	Soil biodiversity	Carryover of pest and disease in rice-wheat or prevailing cropping system Monitor changing weed competition and biology	Impact assessment of the use of external inputs in CA on soil and water quality and on biodiversity

	Items	Europe	Mediterranean	Asia	Latin America
	Carbon sequestration and greenhouse gas emissions	Greenhouse gas emissions from soils under CA Methodical questions on the measurement of greenhouse gases Assessment of benefits and constraints of CA - climate change and CA	Global environmental impacts of CA have to be considered: climate change, resource management, and fuel consumption. Carbon sequestration in agricultural soils Greenhouse gas emissions and global warming	SOM quality and carbon dynamics Monitor the effects of CA on greenhouse gas emissions	Quantification of the potential of CA for carbon sequestration
	Food safety	Food safety considering pollutants of various kinds. Effect of CA systems on the food chain, example of mycotoxins.	Crop production and quality under no-tillage systems		
Socioeconomics	Cost reduction	Yield change and cost reduction per unit production		Socioeconomic analysis of benefits	Development of CA systems less dependant on external inputs

1.1.4. Organic farming

The European team noted knowledge gaps in links between conservation agriculture and organic farming. They perceived that conservation agriculture can help overcome some gaps or shortcomings of organic farming, e.g., problems with weed control, low yield levels, some possibly negative impact on soil properties and functioning, etc. They anticipate that the principles and practice of conservation agriculture can strengthen and improve organic farming practices.

1.1.5. Water management and erosion control

The Mediterranean team perceived a generalized gap in knowledge on ways to introduce conservation agriculture into irrigated agriculture. The Asian and Latin American teams observed more specific gaps with regard to technologies for managing water run-off and for improving water productivity in irrigated agriculture through bed and furrow systems.

1.1.6. Soil fertility management

All platforms felt that a greater understanding was required on how to manage fertilizers and other inorganic and organic inputs within conservation agriculture systems in order to improve use efficiency and foster increased levels of soil organic matter. Knowledge gaps regarding soil organic matter maintenance and accumulation was of special concern to the European team.

1.1.7. Technology targeting and recommendation domains

The European platform team noted a need for better information and decision support systems on site specific suitability of conservation agriculture, taking into account climate and soils. The Asian team concurred, noting a similar need for targeting the various environments where puddled rice is currently part of the system. Technology targeting questions are also likely to be important for Latin America and the Mediterranean.

1.1.8. Implement development

All platform teams noted a knowledge gap relating to the development of advanced conservation agriculture implements – for seeding into cold, moist soils (Europe), for precision agriculture (Latin America) or for drilling into loose residues (Asia).

1.1.9. Socioeconomics, policy and institutional change

The Asian and Mediterranean teams perceived a generalized gap in knowledge regarding methods for helping policymakers arrive at prudent, sensible decisions on topics touching on conservation agriculture. The European team urged changes in policies and institutions to foster better research targeting; training, education and knowledge sharing regarding conservation agriculture; the profitability and economic

viability of conservation agriculture; and improvements in local and regional policy in support of a European transformation towards conservation agriculture.

1.1.10. Research management and innovation systems

The Asian and Mediterranean platform teams observed a gap in understanding how to organize and manage effective research and innovation systems, noting that such systems must go beyond compartmentalized and hierarchical arrangements to those featuring more participatory action research with farmers. These observations also appear to be relevant for Europe and those parts of Latin America that have not as yet benefited from the introduction of conservation agriculture.

The European team noted that conservation agriculture is likely to require an entire transformation of crop management systems, and that stronger systems of governance are needed to foster knowledge generation and promote conservation agriculture systems.

1.2. Knowledge gaps in impact assessment

1.2.1. Impacts on water productivity, input use efficiency, erosion, and soil and water pollution

All teams observed gaps in knowledge regarding the consequences of using conservation agriculture for changes in soil fertility; the dynamics of soil organic matter; soil compaction; wind and water erosion; water productivity; the pollution of water resources with nitrates, pesticides, heavy metals or persistent organic pollutants – and, tying these together, gaps in knowledge regarding the choice of suitable soil quality indicators.

The European team in particular emphasized issues of plant nutrient availability, soil fertility management, organic and inorganic fertilization, and ways to decrease nutrient losses, ground water protection, and the fate of heavy metals and persistent organic pollutants (POP) in soils under conservation agriculture, and how these may impact on the food chain.

1.2.2. Impacts on yields and costs

Knowledge regarding the impacts of conservation agriculture on farm-level yields and production costs, and the resulting consequences for the profitability of conservation agriculture systems was felt to lacking by the European and Asian teams. There was a generalized desire for improved information on the effects of conservation agriculture on yields and yield stability, particularly in dry regions and during dry periods.

1.2.3. Biodiversity and pest carryover

Once again, all teams concurred that knowledge was incomplete regarding the impacts of conservation agriculture on pest carryover in crop residues; the emergence of new pests, e.g., slugs; and changes in soil biodiversity – and how to measure these impacts.

1.2.4. Carbon sequestration and greenhouse gas emissions

All platform teams agreed that knowledge was lacking with regard to the effects of conservation agriculture on carbon dynamics, carbon sequestration in agricultural soils, and emissions of carbon dioxide, methane and nitrous oxide.

1.2.6. Genetically Modified Organisms

Herbicide-resistant genetically modified soybeans have been largely used in Argentina and Brazil. The main driving force for the adoption of this technology is that it simplifies the cropping management and according to farmers, reduces operational costs. However, the adoption by farmers - although it is an important indicator- has been the only evidence of its benefits. Yet there is no scientific data available addressing the economic, social and environmental impacts of this technology in the short, medium and long term.

1.2.6. Impacts on food safety

Knowledge regarding possible impacts of conservation agriculture on food safety was mentioned by the Mediterranean team – and was heavily emphasized by the European team. The latter seeks further information on food safety, considering pollutants of various kinds, and the effect of conservation agriculture practices on the food chain, e.g., regarding mycotoxins.

IV.

Implications for future research and policy

From the preceding, it is clear that there continues to be a great need for knowledge generation on conservation agriculture. The inventory-assessment-sharing-learning-refining process performed in each regional platform of KASSA allowed identifying knowledge gaps and defining needs for future research in each platform. The nature and size of knowledge gaps varies across the platforms. The purpose of this section is to list the further research needs as suggested by KASSA platform teams. This will help stakeholders identify research priorities and strategies for the future.

1. Research proposed by the European platform

Discussions in the European platform included deliberations on methodological approaches, e.g., combining short- and long-term experiments with on-farm research and modelling. Most suggested research topics are closely linked to each other or have cross-linked impacts. Therefore, integrated research approaches were proposed, of the kind that can go beyond individual questions in order to tackle “super-ordinate” questions. There are three such proposals for integrated research. These are described below.

1.1. Integrated research on agronomic challenges and environmental impacts of conservation agriculture

When shifting from conventional to conservation agriculture, farmers must tackle several challenges in order to maintain or improve their agronomic and economic standards. Abandonment of the plough goes beyond mere changes in tillage systems as such – rather, it implies comprehensive changes and adaptation in the entire farming system. Some aspects hinder and constrain the implementation of conservation agriculture. Among the most important are:

- Site specific suitability of pedoclimatic conditions for conservation agriculture;
- Effects of conservation agriculture on yields and yield stability, particularly in dry regions and during the dry periods;
- Reductions in cost per unit production (even more important than yield improvement);
- Appropriate technology (machinery);
- Management of cover crops and catch crops;
- Adapted crop rotations;

- Weed and pest management;
- Soil organic matter maintenance and accumulation;
- Plant nutrient availability, management, organic and mineral fertilization, decreased nutrient losses;
- More efficient water use;
- Water and wind erosion of soils.

Even seemingly straightforward agronomic questions often have environmental implications. For example, the abandonment of ploughing often leads to increased use of herbicides. The challenge is to develop conservation agriculture practices that require less herbicide use. From farmers' experiences, it is known that an adapted crop rotations as well as cover crops can help prevent severe weed infestations. In general, when working to overcome agronomic challenges, the linked environmental impacts must not be neglected.

Many knowledge gaps concerning such environmental impacts were identified within the framework of the KASSA Project. Among these, the most important environmental questions to be tackled by future research are:

- Pollutants (groundwater protection, fate and behaviour of pesticides and persistent organic pollutants, fate of heavy metals in soils under conservation agriculture);
- Greenhouse gases and the carbon cycle (greenhouse gas emissions from soils under conservation agriculture, methodical questions on measuring greenhouse gases, assessment of benefits and constraints of conservation agriculture, climate change and conservation agriculture);
- Biodiversity (impacts of conservation agriculture on agrobiodiversity, up-scaling from field scale to regional scale, biodiversity and agronomic problems, e.g., pests like slugs).

From the knowledge base of the KASSA-Project it is recommended to set up integrated research approaches for the following general topics:

1.1.1. Integrated weed and pest management

One common purpose of ploughing is simply to fight weeds, pests and diseases. Any new strategy based on no-till must be able to deal with weeds, pests and diseases in ways that do not neglect environmental aspects.

Research approaches on integrated weed and pest management should assess the effect of herbicide use on the environment and identify strategies to reduce their use, e.g., through appropriate crop rotations and cover crops. Hazardous ingredients in pesticides, their metabolites, and their contamination paths should be topics of closer scrutiny. The effect of pesticides on non-target species is another critical issue, e.g., the effect of anti-slug pesticides on earthworms. The possibility should be assessed that conservation agriculture may increase the carryover of pests and diseases from one crop to the next. Ways to mitigate this risk through crop rotations and catch crops should be found. The possible development of resistance to commonly used pesticides should be taken into account. Opportunities to replace pesticides should be identified and assessed, e.g., fungicides with bio-preparations or the introduction of new

resistant varieties (including GMOs). Other opportunities made possible by biotechnology should also be considered.

1.1.2. Strategies for organic farming and knowledge exchange

Organic Farming is emerging in most European countries. It will be a challenge to find ways of implementing reduced tillage in the context of Organic Farming systems with the total prohibition of chemical pesticides. At that moment, farmers engaged in Organic Farming cannot benefit from the advantages of conservation agriculture because yield depression and severe weed infestation are inescapable. Both systems, CA and OF, may adopt strategies from each other. Development of joint CA and OF systems that would be suitable for small farms in less favoured soil and climate conditions should be an important research topic.

1.1.3. Management of biodiversity

Biodiversity is a major topic in the future of European agriculture. The CAP has again made one step forward to pronounce the multifunctional role of agriculture in Europe. It seems important to assess the impacts of conservation agriculture on biodiversity. Although several benefits of conservation agriculture on biodiversity have been identified, knowledge of this area is far from complete. In studying conservation agriculture and biodiversity, different scales of analysis should be considered, particularly the landscape scale. Special attention should be paid to soil biodiversity assessment, methodologies for which are still unsatisfactory. Soil biodiversity is closely connected to soil fertility, maintenance of the soil ecological functions and the sustainability of agricultural land use.

1.1.4. Integrated crop rotations and the use of cover plants

Suitable crop rotations are crucial elements in the transition to conservation agriculture. The introduction of new rotations must take account of biophysical conditions (soil, climate, biology) as well as socioeconomic factors (economic viability). As mentioned above, appropriate rotations are a means of coping with weed, pest and disease problems, plant nutrition, organic and mineral fertilization, soil cover, and organic matter balance. Nevertheless, new rotations must be economically sound. The goal of research should be to develop rotations that decrease weed problems while also improving farmers' income. Such research should also assess opportunities made available through adapted crop varieties, biotechnology, and seeding practices. For many decades, plant breeding has been oriented to conventional tillage.

Cover plants may enhance soil fertility and protect soil from erosion. On the other hand, cover plants may decrease or increase weed infestation, according to the way they are used. Techniques of conservation agriculture may also improve soil physical properties, for example, through increased earthworm populations.

1.1.5. Integrated nutrient management and the conservation of soil fertility

Conservation of soil fertility and the maintenance of the soil ecological functions is a major concern of sustainable agriculture. Surface application of organic and inorganic fertilizers – and reductions in the intensity of tillage – affect the nature and distribution of soil organic matter. A profound understanding of soil organic matter and nutrient dynamics is needed to foster sustainable soil fertility management and an environmentally sound use of fertilizers. Research of this nature must include techniques for the use of manure and sludge when reducing tillage intensity. Dynamics of soil organic matter proceeds over a long time frame, often several decades. Long-term field experiments are therefore invaluable. Conservation agriculture can alter plant nutrient dynamics and availability within soil profile. Often this takes the form of increased demand for mineral nitrogen. More experimental data are needed to assess the availability of plant nutrients. From an environmental point of view it is important to assess the risk of nutrient leaching and ground water pollution with the knowledge that preferential flow might be pronounced in soils under reduced tillage. Pollutants originating from organic wastes (compost and sludge) as well as hazardous substances from mineral fertilizers should be considered.

1.1.6. Indicators of soil fertility and soil quality in conservation agriculture

Conservation agriculture remarkably affects soil properties. Indicators must be identified for assessing the effects of conservation agriculture on soils. These might include physical, chemical and biological properties of soils; changes in soil structure; detailed studies on erosion of soils; studies of soil compaction; short term and long-term dynamics and balance of C in soils; and soil microbiological changes (biodiversity).

1.1.7. Development of new machinery

Effective, high performance, lower energy demanding machinery is needed that are tailored to specific soil and climate conditions and different farm sizes (e.g., small in marginal regions, big in the lowlands).

1.2. Implementation and propagation of conservation agriculture

Farmers implementing conservation agriculture must confront several challenges. In doing so, they must maintain their competitiveness and income. Research on conservation agriculture implementation, then, must be seen from socioeconomic viewpoints as well as from agronomic and environmental viewpoints. Among principle issues for future research are the following:

1.2.1. Profitability

It includes:

- **Market conditions** – under what market conditions is conservation agriculture likely to be profitable? What are the boundaries for profitability?
- **Savings** - it is known that a shift to conservation agriculture can result in savings of time, costs, labour and natural resources. Research is needed to quantify and value these savings under different conditions. Comparative economic studies between conventional and conservation agriculture should be conducted in specific soil and climate conditions. Methods for cost-benefit calculation adapted to conservation agriculture should be further developed.
- **Investment** – one constraint for farmers wishing to shift to conservation agriculture is sometimes the high investment cost for new machinery. Strategies should be developed to help overcome this constraint, especially in the European platform, where much uncertainty remains regarding the length of the transition period.
- **Transition period** – what is needed to facilitate the transition from conventional to conservation agriculture? Training, education and advice for the farmer should be considered.
- **Small-scale farmers** – good experiences have been reported for conservation agriculture in large-scale farms. But is it a viable alternative for small-scale farms? Can it help improve incomes in rural areas?

1.2.2. Suitability and targeting

Local biophysical conditions are of crucial importance for the success or failure of conservation agriculture. Climate and soil are the major factors. It is recommended that databases and decision support systems (DSS) be developed, where biophysical data are merged with data on crops and agronomic techniques in ways that allow models to be used to facilitate farmer decision-making. These tools could also be used to support advisory institutions and to inform the policy debate regarding suitable land use strategies.

1.2.3. Appropriate local and regional policies

Strongly linked to the above issue is the need to develop policies to support the dissemination of conservation agriculture.

- **Support for transition** – as stated above, the process of transition from conventional to conservation agriculture can be critical for farmers. Training and education are needed and farmer experimentation should be encouraged. It has to be proven whether subsidies or financial support is a suitable means for supporting the dissemination of conservation agriculture in Europe;
- **Machinery** – machinery is a key issue. Cooperation is needed between farmers and industry to design and adapt new models of implements useful in conservation agriculture;
- **Suitable areas** – if areas most suitable for conservation agriculture can be identified, policy support can be targeted at these specific areas;

- **Rural development** – impact of conservation agriculture on rural communities and activities have to be taken into account;
- **Land stewardship** – when conservation agriculture has beneficial effects for the environment in rural areas, the corresponding benefits should be assessed, quantified and valued, and farmers should be compensated for their investments. Objective criteria for doing so are needed.

1.2.4. Propagation of conservation agriculture

- **Knowledge transfer** – conservation agriculture is not well known among institutions and political decision-makers in Europe. For it to be more effectively promoted, information on its benefits and constraints must be conveyed from scientists to decision-makers;
- **Support for farmers' initiatives** – in many regions, farmers' initiatives have been a main driving force in the development and dissemination of conservation agriculture. Ways in which these farmers' initiatives could be supported by a political or institutional framework is a question for future research;
- **Farmers' networks** – it was reported that a major driving force for conservation agriculture were farmers networks. Ways have to be found to strengthen these networks and knowledge exchange among European farmers;
- **Advisory services** - agricultural advisors must be systematically trained to help farmers deal with the many questions that emerge as they try to implement conservation agriculture. Appropriate tools have to be developed for practical decision support.

A detailed project for the implementation and propagation of conservation agriculture is indispensable. It should consider the following: suitability of soil and climate conditions; farm size and resources; cultivated crops and crop rotations; financing investments in machinery, chemicals, and seeds; subsidies, credits, leasing and other kinds of support; formation of consortia; and machinery sharing and rental services.

1.3. Food quality and human health

Within the European Union, the quantity of crop production is currently assured. There are, however, some concerns regarding present and future food quality. The global distribution of organic and inorganic pollutants and their accumulation in certain environmental media may result in increasing levels of pollutants in vegetable and animal food. Inadequate farming practices can raise the incidence of biogenic harmful substances such as mycotoxins. Soils can act as a sink for pollutants. From soils, these may be transferred to plants and then to the animals which feed on them. The contamination of soil is clearly influenced by the form of cultivation.

The introduction of conservation agriculture must not only take account of soil quality and farm family income. It should also take account of the health and well-being of current and future generations. With a “fork-to-farm” approach to protect consumers from health threats, food quality should be ensured along the production chain.

As a first stage of the food production chain, research and development in conservation agriculture should tackle the following human health sensitive themes:

1.3.1. Behaviour of and reductions in the use of pesticides

In many cases, the introduction of conservation agriculture has led to a higher usage of synthetic pesticides such as herbicides. Until now, there are knowledge gaps regarding the degradation of these herbicides in soils and on plant surfaces. Further, transport from soil to water bodies (i.e. ground water and surface waters, respectively) of herbicides and their metabolites must be elaborated at different scales. A better understanding of the uptake of plant protection agents and their degradation products into plants is an important task with special regard to consumer protection. For this, it is indispensable to develop suitable high-throughput analytical procedures to investigate and monitor the fate of pesticides within the food production chain. Generation of a valid data set then should allow for the assessment of pesticides and metabolites in soil, water, and plant by existing modelling approaches. With such a tool box, recommendations for an adjusted use of pesticides in conservation agriculture can be made.

1.3.2. Strategies to reduce pesticide input

The most important way to reduce pesticide input in conservation agriculture is the establishment of suitable crop rotations. With suitable rotations, weed and pest pressure can be reduced significantly, often below thresholds of damage. By this, soils can be prevented from becoming minerally depleted. They can therefore continue to produce healthy crops. An integrated approach regarding the use of cover crops, “green manures”, and the inclusion of energy plants and renewable raw materials for industry should be pursued.

1.3.3. Mycotoxins in pre-harvest contamination of agricultural crops

Toxic metabolic by-products of fungi, known as mycotoxins, have received considerable attention during the past several years. Some mycotoxins have been associated with human health problems. Certain mycotoxins are suspected carcinogens. Plant protection strategies and extent of nitrogen fertilization can influence the mycotoxin content in plants. To reduce extended use of synthetic pesticides such as fungicides, the use of 'alternative' plant protective agents such as micro algae should be examined under conservation agriculture conditions with special regard to protect consumers against mycotoxins.

1.3.4. Reducing the uptake of pollutants into crops and animals

There is increasing concern for the accumulation of organic and inorganic pollutants in crops. Some of them, i.e. cadmium, pose threats to consumer health. Diet is the main source of cadmium exposure for non-smoking people. The positive correlation of cadmium concentrations in grain with soil cadmium concentrations justifies a distinct investigation of the behaviour of heavy metals in soils under different cultivation regimes. In conservation agriculture, the accumulation of pollutants like heavy metals and organic pollutants like PCB can be in parallel to humus accumulation. On the other hand, the availability for any transport of these substances to adjacent ecosystems and plant uptake may be reduced. The long-term behaviour of persistent pollutants should be assessed by modelling which should allow for

recommendations to minimize the transfer of pollutants from soil to water and plants. With crop rotations supplemented by hyper accumulating plants (usable as energy plants), soils are to remediate to some extent to ensure sustainable crop production.

2. Research proposed by the Mediterranean platform

The Mediterranean platform team suggested research topics to fill knowledge gaps, and for appropriate local and regional policies. Separate research topics and policies were suggested for conservation agriculture on the one hand, and for organic farming on the other. Here are the proposals with respect to conservation agriculture.

2.1. Knowledge gaps

The adoption of conservation agriculture leads to the necessity to re-visit the whole crop management process. Yet, it appears that gaps in knowledge in crop and soil management under conservation agriculture still persist in most countries. Most data are gathered from experimental plots. Extrapolation or out-scaling will be difficult in countries where no-tillage is still at the experimental or R&D stage.

To date, there has been little research that has focused directly on the sociological and economic factors associated with the evolution and the social impact of conservation agriculture systems. Various authors state the need for more research on the social and economical consequences of these ‘new’ agricultural systems. In fact, from existing results, socioeconomic impacts of conservation agriculture may be contradictory. Global environmental impacts of conservation agriculture have to be considered: climate change, resource management, and fuel consumption.

For the Mediterranean platform, it is important to develop a network of benchmark sites for long term research on conservation agriculture among Mediterranean countries to generate knowledge. The research gaps concern the following topics:

- Crop production and quality under no-tillage systems;
- Crop and livestock integration;
- Combined water and nitrogen use efficiency under conservation agriculture;
- Integrated weed control practices in conservation agriculture;
- Integrated pest and disease management in conservation agriculture;
- Nutrient cycling and fertilization under conservation agriculture;
- Long term experiment in crop rotations for weed, pest and diseases control;
- Crop breeding for conservation agriculture;
- Irrigation systems vs. conservation agriculture;
- Crop diversification in conservation agriculture;
- Intercropping and cover crops performances in conservation agriculture;
- Soil quality indicators under conservation agriculture;
- Soil erosion control;
- Soil biodiversity;

- Crop residue management;
- Carbon sequestration in agricultural soils;
- Contamination and pollution of soil, air and water;
- Greenhouse gas emissions and global warming;
- Social and economic studies;
- CA adoption studies.

2.2. Research needs

Research needs in conservation agriculture for the Mediterranean platform should be focused to fill gaps of knowledge in the following general subject matters:

- Site-specific and well-designed long-term experiments are needed in benchmark areas of the Mediterranean Region (rainfed and irrigated conditions; research on-farm level);
- Perennial crops management for conservation agriculture (olive, almond, vineyard);
- Crop residue management under conservation agriculture;
- Weed management and control under conservation agriculture;
- Crop and soil response of conservation agriculture under irrigation conditions (different irrigation methods);
- Plant breeding and biotechnology for conservation agriculture;
- Soil conservation and erosion control studies under conservation agriculture;
- Soil and water contamination under conservation agriculture;
- Water economy, quality and management under conservation agriculture;
- Machinery and equipment for conservation agriculture development adapted to some selected areas (e.g. Southern Mediterranean countries);
- Crop nutrition and fertilization (research has to be focused on soil test calibration and plant analysis for recommendations under conservation agriculture and on banding fertilizers and type of fertilizer application in some areas);
- Studies on integrated crop and animal production systems under conservation agriculture;
- Research is needed on short and long-term dynamics and balance of Carbon and Nitrogen in soils;
- Soil organic matter (quantity and quality) and Carbon sequestration under conservation agriculture;
- Soil biology and biochemistry (ecology) evolution under conservation agriculture (drylands and irrigated lands);

- Socioeconomic impact of conservation agriculture (studies on farmer perception of conservation agriculture systems; no-tillage sociology; economic analysis and modelling);
- Integrated pest and/or disease management under conservation agriculture.

2.3. Research needs for policy change

Given that conservation agriculture contributes to reduced poverty, improved food and environmental security, enhanced natural resources conservation, better livelihoods and the further development of rural communities in the Mediterranean area, it is recommended that future local and/or regional policies (i.e. forthcoming Common Agricultural Policy agri-environmental measures in Northern European Mediterranean countries) should be aimed at:

- Promotion of education, demonstration and dissemination of conservation agriculture;
- Promotion of extension services for conservation agriculture technology transfer;
- Involvement of farmers and their societies in conservation agriculture development and dissemination;
- Support of integrated studies for national, regional or local adoption of conservation agriculture;
- Promotion and support the access of farmers to conservation agriculture technology;
- Support networking on conservation agriculture for knowledge development and sharing;
- Promotion of participatory conservation agriculture projects involving all the stakeholders;
- Legal measures to support the development of conservation agriculture.

3. Research proposed by the Asian platform

The Asian agroecosystems studied by KASSA are very different. These are rice-wheat and related systems in the Indo-Gangetic Plains, intensive rice-based systems in the river valleys of northern Vietnam, and sloping land systems on hillsides in northern Vietnam.

Conservation agriculture experience within these agroecosystems is too recent. Conservation agriculture practices in use, their drivers and the conditions of their development and dissemination are different. The experience gained in the other KASSA platforms helped the Asian team to refine the knowledge acquired locally and to identify the gaps and the research priorities.

3.1. Knowledge gaps

3.1.1. Technology development, knowledge management and policy

In South Asia, the concept of conservation agriculture has not yet established its roots and is just beginning to make its mark. Thus, adaptive strategies for conservation agriculture system will be highly site specific yet learning across the sites will be a powerful way in understanding why certain technologies or practices are effective in a set of situation and not effective in another set. This learning process will greatly accelerate building a knowledge base for sustainable resource management.

A well articulated policy goal for livelihood security and rural development must now replace the myopic ‘food security’ policy based on cereal production. Policy framework for promotion of conservation agriculture will require radical changes and these will have to be identified and promoted in a holistic manner. A factor price support followed by mandatory procurement for the crops alternative to rice, that do not overexploit natural resources, thereby enabling policy mechanism and environment for other alternative crops. Emphasis should be on selecting and developing short duration varieties instead of long duration for saving various inputs like, water, electricity, fertilizers etc.

Sharing of information amongst farmers, scientists and other stakeholders would be critical, in advancing the spread and continued upgradation of conservation agriculture systems. Therefore, geo-referenced databases will be critical for extending the principles of conservation agriculture.

Appropriate local and regional policy and gaps to be filled in South East Asia must take into account the following considerations:

- Conservation agriculture practices e.g. no-tillage and surface maintained crop residues result in a gradual improvement of the resources and benefits came about only with time. Hence, it is important that evaluation of conservation agriculture takes into account its impact on the environment, and improvement in the quality of natural resources.
- Promoting conservation agriculture will call for moving away from the conventional compartmentalized and hierarchical arrangement of research that generated and perfected technologies, extension that delivers it and farmers who adopt it. All the stakeholders involved would need to be brought together on a common platform to conceive end-to-end strategies. Roles of research, extension, farmers and other stakeholders should be institutionalized in a way that strengthens these partnerships.
- As systems are much more complex, managing the systems efficiently will require understanding of basic processes and component interactions which determine the whole performance of the system. Understanding system interactions and developing management strategies will call for team work using an innovation system framework. This will also call for new ways of managing and funding research.
- In the spread of conservation agriculture, the link between agricultural research and rural development is must for effective use of the technologies. Institutional mechanisms are required to ensure that conservation agriculture/ RCTs is seen as an

important component of the national strategy for food security, poverty alleviation, health for all, rural development, enhancing productivity, improve environmental quality and preserve natural resources.

- There is a need for policy analyses to understand how conservation technologies integrate with other technologies, policy instruments and institutional arrangement that promote or deter conservation agriculture. It is therefore a challenge both for the scientific community and the farmers to overcome the past mindset and explore the opportunities that conservation agriculture offers for sustained agriculture. Conservation agriculture is now considered a route to sustainable agriculture. Spread of conservation agriculture, therefore will call for a greatly strengthened research and linked development efforts.

3.1.2. Understanding the functioning of conservation agriculture systems

Decomposing residues in no-till systems trigger a series of processes which lead to enhanced biological activity, creating a gradient of carbon from the surface to deeper layers, accumulation of mobile nutrient elements in surface layers and changes in soil properties. The nature and magnitude of these processes will depend on agro-climatic situations and cropping and cultural practices. These changes have a profound influence on the management needs, options and overall role in ecological functions.

In Asia, with monsoonal climate, farmers generally incorporate the residues into soils for their fast decomposition. Retention of residues on the surface, require a new set of practices for crop establishment, fertilizer use, water and weed management. European and Latin American platforms report a number of long-term studies aimed at undertaking the dynamic of changes following adoption of CA practices. Such understanding is continuously helping in improving strategies necessary for achieving sustainability goals. South Asian countries should also establish some long-term sites for studying the consequences of no-till agriculture.

Compared to soils in Latin Americas and European platform countries, organic matter content of soils in Asian platform countries is very low. Understanding the dynamics of changes following CA will be extremely important under a range of situations in both irrigated and rainfed situations for protecting soil organic matter against microbial decomposition.

The primary aim of management strategies in CA systems in many countries of European platform, particularly Western Europe, is to minimize the environmental impact of using pesticides and or other pollutants (e.g. heavy metals and fertilizers, organic pollutants originating from agricultural use of fertilizers sludge, and composts), and reduce leaching losses of nitrates. Other issues, that have drawn increasing attention relates to building up carbon stocks, quality of soil organic matter, bio-diversity changes etc. Development of indices that integrate major physical, chemical, and biological properties to measure and monitor soil quality changes as sustainability indicators is emerging a key researchable issue. These aspects will be increasing research focus in Asian Platform countries.

3.1.3. Managing conservation agriculture systems: Crop-Livestock integration

One of the constraints frequently cited in adoption of mulch based systems is the availability of crop residues as they are consumed by livestock. These are the issues, which will call for working hand in hand with the farmers for generating residues without additional need for irrigation water, learning and educating them in developing and promoting conservation agriculture systems under a range of agro-climatic / farming situations.

Diversification at times is taken as substituting a cereal crop with another cereal or legume crop. Such a diversification strategy is very restrictive for capturing the 'double productivity and profitability gains'. Experiences in other platforms suggest that diversification through crop-livestock interactions provide such opportunities, for example, one from the high-value cereal grain product and the other from using the green maize stalks as high-value feed for dairy production. When crop- livestock interactions are integrated in pursuing conservation agriculture, it is probably the best form of conservation agriculture.

3.1.4. Socioeconomic impact

Results of research summarized by different KASSA platforms permit to conclude that benefits from conservation agriculture comes about in different ways. The nature of benefits will change over time. Benefits of conservation agriculture accrue from cost reductions linked to savings in fuel, labour and machinery cost. Effects of conservation agriculture on major gains in crop yields are expected to result from changes in soil physical, chemical and biological properties, which likely come about only with time. Near-term benefits from reduced costs in initial years usually enthruse farmers to adopt conservation agriculture. However, near-term benefits have to be balanced against increased costs resulting from increased pesticide use experienced in other platform countries. Experience with no-till wheat in India, however, has shown reduced incidence of weed, *Phalaris minor*. There are not many studies which document that residue cover in unploughed fields leads to proliferation of pests and diseases compared to conventionally ploughed system. Residues of different crops which may serve as changing food substrate for the microbes likely also have a major effect on the ecological balance. Socioeconomic impact of conservation agriculture appears not to have been studied/ documented well.

3.1.5. Agronomic impact

Conservation Agriculture has emerged as a major strategy to achieve goals of sustainable agriculture. No-tillage when combined with surface managed crop residues sets in motion processes whereby slow decomposition of residues results in soil structural improvement and increased recycling and availability of plant nutrients.

In the context of Asian platform countries it would appear that while environmental problems associated with high productivity regions have been increasingly highlighted, effective strategies are constrained by water shortages and thus appear to

be not in place to devise ways to minimize their impact. Some studies show that nitrates leaching to ground water during the monsoon season can be prevented by growing a catch crop before rice season. However, water shortage for summers have restricted the use of such practices on large scale. Only few attempts have been made to understand the practices that minimize adverse effects.

‘Soil nutrition principle’ is an approach, which has evolved over a period in Argentina looks beyond the concerns for crop fertilization. It provides a more systematic approach that considers the interactions among soil chemistry, soil biology, soil organic matter and structural properties, nutrient cycling etc, rather than putting just the addition of nutrients to a given crop. This has been the result of some long-term studies carried out on no-till. So there is a need for good research on the effect of tillage on changes in soil profile. This aspect in Asian platform needs to be strengthened.

3.1.6. Environmental impact

Similarly as indicated earlier one of the driving forces for evolution of conservation agriculture in many of the Mediterranean platform countries has been the necessity of controlling erosion by rainfall – runoff and wind. Crop residues left on soil surface are an effective way to reduce erosion and several studies have elaborated on processes that contribute to reduced erosion. These include reduced impact of raindrops on soil surface, reduced velocity of runoff and greater opportunity time for infiltration. Other studies bring out the role of decomposing residues in promoting aggregation and stability of aggregates of surface few mm of soil, contributing to enhance infiltration capacity and reduced crusting and proneness to erosion by water and wind. Soil degradation resulting from erosion by water and wind are wide spread and serious problem in both irrigated and rainfed regions in countries of Asian platform. In the Indo-Gangetic Plains, soils are deep and erosion process being insidious; this aspect has not received the desired attention. High intensity monsoon rains concentrated in a span of about 100 days cause heavy soil losses with adverse effects both on on-site and off-sites. In the rainfed ecologies, controls of runoff and soil erosion are most critical in enhancing and stabilizing yield in many risk prone regions where the poorest live. There is urgent need to evaluate and promote elements of conservation approach in addressing resource degradation and livelihood issues for vast majority of people who have been bypassed by ‘Green Revolution’ technology.

3.2. Research gaps and priorities

Research priorities identified by the Asian team in different thematic areas are listed in the table 20.

Table 20. Research gaps and priorities for the Asian platform

Thematic Area and Research Gaps	Priorities
Tillage and crop establishment	
• Extend zero-till /conservation agriculture practices to rainfed and irrigated areas in system crops with contrasting edaphic needs (e.g. double no-till rice –wheat system).	***
• Develop conservation agriculture to improve soil structure to promote rainwater infiltration - long term trends in soil physical properties.	* (***) Sloping lands)
• Refine existing drilling implements for planting into loose residue conditions to prevent burning of straws.	***
Soil fertility and crop nutrition	
• Develop co-culture of green manure and cover crops for major cropping systems.	***
• Role of crop residues (Si) in meeting nutrient (P, K), demands in micaceous and acidic soils.	**
• Sensor based technologies (NDVI) for improved N management.	**
• Develop practices for organic carbon (SOC) accumulation in soils in response to climate change	**
• SOM quality and carbon dynamics	**
Genetic enhancement	
• Develop cultivars with efficient nutrient translocation systems- Nutritionally good quality grains for reduced Medicare costs	***
• Breed-germplasm for heat and drought / excessive moisture tolerance better adapted to conservation agriculture. Interaction effects of genotype-tillage-environment (G x T x E) yet to be harnessed in germplasm improvement programs.	***
• Breed shade loving compatible cultivars in crops for agro-forestry systems and cultivars for improved WUE.	***
Water management	
• Develop zero-till rice seeding practices to save water	***
• Introduce and train, service providers /farmers on precision land levelling. Improve farm advisory services on water use.	***
Crop diversification for better livelihoods	
• Introduce permanent system of raised bed planting to promote diversification through crop incorporation (intensification), crop substitution and mixed cropping/ farming systems (crop-livestock).	***
• Introduce and test efficiency of cover crops in weed and soil moisture management	***

Integrated Pest Management	
• Weed management in zero-till rice.	**
• Develop new molecules for weed management in intercropping systems (e.g. Maize + beans /peas or sugarcane + wheat).	**
• Carryover of disease and pest in rice-wheat or prevalent cropping system.	
• Innovative crop rotations in CA for addressing emerging issues of changing weeds and pests. (less dependence on pesticides)	**
• Role of conservation agriculture vis-a-vis herbicide use in effecting agro-biodiversity.	**
Environmental concerns	
• Monitor the effects of conservation agriculture on GHG emissions and climate change.	**
• Adjust practices to reduce GHG emissions and obviate Climate change effects.	***
• Minimize pollution of land and water resources with nitrate and agrochemicals.	*
• Improve farm advisory services in conservation agriculture for different eco-regions (decision support systems and web based services).	***
Socioeconomic and policy research	
• Socioeconomic analysis of benefits.	**
• Monitor second-order system constraints, particularly changing weed composition and biology with use of herbicides.	*
• Develop knowledge-based system for up-scaling and scaling out conservation agriculture.	**
• Develop indicators to assess impact of conservation agriculture / farming system on quality of natural resources.	***

* Low; ** Medium; *** High

4. Research proposed by the Latin American platform

Three agroecosystems in Latin America were studied by the KASSA project – wheat-soybean and related systems in lowland tropical Bolivia, crop – pasture systems in the Cerrados of Brazil, and multiple-cropping in high rainfall environments in southern Brazil and Argentina.¹²

Apart from all being located in Latin America, these three systems have much in common. They all feature multiple-cropping in non-irrigated, high rainfall environments. They all have experienced substantial farmer adoption of one or more conservation agriculture practices. They all have more or less serious problems of

¹² A fourth system, irrigated horticultural systems in eastern Brazil, was only occasionally mentioned.

“partial adoption” (use of one or more conservation agriculture practices but not others). In all of them, dynamic innovation systems are led and driven by farmers. Finally, they all have one or more soil-related constraints: erodibility, acidity, compaction and/ or crusting.

The suggested proposals for the Latin American platform aim to build on existing strengths. More so than in northern Europe or the Mediterranean, innovation systems in Latin America are more or less in place, some progress in recommendation domain definition has been made, some technologies attractive to farmers have been developed, and a good deal of information has been generated on the consequences of conservation agriculture adoption. In this context, then the following priorities are suggested.

4.1. Impact assessment of the use of external inputs in conservation agriculture on soil and water quality and on biodiversity

High soil quality is a requirement for the conservation of water resources, in addition to being the basis for sustainable agricultural production and to improve ecosystem functions. Ideally, by keeping the soil covered with a straw layer and sowing directly with minimal soil disturbance and using complementary conservation practices such as terracing systems, conservation agriculture reduces soil erosion and the runoff of water, soil sediments and organic matter to rivers and small streams. However it has been observed that the partial adoption of conservation agriculture practices in some countries has resulted in an increase in the use of external inputs such as pesticides. Further research is necessary to better quantify these aspects.

There is a need to define, for every agro-ecological region, a minimum data set of soil and water parameters that best indicate their improvement or degradation. These studies must take into account the diversity of conservation agriculture systems found all over the region.

4.2. Definition of soil quality indicators for different agroecosystems

Practical assessment of soil quality requires a consideration of the physical, chemical and biological functions of the soil. The identification of early warning indicators of ecosystem stress is needed to provide strategies and approaches for land resource managers and policymakers to promote long-term agricultural sustainability. Many evidences show that the microbiological indicators (soil microbial biomass and diversity and soil enzymes activities) are able to detect early changes in soil quality. Since there is a variety of methods to assess the microbiological status of a soil, studies must be conducted to define what methods should be included in a data set of microbial indicators of soil quality in concert with soil chemical and physical measurements.

Considering the continental dimensions of the Latin American platform, it is probable that a soil quality data set will vary from region to region and even among the different management systems in one same region. Another challenge consists in defining the critical values for each of the parameters of this data set, and the most appropriate reference areas (native/ undisturbed vegetation) that will act as control or base line. Efforts in terms of the definition of a soil quality index are necessary to identify problem areas and to monitor changes in sustainability and environmental

quality as related to agricultural management. The idea is that in the future, assessments of the soil quality status of a given area could be made in a routine basis by using proper indicators that are at the same effective, simple, cheap and relatively rapid, allowing the farmer to evaluate the impacts of local management systems.

4.3. Dynamics of soil organic matter in agroecosystems

The clearing and cultivation of undisturbed native areas is accompanied by a decline in soil organic matter (SOM). In the humid tropical regions, SOM decomposition may be intense due to high mean annual temperature and precipitation, especially under intensive or annual soil tillage. Conventional tillage practices cause a disruption in soil aggregates and place crop residues in intimate contact with soil, leading to a more rapid decomposition than surface placement with no tillage. Conservation agriculture practices, especially no-till, result in the accumulation of organic matter in the first few centimetres of the soil profile.

On the other hand, carbon levels at lower depths are similar in both systems, or slightly higher under plough tillage. The stratification of SOM observed under no tillage systems associated with increased levels of soil moisture and smaller variations in temperature, due to soil cover, reflects directly upon the soil microbial community, which has its total microbial biomass and activity more concentrated in the first centimetres of the soil profile as well. For this reason the biological functioning of soils under no tillage systems is completely different of that found in soils under conventional tillage, which affects the organic matter dynamics in the whole system. Diverse crop rotations can change soil habitat by affecting nutrient status, depth of rooting, amount and quality of residue, aggregation/microbial habitat, and microbial activity. For these reasons, the consequences of the partial adoption of conservation agriculture practices with the large predominance soybean monocropping on the different size fractions of soil organic matter with different turnover times also need to be addressed.

Losses and gains of soil organic carbon are not well defined for principal soils in Latin America and more studies are necessary to fill in these gaps. The studies on soil organic matter dynamics (quality, decomposition and accumulation) should be carried out under different management systems including soybean monocropping, and ley farming systems. The changes in SOM and their implications for microbial activity, nutrient cycling, soil structure, aggregates stability and water storage in the humid tropics also need to be determined.

4.4. Quantification of the potential of conservation agriculture for carbon sequestration

Investigations of the soil organic carbon (SOC) dynamics of tropical and subtropical soils can provide valuable information on how to manage such soils to increase stocks and promote C sequestration. Compared to conventional tillage, no-tillage increases the C stocks. Most research on tillage impacts on soils of Latin America is not readily available on literature. Some studies have reported similar mean rates of C sequestration for Brazilian and North and American soils, for instance. However assessments of changes in SOC stocks for different Latin American eco-regions or different non-intensive systems are inconclusive due to high variability and small

number of observations. The adoption of conservation agriculture in large areas such as the Brazilian Cerrados (occupying 207 million hectares) and its impact on C sequestration needs more investigation.

Research on the potential of conservation agriculture for carbon sequestration needs to include data on SOC concentration and bulk density for different layers, but at least to the depth of disturbance (typically 20-40 cm), so that SOC stock and dynamics can be assessed. A larger data base of undisturbed and cultivated soils needs to be compiled to enable better assessment and modelling of SOC with land use change for major Latin American eco-regions and soil types (specially regarding clay content and mineralogy).

4.5. Development of cash and cover crops more tolerant to abiotic stress and compatible to different farming systems

By building up organic matter both directly through decomposition of root and shoot residues, and indirectly through stimulation of microbial activity in their root sphere legume and non-legume cover crops have shown some potential for improving soil structure. In temperate regions these effects include: reductions in bulk density and soil resistance, increases in water retention, infiltration properties and in the stability and amount of macro-aggregates. In addition, while a legume winter cover crop can be a significant source of N for the summer crop, non-legume cover crops can sequester residual nitrate and prevent leaching to ground water. Although crop rotation is one of the most important aspects related to the no-tillage management systems, due to climatic conditions and sometimes economic reasons, few farmers are able to use cover crops for their properties. In the tropical region the most limiting factors are the planting date, which generally occurs after the harvest of the cash crop, and the reduced amount of rainfall during the winter season.

There is a need to select drought tolerant cover crop species adapted to tropical conditions that can be planted after harvesting the cash crops. These species must have a fast initial growth, promote a good soil covering and be able to improve soil chemical, physical and biological properties.

4.6. Dynamics of soil nutrients in agroecosystems and technology development for the increase of efficiency of liming and fertilization

Research developed under conservation agriculture, in the Latin American platform, has shown that the rate, placement and timing of fertilization and soil acidity correction by limestone and consequently nutrients dynamics are altered by adoption of no-till system. Some nutrients concentrate on the surface layers, increasing the risk of loss by runoff, while others are lost by leaching. In addition, by eliminating soil tillage the availability of nutrients to plants is increased. So, the recommendation of fertilizer and limestone for different crops used in various production models that were developed for conventional tillage, require adjustment for rate, placement, and timing. These aspects aim to promote reduction in production systems cost and to prevent environmental adverse impact.

This type of study has to be carried out under systems' approach considering the different agroecological and socioeconomic conditions. These aspects have to be assessed through field studies and on-farm validation and demonstration.

4.7. Studies of genesis, diagnosis, and mitigation of soil compaction in conservation agriculture areas

Under no-till system in various agroecological conditions, the farmer has the perception and different soil studies have shown development of a compacted layer. This compacted layer, characterized by increased soil bulk density and soil resistance to penetration, and reduction of macro pores and total porosity, restricts water fluxes, air diffusion, and plant root development. Chisel ploughing has not been a solution for to this problem. The use of crops in the production models that do not add organic material higher than the decomposition rate may be the main cause of this problem under no-tillage. So, studies of the causes, diagnosis, and mitigation of soil compaction in conservation agriculture areas, require technology development. Solution of this aspect aims at avoiding climate risks and losses in harvest.

This type of study has to be carried out under systems' approach considering the different agro-ecological conditions and different socioeconomic and biophysical features, considering mainly the plant species with potential to add more organic material to the system.

4.8. Technology development for runoff management in conservation agriculture

Under no-till system farmers and technician have perception that the soil surface coverage is sufficient to control soil erosion. This perception has induced farmers to plant without paying attention to landscape and removing all terraces from the field. Terracing systems developed for conventional tillage are too dense to be maintained under no-tillage. In fact conventional tillage terracing imposes far more difficulties for any farm operation than really help to control erosion, mainly due to the highly rolling landscape. These problems associated to the concentration of nutrients on soil surface and intensive rainfall events have promoted losses of soil, water, nutrients, and inputs on site specific points of farmers' fields.

This problem requires field studies, considering the different agroecological conditions, oriented to the development of strategies to control runoff in specific points of the field under no-till system.

4.9. Technology development for precision agriculture

Conservation agriculture considers that farming systems have to focus on economic, social, and environmental aspects, leading to a rational use of farming inputs.

These studies must contemplate different agroecological conditions and different socioeconomic and biophysical features, to develop technologies to efficiently use farming inputs so that to reduce production cost and avoid negative impacts to the environment.

4.10. Study (adaptation/breeding) of species aiming at cropping systems' diversification for different agroecological conditions

Crop rotation is the key factor for the success of no-till system. Thus development of production models composed of different plant species has to be focused on. Plant breeding oriented to modify plant cycle and adjust seeding time, as well as to develop species to promote plenty organic material is an important tool to be used. The results of this research should provide to the farmers a wider plant diversity which helps to plan production models with the least time between harvesting and planting the next crop.

These studies have to cover different agroecological conditions and different socioeconomic and biophysical features, in order to offer different plant materials able to fit to production models.

4.11. Analysis of the sustainability of farmers' conservation agriculture practices in relation to the conservation agriculture "model"

The Latin American platform is recognized as the region with the highest conservation agriculture adoption rates, both by small-and large-scale farmers. Three main components comprise the conservation agriculture "model": suppression of soil disturbance, use of cover crops and crop rotations. However, in most of the situations, farmers have adopted only some parts of the conservation agriculture "package". For instance, some farmers suppress soil disturbance and keep the soil covered, but do not use crop rotations. Other farmers may use crop rotations and cover crops, but perform some soil tillage once every few years. Based on the benefits of the conservation agriculture "model" mainly regarding the improvement of soil characteristics, the conservation agriculture "model" has been largely promoted and many efforts to improve farmers' practices in order to adopt the conservation agriculture "model" has been carried out. However, there is little information regarding the sustainability of the modified "conservation agriculture" practice as performed by many farmers.

The study must be carried out under a systems' approach and have to take into account the different agroecological conditions and the different farming systems. The research should encompass three phases: -i) identification and description of conservation agriculture farmers' practices; -ii) understanding the rationale behind the practices and; iii) assessing the sustainability of these practices, from the technical, environmental and socioeconomic perspectives. Phases i) and ii) can be carried out through interviews and phase ii) can be carried out through interviews, on-farm measurements and on-station experiments.

4.12. Development of conservation agriculture systems less dependant on external inputs

The practice of conservation agriculture generates a new dynamic, with an increased incidence in some weeds, insects and diseases, and a reduced incidence in others. Some pests such as rats and slugs whose incidence is sometimes higher under conservation agriculture still lack studies. For weed, insect and diseases management, crop rotations are the pillar of any IPM/IWM program. If crop rotations are not used

in conservation agriculture, the reliance on chemicals is higher, resulting in higher costs and negative environmental consequences. More research in both tropical and subtropical regions is required in order to develop alternatives to chemical control for conservation agriculture, starting by basic studies aiming at understanding the dynamics of pests and weeds generated by the introduction of conservation agriculture.

Besides policies for the promotion of the use of crop rotations, basic studies are necessary in order to better understand the new dynamics created by the practice of conservation agriculture. Research on allelopathy, biological control and others aiming at decreasing the reliance on pesticides use are necessary.

4.13. Technology development for specific crops under conservation agriculture

Despite the available technologies for the cultivation of cotton under conservation agriculture principles, residues are buried by ploughing in order to prevent the incidence of the pest *Anthonomus grandis*. Despite the efforts of tobacco companies in the promotion of conservation agriculture, tobacco is still cultivated under conventional systems by small-scale farmers in subtropical region. Although lacking scientific data, evidences from farmer's experiences indicate that the main reasons for the inappropriateness of conservation agriculture to tobacco cultivation are: -i) susceptibility of the crop to high soil moisture; -ii) higher incidence of slugs in conservation agriculture mainly during wet periods and; -iii) lack of broadleaves herbicides. Although the availability of technologies for potatoes, groundnuts and cassava, when these crops are harvested, great amounts of soil are disturbed. Development of harvesting equipment with lower soil disturbance is required.

4.14. Impact assessment of the adoption of GM crops and conservation agriculture

Herbicide-resistant genetic modified soybeans have been largely used in Argentina and Brazil. The main driving force for the adoption of this technology is that it simplifies the cropping management and, according to farmers, reduces operational costs. However, the adoption by farmers - although it is an important indicator- has been the only evidence of its benefits. Yet there is no scientific data available addressing the economic, social and environmental impacts of this technology in the short, medium and long term.

V. Conclusions

Sustainability of agriculture is one of the most relevant and global issues. Within the context of the KASSA project, sustainable agriculture is defined as a kind of agriculture that “*ensures social and economic viability, food security and safety while conserving and even improving local and global basic resources and the environment*”.

Beyond this official KASSA project definition, the notion of sustainability was used by platforms’ teams in at least five distinct but interrelated ways:

- Sustainability as continuity – the ability of an agroecosystem to preserve its productive capacity for an indefinite period;
- Sustainability as resilience – the ability of an agroecosystem to flexibly adapt to changing circumstances and still remain productive;
- Sustainable intensification – the continuous enhancement of the productivity of an agroecosystem in ways that do not threaten its long-term productive capacity or resilience;
- Sustainability as resource conservation – management of an agroecosystem in ways that conserve land and water resources;
- Sustainability for public health and welfare – management of an agroecosystem in ways that avoid processes of pollution that could threaten public health or food safety.

Regardless of how the notion of sustainability is interpreted, it is clear that the introduction of conservation agriculture has improved sustainability in at least two ecosystems – “multiple-cropping in high rainfall environments in southern Brazil and central Argentina” and “crop – pasture systems in the Cerrados of Brazil”. Partial adoption of some conservation agriculture practices has also occurred in the Indo-Gangetic Plains and in lowland tropical Bolivia, but it is too early to determine whether system sustainability has truly been assured. Fortunately, in both systems, work proceeds to develop and foster the adoption of a more complete set of conservation agriculture practices.

The “pillars of sustainability”, (“*ecosystem, society and policy*”, “*knowledge generation*”, “*technology*” and “*social, economic and environmental impacts*”) featured in the conceptual framework of the KASSA project, were shown to be useful in understanding the strengths and weaknesses of conservation agriculture, and pointing the way for further action in order to improve its sustainability.

Ecosystem contributions to food security, poverty reduction, environmental preservation and climate change

KASSA project results allow some limited conclusions to be drawn regarding the contributions of selected agroecosystems towards social goals, among them food security, poverty reduction, environmental preservation and climate change. Of great interest is the extent to which the adoption of conservation agriculture in these systems has improved their capacity to contribute to these goals.

Poverty

Of all of the agroecosystems studied by KASSA, only three of them are troubled by problems of absolute poverty among large numbers of people. These are the three ecosystems in Asia – the Indo-Gangetic Plains, and the river valleys and rainfed hillsides of northern Vietnam. The development and adoption of conservation agriculture in Vietnam has not yet reached the stage where conclusions can be drawn regarding its contribution to poverty reduction.

In the Indo-Gangetic Plains, initial adoption and ongoing impact studies (not cited by platform teams) suggest that no-till wheat after rice has resulted in improved incomes for hundreds of thousands of small – scale farm households. No-till has led to decreased production costs, higher crop yields, and expanded opportunities for system diversification. As of yet, there is no indication that landless households have been harmed by labour displacement. There is one group of farmers who have been negatively affected by the introduction of no-till –larger farmers with extensive investments in conventional tillage equipment, who have experienced a steep reduction in demand for conventional tillage rental services. No-till adoption has not yet reached levels at which it might affect food prices for urban consumers.

Food security

For the most part, food security is not at present a problem in ecosystems studied by KASSA. Such problems are heavily concentrated in sub-Saharan Africa and, to a lesser extent, South Asia. In the Indo-Gangetic Plains, food insecurity is mostly a threat to specific vulnerable groups, e.g., the landless and, in some instances, women and children. At the South Asia regional level, there is a food surplus.

Future food security, however, is an issue. In the coming decades, the demand for food products will continue to expand, driven by population and income growth. Food insecurity during this time frame will be concentrated in eastern and southern Africa, and parts of Central, South and East Asia. Conservation agriculture practices are likely to become a critically important part of efforts to sustainably intensify and diversify agroecosystems, without irreversibly damaging the resource base. Efforts described by the KASSA Asian platform team, regarding the development of conservation agriculture technologies in the Indo-Gangetic Plains, and in Vietnam, are important initial steps.

Environmental preservation

KASSA results show convincing evidence that conservation agriculture can reduce soil erosion and land degradation in those environments where erosion is an overwhelmingly serious threat. This evidence comes from high-rainfall sloping land agroecosystems in southern Brazil and northern Vietnam. However, in some situations, complementary technologies for runoff control are necessary. In the Mediterranean dryland systems, conservation agriculture reduces erosion by water and wind.

Another possible contribution of conservation agriculture to environmental preservation comes from its potential to improve water productivity in water-scarce environments. In principle, improved farm-level water productivity conserves agricultural water (e.g., reduced pumping of groundwater) or frees up water for other agricultural or non agricultural uses. Unfortunately, not much information on the relationship between conservation agriculture and water productivity was provided, apart from some limited evidence drawn from irrigated systems in the Indo-Gangetic Plains.

The relationship between conservation agriculture and environmental pollution linked to the use of fertilisers and pesticides and their fate in the agroecosystems remains less clear.

Climate change

Evidence presented in earlier sections suggests that conservation agriculture contributes in many instances to carbon sequestration and to reduction of carbon dioxide emissions. It does so by means of three mechanisms: reduced fuel use for agricultural machinery and water pumps, increased levels of soil organic carbon, and likely reduced emissions from the soil. However, the extent to which each of these mechanisms is present varies a great deal across conservation agriculture technologies and across ecosystems and, no information was provided on methane and nitrous oxide emissions.

Two important subjects related to climate change were not addressed in KASSA - the extent to which the use of conservation agriculture practices can help agroecosystems adapt to climate change, and the relative importance of conservation agriculture practices vs. non-agricultural interventions in global efforts to sequester carbon or reduce greenhouse gas emissions.

Ecosystem limitations in adopting conservation agriculture

Conservation agriculture is not equally appropriate for all agroecosystems. The list of constraints presented earlier makes it clear that conservation agriculture technologies will be relatively difficult to introduce when one or more of the following are present:

- Soil cover and no-till result in cooler soil temperatures, delayed sowing, and depressed yields;
- Soils are susceptible to compaction;
- Soil cover from crop residues is either insufficient or excessive;

- Soil puddling is performed for wetland rice production;
- Cover crops increase costs but produce few benefits;
- The use of agronomically sound rotations is ruled out by farm-level economics;
- Pest, disease or weed problems are increased.
- Unit production costs are increased, taking account of all changes in cost categories;
- Suitable conservation agriculture implements are not available;
- Farmers are not compensated for the social benefits they produce when using conservation agriculture (e.g., land and water conservation);
- Farmers and technicians have little knowledge about conservation agriculture, or have a mind-set that discriminates against its use;
- Agricultural research and other policies do not encourage the emergence of dynamic farmer-led innovation systems for knowledge generation and sharing.

Knowledge limitations in sustaining conservation agriculture

Results of the KASSA project show that the shifting from plough-based agriculture to conservation agriculture is far from a straightforward technical change. The proper use of the technology i.e. simultaneous use of no-till/reduced till, cover crop and crop rotation require a continual adjustment of the system which is knowledge consuming. Yet, there are relatively few scientific data available on conservation agriculture systems. Major gaps in knowledge identified by KASSA teams relates to:

- The impact of conservation agriculture technologies on soil processes and soil life and health (micro and macro biodiversity) and consequences for sustainable soil management are not yet well understood. Knowledge generation in this domain may help improving soil fertility and water management and help fine-tuning strategies for improved pest, disease and weed management; crop breeding; carbon sequestration and reduction of greenhouse gas emissions and erosion mitigation.
- The impact of agro-chemicals used in conservation agriculture on the natural resource base and human health needs more study as well, particularly the fate of heavy metals, pesticide and persistent organic pollutants in the environment and their risks for soil, water and the food chain quality.
- The impact of conservation agriculture on farm incomes and more generally on e.g. costs, employment, rural development, natural resource base quality and food prices... are not well known. More studies in this domain may help addressing the profitability and the economic viability of conservation agriculture in both small scale and large scale farming and, rainfed and irrigated systems taking into account the conditions of market, policy and institutional change.

Also, there are clear needs for better information and decision support tools on site specific suitability of conservation agriculture taking into account climate, soils and market conditions and for the development of adapted implements.

The complexity of conservation agriculture requires a much more systematic, participatory and multi-disciplinary approach to research, involving all relevant stakeholders, and more emphasis on knowledge management, education, training, and dissemination strategies. Research and education remain fundamental to help ensure that conservation agriculture will contribute to objectives of sustainable development.

Final word

Wherever agriculture is practiced, it affects – and is affected by – human activity. Agriculture provides food and fiber, is fundamental to rural incomes, and contributes to many other functions, e.g., landscape preservation and carbon sequestration. However, in many cases agriculture adversely affects biodiversity, soil quality, the quantity and quality of water resources and the environment. For these reasons, agriculture often has been subjected to political debate and scrutiny and has been governed and shaped by multiple policies.

In the recent past, agriculture was mainly driven by productivity goals. At present, however, the sustainability of the current agricultural model is being questioned. However, information on the theory and practice of sustainable agriculture is scattered around the world. In response to such concerns, several models for sustainable agriculture have emerged: conservation agriculture, direct-sowing, conservation tillage, no-till, resource-conserving technologies, organic farming, etc.

One of the most spread systems worldwide is conservation agriculture. It is being practiced in a number of places, including Australia, North America, the southern part of South America, the Indo-Gangetic Plains of South Asia and China. Its socioeconomic and environmental impacts are thought to be favourable and significant. Understandably, conservation agriculture has become an item of widespread interest, also in Europe.

The objective of KASSA project – (Knowledge Assessment and Sharing on Sustainable Agriculture) was to make a systematic state of the art inventory of the global knowledge on conservation agriculture. For the last 18 months, the 28 international partners of KASSA had built up a comprehensive knowledge base on the experiences in conservation agriculture in Europe, Asia, Latin America and North Africa – its practices, approaches, systems, conditions and challenges. Results apply to local stakeholders and among them, farmers and professionals, researchers and policymakers.

The KASSA team hopes that these results can strengthen the efforts in making agriculture meeting socially desirable goals: improve food security and safety, generate employment, slash production costs, conserve soil, enhance biodiversity, improve water availability, quality and productivity, reduce pollution and lower the emission of greenhouse gases.

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