The economics of conservation agriculture

Food and Agriculture Organization of the United Nations

Preface

Conservation agriculture (CA) improves resource use through an integrated management approach. It contributes to sustainable production and its advantages include lower inputs, stable yields and improved soil nutrient exchange. CA is also generally more profitable than other conservation technologies.

In addition to financial factors, CA-adoption models identify other significant factors relating to management objectives, stewardship motives and fundamental constraints. The collective dimension is sometimes critical to success.

Policy is important to CA adoption. Successful policies require a thorough understanding of farm-level conditions and site-specific programmes that utilize various policy tools. More uniform policies could help develop social capital and promote conditions for collective action.

Developing sustainability indicators that evidence the benefits of CA can help meet the need for improved analysis and information. A whole-farm approach may be the most appropriate basis for financial analyses as it can capture the full range of farmers’ responses and incorporate the options available.

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Chapter 1

Introduction

Background and objectives

Conservation agriculture (CA) aims to make better use of agricultural resources through the integrated management of available soil, water and biological resources, combined with limited external inputs. It contributes to environmental conservation and to sustainable agricultural production by maintaining a permanent or semi-permanent organic soil cover. Zero or minimum tillage, direct seeding and a varied crop rotation are important elements of CA.

Adoption of CA at the farm level is associated with lower labour and farm-power inputs, more stable yields and improved soil nutrient exchange capacity. Crop production profitability under CA tends to increase over time relative to conventional agriculture. Other benefits attributed to CA at the watershed level relate to more regular surface hydrology and reduced sediment loads in surface water. At the global level, CA sequesters carbon, thereby decreasing CO_2 in the atmosphere and helping to dampen climate change. It also conserves soil and terrestrial biodiversity.

Conservation agriculture is practised on about 57 million ha, or on about 3 percent of the 1 500 million ha of arable land worldwide. Most of the land under CA is in North and South America. It is rapidly expanding on small and large farms in South America, where practising farmers are highly organized in local, regional and national farmers' organizations. In Europe, the European Conservation Agricultural Federation, a regional lobby group, unites national CA associations in the United Kingdom, France, Germany, Italy, Portugal and Spain.

Despite these apparent advantages, and despite the few notable exceptions in the developing world, CA has spread relatively slowly, especially in farming systems in temperate climates. The transformation from conventional agriculture to CA seems to require considerable farmer management skills and involves investment in new equipment. However, it may also require minimum levels of social capital to foster its expansion.

In the light of this situation, the aim of this study is to identify and analyse the financial and other conditions that spur farmers to adopt CA practices. The study reviews the literature and analyses the economics of technology adoption at farm level. It identifies divergences between privately appropriable benefits and national or global economic benefits stemming from an expansion of the area under CA. It also examines the policies and options for bridging these, particularly in the light of the current policy setting in both developed and developing countries.

The remainder of this chapter examines the concept of CA. It discusses the economic benefits of CA in order to develop a rationale for intervention at the national and international levels to promote CA adoption. It then presents a conceptual framework to help understand the influences that correlate with the adoption of CA by farmers. Chapter 2 analyses the farm-level situation in terms of financial incentives for adoption and other factors. Chapter 3 discusses the existing policy setting for CA and highlights new directions for policy. Chapter 4 presents conclusions and recommendations from the study. The appendixes provide summaries of other studies examined in the course of the research.

Defining conservation agriculture

CA has emerged as an alternative to conventional agriculture as a result of losses in soil productivity due to soil degradation (e.g. erosion and compaction). CA aims to reduce soil degradation through several practices that minimize the alteration of soil composition and structure and any effects upon natural biodiversity. In general, CA includes any practice that reduces, changes or eliminates soil tillage and avoids the burning of residue in order to maintain adequate surface cover throughout the year (ECAF, 2001). In contrast, conventional forms of agriculture regularly use ploughs to enable a deep tilling of the soil (FAO, 2001). The line between conventional and CA often blurs as conventional agriculture utilizes many practices typical of CA, such as minimum or no-tillage. Hence, the differentiating feature of CA and conventional agriculture is the mind-set of the farmer. The conventional farmer believes that tilling the soil will provide benefits to the farm and would increase tillage if economically possible. On the other hand, the conservation farmer questions the necessity of tillage in the first place and feels uncomfortable when tillage occurs.

CA maintains a permanent or semi-permanent organic soil cover consisting of a growing crop or a dead mulch. The function of the organic cover is to physically protect the soil from sun, rain and wind and to feed soil biota. Eventually, the soil micro-organisms and soil fauna will take over the tillage function and soil nutrient balancing, thereby maintaining the soil's capacity for self-recuperation. Residue-based zero tillage with direct seeding is perhaps the best example of CA, since it avoids the disturbance caused by mechanical tillage. A varied crop rotation is also important to avoid disease and pest problems. The last two decades have seen the perfecting of the technologies associated with minimum or no-tillage agriculture and their adaptation for nearly all farm sizes, soil and crop types and climate zones.

Some examples of CA techniques include:

- Direct sowing/direct drilling/no-tillage: The soil remains undisturbed from harvest to planting except for nutrient injection. Planting or drilling takes place in a narrow seedbed or slot created by coulters, row cleaners, disk openers, in-row chisels or roto-tillers. Weed control is primarily by herbicides with little environmental impact. Cultivation is a possibility for emergency weed control. This strategy is the best option for annual crops.
- Ridge-till: The soil remains undisturbed from harvest to planting except for nutrient injection. Planting takes place in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is by herbicides and/or cultivation. Ridges are rebuilt during cultivation.
- Mulch till/reduced tillage/minimum tillage: The soil is disturbed prior to planting. Tillage tools such as chisels, field cultivators, disks, sweeps or blades are used. Weed control is by herbicides and/or cultivation. In non-inversion tillage, soil is disturbed (but not inverted) immediately after harvest to partially incorporate crop residues and promote weed seed germination to provide soil cover during the intercrop period. These weeds are later chemically destroyed (using herbicides) and incorporated at sowing, in one pass, with non-inversion drills.
- Cover crops: Sowing of appropriate species, or growing spontaneous vegetation, in between rows of trees, or in the period of time in between successive annual crops, as a measure to prevent soil erosion and to control weeds. Cover-crop management generally utilizes herbicides with a minimum environmental impact.

The definition of CA used in this study is broader than that used by FAO (no-tillage with direct seeding and maintenance of soil cover/crop residues with no incorporation, along with crop rotations). The wider interpretation of the concept encompasses a larger number of data and informational sources, as many studies employ differing definitions of CA and the broad definition presented here captures most of this variation.

An economic rationale for promoting conservation agriculture

Table 1 presents a profile of benefits and costs associated with CA. The distinction between local, national and global impacts is important as it is possible to rationalize national or global programmes supporting the adoption of CA according to how significant the net benefits are at this level. The benefits at the national level are especially important and they strongly argue for policy support at this level. Uri *et al*. (1999a) estimated that the realized erosion benefits (avoided losses from sheet, rill and wind erosion) for the United States from the existing areas under conservation tillage ranged from US$90.3 million to US$288.8 million in 1996.

From the farmer's perspective, the benefits of CA can be either on-site (private) or off-site (reduced sediment pollution, carbon sequestration, etc.). Table 1 shows that while many of the incremental costs associated with adopting CA accrue at the farmer level, relatively few of the benefits do so. Table 1 appears to confirm that there is a divergence between the social desirability of CA and its potential on-farm attractiveness.

Few empirical studies consider the economic benefits of adopting CA in the tropical agro-ecological zone, so most accumulated evidence is for developed regions such as North America. For example, Stonehouse (1997) simulated full-width no-plough and no-till use in southern Ontario, Canada, and found that both provided modestly higher on-farm benefits than did conventional tillage. The advantage of no-plough and no-till was even greater with off-site benefits included. The off-site benefits considered were downstream fishing benefits and reduced dredging costs. These accounted for 43 percent and 10 percent, respectively, of the net social benefits from conservation tillage. Thus, despite marginally higher profits under CA, the inability to capture off-site benefits means that fewer farmers adopt CA than might otherwise be the case.

Other studies find a trade-off between economic returns and environmental integrity with the adoption of increasingly intensive conservation agricultural practices. Kelly *et al*. (1996) find that strict no-till produces higher returns than conventional tillage and reduces an environmental hazard index from 78.9 to

TABLE 1
Potential economic benefits and costs associated with conservation agriculture and their incidence

Benefits and costs	Incidence		
	Local	Nat./reg. level	Global
Benefits			
Reduction in on-farm costs: savings in time, labour and mechanized machinery	✓		
Increase in soil fertility and retention of soil moisture, resulting in long-term yield increase, decreasing yield variations and greater food security	✓	✓	✓
Stabilization of soil and protection from erosion leading to reduced downstream sedimentation		✓	
Reduction in toxic contamination of surface water and groundwater		✓	
More regular river flows, reduced flooding and the re-emergence of dried wells		✓	
Recharge of aquifers as a result of better infiltration		✓	
Reduction in air pollution resulting from soil tillage machinery		✓	✓
Reduction of CO_2 emissions to the atmosphere (carbon sequestration)			✓
Conservation of terrestrial and soil-based biodiversity			✓
Costs			
Purchase of specialized planting equipment	✓		
Short-term pest problems due to the change in crop management	✓		
Farmer needs new management skills – requiring farmer's time commitment to learning and experimentation	✓		
CA involves the application of additional herbicides	✓	✓	
Formation and operation of farmers' groups	✓	✓	
High perceived risk to farmers because of technological uncertainty	✓	✓	
Development of appropriate technical packages and training programmes		✓	

Sources: adapted from ECAF, 2001; and FAO, 2001.

64.7. The index takes into consideration soil erosion risk, phosphorous and nitrogen losses, and potential pesticide contamination. By further incorporating cover crops and replacing fertilizers with manure, the CA option becomes less profitable than conventional tillage. However, the environmental hazard index declines to 50 or lower, making the economic-environmental trade-off clear from a social perspective.

The global concern about soil degradation helps support an argument for intervention at the international level. This argument stems not just from a concern about what is occurring within individual nations but also from the possible presence of regional or global costs imposed by soil degradation. In other words, there may be global benefits from adopting CA and other soil-enhancing technologies. Table 2 presents a classification of the various ecosystem functions associated with soil resources that might have a global dimension.

Table 2 shows that there are potential global benefits associated with the adoption of CA. For example, there is a link between carbon sequestration in soil and global warming as the long-term capture of carbon in organic matter reduces the atmospheric load of carbon. However, the benefits associated with carbon sequestration in soil may be elusive if soil degradation results in a transfer of carbon from one location to another with no net release to the atmosphere. For CA, Uri (1999a) argues that the "benefits to be gained from carbon sequestration will depend on the soil remaining undisturbed".

In the absence of sustainable soil management practices, soil degradation can lead to crop and livestock losses, with regional or global consequences (refugees, famine, etc.). Where the rest of the world provides assistance, these

TABLE 2
Ecosystem functions of lands under conservation agriculture and the global consequences of non-adoption

Ecosystem functions of soil (indirect use values)	Potential global or regional consequences of soil degradation
Supports domesticated plants (e.g. crop) and animals (e.g. livestock)	Loss of crop/livestock production, leading to eco-refugee problems & famine; international intervention required
Supports wildlife habitat	Loss of globally important biodiversity
Source of micro-nutrients for human consumption (e.g. food quality vs. quantity)	Dietary deficiencies and diseases, requiring international intervention
Buffering & moderation of hydrological cycle (e.g. drainage, temporary storage, etc.); watershed protection	Flooding, soil transport and trans-boundary sedimentation problems; poor infiltration leads to reduced crop yields (see above)
Decomposition & recycling (e.g. waste disposal)	Loss of significant soil microbe & earthworm biodiversity (e.g. *penicillin, streptomycin*); waste accumulation of global proportions
Regulation of atmospheric gases & elemental cycles (e.g. carbon sequestration)	Greenhouse gas releases and global warming linkage as organic matter is removed

Source: adapted from Scherr, 1999.

resources are wasted if the earlier adoption of CA or other practices could have avoided the situation. In addition, lands under CA support terrestrial wildlife and soil microfauna that are important components in global biodiversity, as demonstrated by the discovery of penicillin and streptomycin. Thus, good soil conservation and management can have benefits that the individual farmer does not anticipate, but which do have real implications for the global environment.

A CONCEPTUAL FRAMEWORK FOR STUDYING THE ADOPTION OF CONSERVATION AGRICULTURE

Farmers who switch to some new technique from conventional practice may do so for a variety of reasons. They may detect a more efficient and profitable way to produce, or they may perceive a problem and in seeking solutions arrive at a new practice, such as CA. The problems stimulating the possible change to CA are typically soil degradation, soil erosion or declining crop yields due to deteriorating soil fertility. These views are associated with the traditional model of innovation and the adoption of new technologies in many industries, including agriculture (Box 1).

Some farmers have adopted CA because they found that immediate yield benefits or profits were attractive. In this situation, a clear financial incentive has induced the change in behaviour, as suggested by the classical model described in Box 1. However, it may be inappropriate to rely on the classical model as a basis for promoting the adoption of agricultural conservation technologies (e.g. no-till). This is because the adoption and diffusion model is based on "voluntarism on the part of the farmer's decision making and the economic gain attached to the new behaviour" (van Es, 1983). As conservation technologies may result in net social benefits, but may also result in a financial loss at the farm level, the classical model shown in Box 1 may not bring about a socially optimal level of CA adoption.

Moreover, some authors argue for the presence of a continuous complex innovation process governing agricultural technologies such as CA, using the example of zero tillage. These innovation systems are non-linear and involve complex interactions and feedbacks among agents (e.g. farmers, extension agents, and private enterprises). These authors argue that continuous complex innovation systems are characterized by the presence of agents that have limited information but are always in search of new technological opportunities. In addition to individual agents' actions, initial circumstances and the working of

Box 1

A primer on innovation adoption and diffusion

The study of innovation adoption and diffusion has its origins in the Midwestern United States. In an Iowa State University study, Ryan and Gross (1943) showed that the pattern of adoption and diffusion of a maize hybrid was systematic (i.e. regular), thereby opening the door for further research. The adoption and diffusion of the innovation process has been characterized as the acceptance over time of some specific item by individuals (or adopting units) linked to specific channels of communication. The 'innovation' includes "any thought, behaviour, or thing that is new because it is qualitatively different from existing forms" (Jones, 1967). This wide definition captures any idea or process that is perceived to have utility. In an agricultural context, this might be a new crop variety or management practice adopted by an individual, family or corporation. Much research has focused on the adopter in order to determine what variables might contribute to the adoption or rejection of an innovation. While profit/satisfaction maximization is commonly a key determinant, other variables such as education levels of adopters can play a significant role in adoption. Finally, 'diffusion' is the process by which an innovation spreads over time within a given social system. Figure 1 shows the bell-shaped distribution of individual innovativeness and the percentage of potential adapters typically thought to fall into each category. On one extreme of the distribution are the innovators. Innovators are the risk takers and pioneers who adopt an innovation very early in the diffusion process. On the other extreme are the laggards who resist adopting an innovation until rather late in the diffusion process, if ever. Figure 2 plots adoption over time. Typically, innovations diffuse over time in a pattern that resembles an s-shaped curve. That is, the adoption rate of an innovation goes through a period of slow, gradual growth before experiencing a period of relatively dramatic and rapid growth.

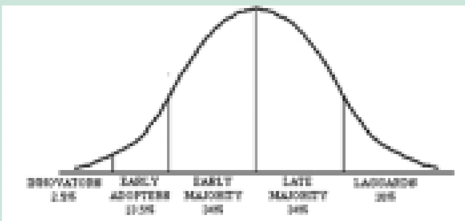


FIGURE 1
Bell-shaped curve showing categories of individual innovativeness and percentages within each cateory

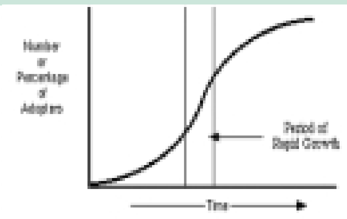


FIGURE 2
S-curve representing rate of adoption of an innovation over time

Source: Surrey, 1997.

feedback loops have a great bearing on the innovation process, making it unpredictable. The resulting technological innovation stems from a particular mix of initial conditions, random events and long-term trends. As an example, the response of pests to new control techniques is unpredictable, yet has a significant influence on the evolution of future technology development and adoption.

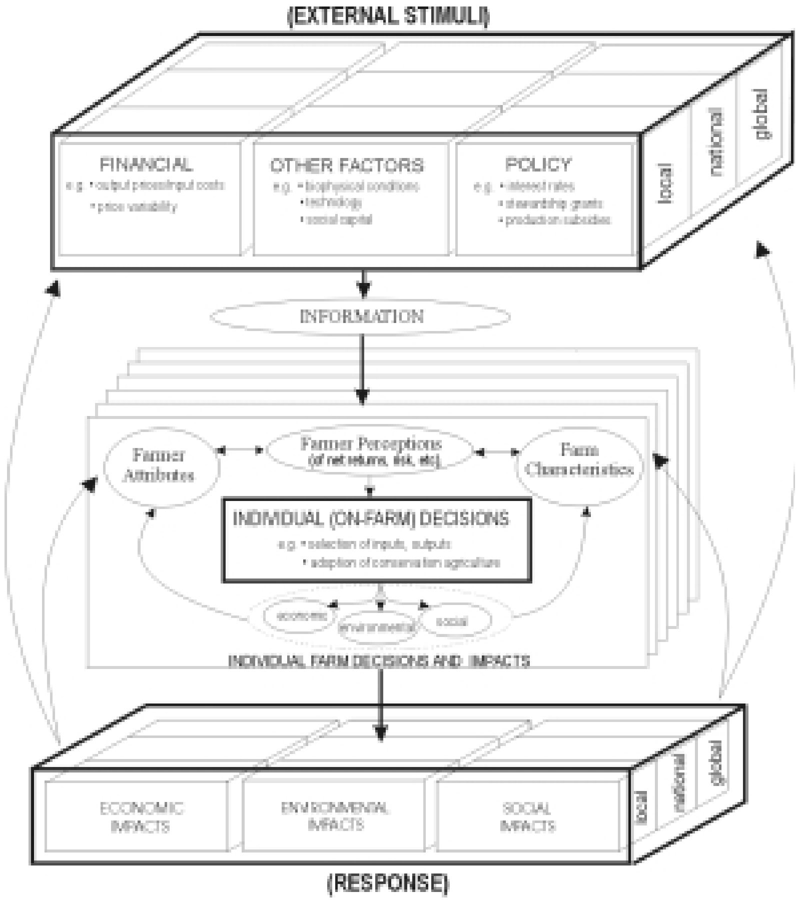
Regardless of the motivating factor or the model of adoption assumed, farmers consider only those aspects of their operation that are relevant from a private perspective. This process typically involves only on-farm considerations. However, it could extend to impacts on neighbours and future generations if social relations and stewardship considerations receive high personal priority. Despite the more limited view, many factors influence this private perspective and help to mould decisions about new technologies or a change in farm practices. Figure 1 shows one view of this process.

In Figure 1, households make technology choices and decisions about the use of their soil resources under the constraints imposed by their socio-economic attributes and on-farm resources, as well as higher level factors at the local to global scales. For example, lacking adequate tenure and access to credit, the farmer cannot invest in CA if this requires a large capital outlay. Information about new technologies and financial conditions is a precursor to changes in farm practices and acquiring it does not usually involve large financial outlays. Government credit and extension policies play an important role here. In contrast to the more direct working of agriculture sector policies and financial incentives, some social and institutional factors have a more indirect influence. Nonetheless, all these factors affect the net returns, risks and other pecuniary elements that drive the decision-making process.

Central to this model of the decision-making process are farmers' perceptions. Changing policy and financial incentives or declining natural resource quality signal to the farmer that the current pattern of use of household resources may no longer be desirable. There is controversy over the extent to which farmers perceive progressive deterioration in their natural resource base. However, there is now sufficient evidence that smallholders are often aware of soil degradation, although other factors affecting production may mask this at times. Figure 3 portrays the detection of soil degradation as the working of feedback mechanisms.

CA is just one of many options available to farmers responding to perceived changes in their production environment. For example, all or a few of the household's members may migrate or accept off-farm employment, or remain behind and modify farming practices. Critically, the impact on soil productivity can be either positive or negative, depending upon numerous factors. If

FIGURE 3
A conceptual framework for studying conservation agriculture adoption



Source: adapted from Bradshaw and Smit, 1997; and FAO, 2001.

households choose migration, they may reduce the intensity with which they farm existing plots, or abandon their old lands altogether and bring new land in frontier areas under cultivation. The latter can have serious implications if farmers transfer unsustainable soil management practices to new areas. There are also many technical alternatives available to producers if they choose to change existing management rather than migrate, and these include CA. The choices of individual farmers are cumulative and can have eventual impacts well beyond the individual farm (Table 2).

The working of the feedback mechanisms (Figure 3) closes the loop and there is the potential for either a self-reinforcing series of improvements in soil productivity, or spiralling degradation.

Chapter 2

Factors influencing the adoption of conservation agriculture

Financial analyses of conservation agriculture versus conventional practices

It might be assumed that CA is more profitable in steep-sloping, high rainfall tropical regions (e.g. Latin America) than in flatter temperate areas (e.g. Canada, the United States), since the former would be subject to a higher risk of erosion under conventional tillage. But such a generalisation would hide a number of the complexities that make the analysis of financial returns from CA difficult. For example, in 7 of the 12 recent cost studies reviewed for this study (Appendix 1), reduced or no-tillage showed higher net returns than conventional tillage, and most of these studies involved temperate regions.

The temperate agro-ecological zone in developed countries

One of the first comprehensive financial analyses of CA on large farms in developed countries (Crosson, 1981) compared the on-farm costs of conventional tillage with conservation tillage in the United States. More recent reviews have tended to reinforce its conclusion that CA has a small cost advantage over conventional tillage but that site-specific conditions could alter this result in various ways (Table 3). The following input cost aspects form the basis for these general conclusions.

Machinery and fuel costs

This is the most important cost item for larger producers and so the impact of CA on these expenditure items is critical. Most analyses suggest that CA reduces machinery costs. Zero or minimum tillage means that farmers can use a smaller tractor and make fewer passes over the field. This also results in lower fuel and repair costs. However, this simple view masks some complexities in making a fair comparison. For example, farmers may see CA as a complement to rather than as a full substitute for their existing practices. If they only partially switch to CA (e.g. on some fields or in some years), then their machinery costs may rise as they must now provide for two cultivation systems, or they may simply use their existing machinery inefficiently on their CA fields.

To capture such complexity, economists distinguish between short-run and long-run costs, where the former assumes no adjustment to existing capital equipment and the latter assumes such an adjustment. A comparative study of CA and conventional tillage in Wisconsin (Mueller *et al.,* 1985) found that short-run average costs under CA exceeded long-run average costs by about 7 percent. The short-run average costs per hectare for CA were greater than for conventional tillage. However, after adjustments to capital, CA costs fell below those of conventional tillage in the long run.

Similarly, the expectation is for fuel costs to be lower under CA, and this is generally the finding in most studies. Falling fuel prices should encourage greater adoption of CA. One study (Uri, 1998a) shows that the price of crude oil has a statistically significant but relatively minor effect on the intensity of CA (but not adoption by new farmers). It finds that a 10 percent increase in the United States in the price of crude oil is associated with an expansion in planted hectares under CA of 0.4 percent, with the expansion being concentrated primarily on existing CA farms.

Pesticide costs

Offsetting lower machinery costs are higher herbicide applications under CA, especially during the early adoption period and with no-till. Indeed, herbicides substitute for the use of machinery to keep weeds under control. Site-specific factors are important as perennial weeds can present problems for CA. Nonetheless, herbicide application rates and the ability to fully control weeds under CA in all situations remains a controversial and continuing area of CA research. Recent assessments have tended to argue that herbicide applications decline over time and may eventually fall to a level equal to that of conventional tillage (USDA, 1998). Insect control is less an issue in conventional and CA comparisons. As most pesticides are petroleum based, crude oil prices are liable to affect their cost to farmers. If so, then a higher crude price would mean higher herbicide costs, partially offsetting CA's relative cost advantage stemming from lower machinery fuel requirements (this may explain the small response found by Uri).

Labour costs

Much attention has focused on the apparent reduction in labour requirements under CA. This reduction follows from the decreased demand for labour for land preparation at the beginning of the growing season. Some estimates put this reduction at 50-60 percent during this time period. On large mechanized farms in the developed world the true impact of this saving is small as labour costs account for under 10 percent of total per acre costs (Table 3). However, on some farms in the developed world, the trend towards increased off-farm work has made even the relatively small labour savings under CA attractive. Indeed, some case studies have cited the time savings provided by CA as the primary motivation for the adoption of conservation tillage (Wandel and Smithers, 2000).

Fertilizer and other input costs

Most comparative analyses of the costs of conventional tillage versus conservation tillage assume that other production inputs remain unchanged following a switch to CA. A debate continues concerning fertilizer use under CA as there is evidence, that CA adoption affects nitrogen use by crops and leaching. Uri (1997) finds some increase in fertilizer use by maize farmers adopting conservation tillage in the United States. Additionally, if the application of fertilizers under CA requires greater management skill, then application costs could rise even if application rates do not. A more general finding is that CA requires greater management skills and it may be costly for farmers to acquire these. CA may also affect seed purchases as farmers may be able to avoid some pest problems by investing in more resistant seed varieties. However, this increases costs.

The comparative data in Table 3 reveal a consistent picture in recent decades concerning conservation tillage costs in the United States. More recent estimates tend to show a wide range for CA, recognizing the variation in site-specific conditions (e.g. drainage, rainfall). Perhaps more significantly, the cost items listed in Table 3 represent only a subset of total costs as other production inputs and land were assumed to remain constant under either cultivation system. Putting the cost savings attributable to CA in the context of these total costs, any cost advantage amounts to about 5-10 percent in 1979 and probably about the same in the 1990s.

Also missing from many cost comparisons of conventional and conservation tillage is an analysis of risk factors. One aspect of risk is a recognition that yields might vary under the different cultivation systems. Much debate has centred on whether switching to CA leads to higher or lower yields. As the results for temperate climates are often contradictory, and any differences are usually not statistically significant, most analysts simply assume no change in yield. Similarly, the impact of adopting CA on yield variability and risk is

TABLE 3
Comparison of conventional and conservation tillage costs for maize and soybeans in the United States, 1979 and 1992

Crop/cost Item	Per acre costs in 1979			Per acre costs in 1992		
	(1) Conventional tillage	(2) Conservation tillage	Ratio (1/2)	(3) Conventiona l tillage	(4) Conservation tillage 2/	Ratio (3/4) 3/
Maize						
machinery & fuel	45.34	38.34	1.18	55	37-44	1.36
pesticides 1/	8.72	11.63	0.75	10-15	5-25	0.83
labour	13.24	6.62	2.00	8	5-7	1.33
total selected costs	67.30	56.59	1.19	73-78	56-76	1.14
Soybeans						
machinery & fuel	38.11	33.11	1.15	55	37-44	1.36
pesticides 1/	9.13	12.17	0.75	14-28	7-40	0.89
labour	12.21	6.10	2.00	8	5-7	1.33
total selected costs	59.45	51.38	1.16	77-91	58-91	1.13

1/ For 1979, includes insecticides while 1992 costs do not.
2/ Includes chisel tillage, ridge tillage and no-tillage; ranges for total costs reflect individual technology totals.
3/ Ratio calculated on the basis of median values for each number range shown.
Source: Crosson, 1981.

controversial. Some studies argue that CA increases yield variability in many situations, thereby worsening risk (Fox *et al.* 1991). By contrast, Australian research shows a reduced variability in crop yields with CA (Kirby *et al.,* 1996), while work in Canada indicates that the net returns were higher under CA than conventional practices in bad years, but lower when averaged over time. Firm conclusions on whether risk is increased or reduced under CA remain elusive.

More certain are the impacts of CA on cropping intensity. With reduced field preparation time, the cropping cycle is shorter, allowing more crops in a given period and even double cropping where it was not possible previously. Where this benefit is available from CA, more efficient utilization of the fixed land resource results in higher annual net returns per hectare. Moreover, farmers may adjust their cropping strategy when switching to CA. Hence, yield trials comparing the same crop under either cultivation system may not represent reality. In fact, fully adopting CA involves switching to a suitable crop rotation that will probably differ from the conventional cropping strategy used previously. For this reason, some writers have called for a broader whole farm approach to comparative assessments in temperate agriculture (Diebel *et al*., 1993).

Overall, a comparison between conventional and conservation practices in temperate agro-ecological zones hinges on two offsetting effects. One involves

CA's labour and possibly machinery cost savings, while the other involves higher herbicide costs, at least initially, under CA. Depending upon the magnitude of each of these effects, CA may appear either more or less costly. For example, in Saskatchewan, Canada, researchers found that the higher herbicide costs characterizing CA overwhelmed any cost savings associated with labour, fuel, machine repair and overheads (Zentner *et al.,* 1991). Similarly, Stonehouse and Bohl (1993) used a linear programming model to argue that conservation tillage in a cash-crop farm system is not profitable. However, most developed-country studies reviewed find that CA demonstrates at least minor cost savings over conventional practices. However, these savings have not been sufficient to induce adoption by large numbers of farmers on large mechanized farms. These farmers may resist new practices unless there is a promise of much higher financial returns.

The tropical/temperate agro-ecological zone in developing countries

One of the success stories for CA has been in Latin America (Box 2). Large-scale mechanized farming is common in many parts of Latin America and farmers have adopted CA on large portions of this cultivated area. While most of the comparative cost analysis presented above for temperate northern regions would apply here, the advantage of CA in Latin America has been more pronounced. In part, this greater advantage reflects physical and climate factors, but also the differences in the nature of the technology adopted. While most studies in the United States document adoption of conservation tillage alone, in Latin America the technology is much closer to the concept of CA described in Chapter 1. That is, it is liable to include not just tillage adjustments but also changes in cover crops and mulching practices as well as the incorporation of crop rotations and other changes.

In Paraguay, yields under conventional tillage declined 5-15 percent over a period of ten years, while yields from zero tillage increased 5-20 percent (Sorrenson *et al*., 1997 and 1998). Savings in fertilizer and herbicide inputs dropped by an average of 30-50 percent over the same period. In Brazil, over a 17-year period, maize and soybean yields increased by 86 and 56 percent, respectively, while fertilizer inputs for these crops fell by 30 and 50 percent, respectively. In addition, soil erosion in Brazil fell from 3.4-8.0 t/ha under conventional tillage to 0.4 t/ha under no-till, and water loss fell from approximately 990 to 170 t/ha.

As a result, the financial benefits for farmers in Latin America who have adopted CA have been striking. However, these take time to fully materialize.

Box 2
Latin American experience with conservation agriculture

Latin America has the highest rate of adoption of no-till practices in the world. The first recorded attempt at mechanized zero tillage was in sub-tropical Brazil between 1969-1972 and in 1981/2 in tropical Brazil. The first field testing of no-till was in the state of Parana in 1972. By 1999, the percentage of the total cultivated area under no-tillage had reached 52 percent in Paraguay, 32 percent in Argentina and 21 percent in Brazil. No-tillage accounts for 95 percent of all conservation tillage in Latin America (44 percent in the United States). At first, the adoption of zero tillage in Latin America was only gradual, due to herbicide and planter limitations and the high incremental costs of adoption (Box 1). However, as farmers received support from farmer NGOs, the public sector and private interests, adoption increased significantly. For example, small, medium and large-scale farm operators in Paraguay have detailed considerable improvements in on-farm profitability and the reduction of risk. The studies also point to the crucial role of skilled personnel for training farmers in new management skills and the importance of credit availability for the purchase of new no-till machinery. By providing institutional and financial support, government has played a crucial role in creating incentives for adoption. Smallholders have been a special target as they lack the capacity to raise funds and retrain on their own. The World Bank reiterated these observations in its review of a project in Brazil promoting sustainable agriculture, modern forms of land management, and soil and water conservation. It considered rural extension to be a pivotal element in the project. In addition, monetary incentives were highly successful in motivating group formation among farmers, leading to an increase in cooperation and social capital. It recognized rapid paybacks and government financial incentives and support as key influences on adoption.

Sources: Sorrenson *et al.*, 1997 & 1998; World Bank, 2000.

Sorrenson (1997) compared the financial profitability of CA on 18 medium and large-sized farms with conventional practice in two regions of Paraguay over 10 years. He found that by the tenth year net farm income had risen on the CA farms from under US$10 000 to over US$30 000, while on conventional farms net farm income fell and even turned negative. Medium and large-scale farmers have experienced:

- less soil erosion, improvements in soil structure and an increase in organic matter content, crop yields and cropping intensities;
- reduced time between harvesting and sowing crops, allowing more crops to be grown over a 12-month period;
- decreased tractor hours, farm labour, machinery costs, fertilizer, insecticide, fungicide and herbicide, and cost savings from reduced contour terracing and replanting of crops following heavy rains;

- lower risks on a whole-farm basis because of higher and more stable yields and diversification into other cash crops.

In Latin America and in other developing regions, CA is a technology with potential appeal for smallholders. However, adopting CA on a small, possibly non-mechanized, farm involves some different considerations when compared to a large mechanized farm. For example, as smallholders use few purchased inputs, discussions on large increases in herbicide costs may not be relevant. Even if smallholders accept the need for herbicides, they may be unable to finance their purchase. In addition, few smallholders use significant amounts of fertilizer so that a debate over the impact of CA on fertilizer use is largely irrelevant. Ultimately, the availability of credit to assist with CA's increased need for purchased inputs plays an important role. If smallholders hire land preparation equipment, then a switch to CA should be relatively simple as there are no machinery investment implications. Short-run costs would be close to long-run costs when switching to CA.

The majority of smallholders worldwide do land preparation and weeding manually, and adopting CA has its greatest impact on the labour used in these activities. In a comparative analysis of traditional bush fallow systems with no-till and alley cropping in Nigeria, labour savings under the no-till technology were substantial (Ehui *et al*., 1990). Whereas alley cropping required from 126 to 151 person-days/ha/year and the bush fallow system needed from 67 to 102 days, the no-till technology required 58 days (with an allowance for land clearing in each case). These labour inputs amounted to more than 50 percent of total production costs for each technology. However, higher herbicide and equipment costs penalized the no-till technology and it was only preferred under conditions of higher population pressure, which penalizes alternative fallow systems. In studies of smallholders in Latin America, net farm income and returns to labour were much higher under CA than conventional practice. Table 4 supports this observation for adopters of CA in Paraguay.

In judging the attractiveness of CA in smallholder systems in Africa, Latin America and elsewhere, labour savings are a key factor. A further point related to labour is that as the labour savings come at both the land preparation and weeding stages (assuming herbicide use), there are liable to be implications for the gender division of labour. In most smallholder systems in Africa, male household members are responsible for land preparation (with a contribution to sowing), while female household members are responsible for weeding. Herbicide use may require some adjustment in these responsibilities as male

TABLE 4
Comparison of conventional and conservation agriculture cropping costs for smallholders at two locations in Paraguay

Crop/cost item (US$ 1998)	Edelira 1/			San Pedro 2/		
	(1)	(2)	Ratio	(3)	(4)	Ratio
	Conventional tillage	Conservation tillage	(1/2)	Conventional tillage	Conservation tillage 2/	(3/4) 3/
Farm area (ha)	15.6	15.6	--	6.8	6.8	--
Labour (person-days)	287	240	1.20	164	163	1.01
Net farm income (US$/year)	2 570	4 272	0.60	1 010	2 229	0.45
Return to labour (US$/day)	8.95	17.80	0.50	6.16	13.67	0.45

1/ average of 3 farms that switched from conventional to a no-till with green manure crop system.
2/ average of 2 farms that switched from conventional to a no-till with green manure crop system.
Source: Sorrensen *et al.*, 1998.

household members usually handle pesticides. Male household members may resist the additional labour demand during the weeding period, so creating a barrier to the adoption of CA.

Furthermore, certain conditions can enhance the relative financial attractiveness of CA. For example, rising land pressure tends to increase the attractiveness of CA relative to bush fallowing. An additional consideration is land quality. Studies of the net returns from mulching, an important component in smallholder CA, suggest that the benefits of this practice increase with the quality of cropland (Lamers *et al*., 1998). Successful instances of CA adoption in Latin America have demonstrated the importance of credit as an important enabling factor. This is because of the need to finance specialized planting equipment and herbicides.

FINANCIAL ANALYSES OF CONSERVATION AGRICULTURE VERSUS OTHER CONSERVATION TECHNOLOGIES

Most financial analyses of CA concentrate on a comparison with conventional practice, whether this is conventional tillage or bush fallow. However, farmers can often select from a number of alternative conservation practices, in which case CA is just one option of perhaps several. This is especially true for smallholder systems as an absence of prior machinery investments and the small-scale adaptability of many soil and water conservation techniques makes adoption relatively easy in physical and financial terms.

To consider CA's attractiveness in relation to alternative conservation practices to a smallholder, a database of over 130 different analyses of individual soil and water conservation technologies was compiled. The analyses concentrated on Africa and Latin America with all technologies coded according to whether they constituted a CA-related technology (Group 1) or not (Group 2), as specified by the World Overview of Conservation Approaches and Technologies (WOCAT) technology classification system. Group 1 includes measures aimed primarily at enhancing soil cover and organic matter, while Group 2 technologies are generally linear, cross-slope approaches intended to reduce erosion from wind or runoff. Information about farm-level financial returns was entered in the database for each technology. The results for each of the two technology groups were sorted based on whether technology adoption provided a positive or negative net present value (NPV). Table 5 presents the results of this procedure.

The analysis presented in Table 5 is somewhat crude as many studies employ differing assumptions about project life, discount rates, land opportunity costs, etc. Moreover, the classification of technologies is not precisely consistent with the definition of CA presented earlier. Nonetheless, the results in Table 5 do indicate that CA and, more broadly, agronomic improvements tend to show higher net returns at the farm level than do other techniques (e.g. vegetative, structural and other improvements). Arguably, this relative attractiveness of CA is more pronounced than was the case from the comparison of only CA and conventional tillage. Thus, when faced with numerous alternatives to conventional practice, CA and related approaches may offer the best possible

TABLE 5
Comparison of financial net present values for conservation agriculture versus other soil and water conservation technologies

Technologies	Total number of analyses	Number with positive NPV	Percent with positive NPV
Group 1 Conservation agriculture and related agronomic approaches (e.g. intercropping, contour farming, green manure)	40	34	85
Group 2 Vegetative, structural and other management improvements (e.g. shelterbelts, terracing, bunding, agroforestry)	96	55	57
Total, all analyses	136	88	65

Source: compiled from a review of 136 soil and water conservation technology analyses.

returns in many situations. Site-specific factors would determine which individual technology offered the best returns for individual farmers.

In summing up the financial evidence in support of CA, a few words of caution are in order. While it is true that CA often conforms to what Pampel and van Es (1977) term an ‘environmentally profitable practice’ (i.e. good for environment and profitable), this is not always so. Particular location constraints might result in reduced yields, or institutional factors may favour alternative practices (Stonehouse, 1995).

Thus, it is necessary to consider site-specific conditions in determining the financial attractiveness of CA. Even where the financial incentives may appear attractive, a consideration of non-financial factors is required to understand the actual and potential adoption of CA.

Other factors influencing the adoption of conservation agriculture

A number of studies have sought to identify barriers to adoption beyond the obvious divergence between on-farm costs and wider social benefits under CA (Smit and Smithers, 1992; Pierce, 1996; Cary and Wilkenson, 1997). For example:

- Large investment costs may discourage adoption (Wandel and Smithers, 2000).
- The perceived risk of adopting CA may serve as a barrier (Uri, 1998b; Stonehouse, 1996; McNairn and Mitchell, 1992).
- Long gestation periods for the benefits of CA to materialize may serve as a barrier to farmers with short-term planning horizons (Tweeten, 1995).
- Barriers may be particular to culture and recent history (Nyagumbo, 1997).

In part, the need to consider factors other than net returns reflects farmers’ competing objectives in farm management, i.e. profitability versus low investment or minimum subsistence food requirements. Competing technologies may meet individual objectives to varying degrees. In terms of maximizing net financial returns, Tables 3-5 suggest that CA can provide better net returns than either conventional practice or other conservation technologies, subject to local site conditions. Table 6 compares various attributes of CA technologies and other soil conservation techniques at the farm level in West Africa. The qualitative analysis applies four criteria representing different smallholder

TABLE 6
Factors influencing the attractiveness of conservation agriculture practices at the farm level in West Africa

Soil management techniques	Financial attractiveness (net returns)	Initial effect on yield	Incremental investment	Incremental labour required
Conservation agriculture				
Mulching	++	+	+	-,+
Ridging	-,++	+	+	--,+
Strip cropping	-,++	-,+	+	+
Alley cropping	-	-	-	--,-
Woody fallow	+,++	+	--,-	--,+
Vegetative and structural				
Vetiver grass lines	-,+	-	--,-	-,++
Fanya juu bunds	-	-	+	++
Stone faced terraces	-	+	+	-
Tree shelterbelts	-	-	--	+,++

Note: The table uses a +/- scale with four possible scores ranging from -- to ++, with the latter the most preferred score.

objectives, of which one is financial profitability (Table 5). While consistent with the net returns analysis in Table 5, the results in Table 6 allow for a much broader evaluation, highlighting assorted shortcomings or advantages of individual technologies that may not be apparent in a financial analysis alone.

The influences other than net returns shown in Table 6 represent only a small subset of the many non-financial factors thought to influence conservation technology adoption. Table 7 lists those other factors found to influence the adoption of CA in a statistically significant sense (based on a review of statistical results contained in Appendix 2). A review of the many studies contributing to Table 7 suggests that results are often not conclusive. Conditions may be too site specific to allow much generalization based on statistical studies alone.

Farm-level factors vary from farm operation to farm operation and higher level factors are also at work, such as the transmission of information (via policy-related activities and social processes). Furthermore, the variables discussed below, and their broader categories, do not act independently, but rather interact to influence adoption.

Farmer characteristics

Since Ryan and Gross (1943) first showed that the adoption of agricultural innovations is typically uneven from farmer to farmer, researchers have directed attention to certain characteristics and attributes of farmers in an effort to explain this unevenness. In the case of soil conservation technology adoption, Gould *et*

TABLE 7
Statistically significant factors affecting the farmer’s decision to adopt a conservation technology

Farmer characteristics	Farm characteristics	Information factors	Biophysical and technical factors	Social factors
Education	Farm size	Contact with extension workers	Land-use intensity	Social capital
Health	Type of farm	Attendance at field demo’s and test plots, etc.	Soil erosion rate	
Experience	Tenure	Source of information (e.g. other farmers)	Cropping system	
Awareness/ perception of soil erosion as a problem	Fit with production goals	Ease of accessibility of information	Soil type	
Concern for soil erosion	Degree of control in decision making	Availability of support	Climate	
Discount rate	Ownership of conventional tillage machinery		Rainfall	
Age	Average/gross/ net farm or off-farm income		Fit with the physical farm setting	
Full time/part time operator			Availability of conservation tillage	
Income				
Ability and willingness to borrow (credit)				

Note: variables listed here show statistical significance in at least one of the empirical studies cited in Appendix 2.

al. (1989) emphasize awareness on the part of farm operators to soil erosion or other soil problems as an obvious prerequisite to adoption. Indeed, farmer awareness or perception of soil problems is frequently found to positively correlate with CA adoption (Stonehouse, 1991). Similarly, the central place of information and knowledge in CA adoption, in terms of being aware of soil problems and potential solutions, should lead the level of education of a farm operator to correlate positively with adoption. Education, be it specific or general, generally correlates positively with the adoption of CA practices, notwithstanding some findings of insignificance or even negative correlation (Rahm and Huffman, 1984; Marra and Ssali, 1990; Warriner and Moul, 1992).

Age and/or experience are difficult factors to link to CA adoption, given that studies have shown both a positive and negative correlation. Based on a study of conservation tillage adoption in Wisconsin, Gould *et al*. (1989) showed that older and more experienced farmers were more likely than their younger colleagues to recognize soil problems. However, they were less likely than their younger colleagues to address the problems once recognized. In contrast, several studies have found that income correlates positively with the adoption of soil-erosion control practices (Okoye, 1998; Wandel and Smithers, 2000).

Farm characteristics

Studies of the adoption of conservation tillage and other CA-type practices have often given significant attention to farm size (or sometimes planted area). Many studies have found that farm size correlates positively with adoption (Westra and Olson, 1997). However, other studies have shown no significant relationship (Agbamu, 1995; Uri, 1999b), or even a negative correlation (Shortle and Miranowski, 1986). Hence, the overall impact of farm size on adoption is inconclusive.

Some studies have found that the presence of soil erosion and other soil problems on the farm correlates positively with conservation tillage adoption (Stonehouse, 1991). However, farmer awareness of and concern for soil problems is probably the more critical factor affecting adoption. Another important farm characteristic is underlying land productivity. In the case of no-till and mulch tillage, Uri (1997) shows that in the United States adoption is more likely on farms with low rather than high levels of soil productivity. In addition, a good fit between CA and the farm's production goals encourages adoption.

A more complex factor liable to affect adoption is land tenure. In simple terms, privatizing land should lead to better incentives for the adoption of conservation technologies. However, studies of the privatization of land or titling

TABLE 8
The effect of agricultural tenure and perceived tenure security on conservation technology investment in Africa

Tenure type	Country	Impact on investment decisions
Private title	Ghana	+/x
	Rwanda/Ghana/Kenya	x
	Uganda	+/x
	Somalia	x
Customary rights	Zimbabwe	+
	Ghana, Kenya	+/x
	Rwanda	+
	Burkina Faso	x
	Niger	+

Note: + positive effect on investment in improvements; - negative effect on investment; x neutral or no effect on investment (statistically insignificant).
Source: FAO/IFAD (1999) for a list of the studies indicated above.

have not shown that this is necessary to motivate sustainable practices and, in some instances, it has had the opposite effect. As a result, it appears that producers may accept titling because it guarantees land rights, but this does not necessarily bring about changes in their land management. In contrast, there are numerous studies indicating that traditional institutions governing access to land resources in developing regions are flexible in responding to internal and external pressures. Table 8 summarizes the empirical evidence provided by a number of African studies addressing both private title and customary tenure. It shows that the former institutional arrangement does not bestow any advantage over the latter, in terms of investment incentives. Thus, general claims that titling will lead to increased investment in land improvements should be viewed with caution.

Information

Without knowledge of the practices associated with CA via some information or communication channel, adoption is improbable. Indeed, studies of innovation adoption and diffusion have long recognized information as a key variable, and its availability is typically found to correlate with adoption (de Harrera and Sain, 1999). Information becomes especially important as the degree of complexity of the conservation technology increases (Nowak, 1987).

Information sources that positively influence the adoption of CA-type practices can include: other farmers; media; meetings; and extension officers. However, with respect to this latter source, Agbamu (1995) shows that contact alone will not promote adoption if information dissemination is ineffective, inaccurate or inappropriate. Studies have not always shown that the ease of obtaining information correlates with adoption.

Biophysical and technical factors

In technical terms, the characteristics and availability of CA technologies are crucial factors in adoption. However, de Harrera and Sain (1999) note that availability does not imply individual ownership of the necessary machinery as lease/hire arrangements proliferate. Furthermore, potential adopters must believe that the technology will work. Technical factors interact with biophysical factors, e.g. soil type, rainfall or topography can encourage/facilitate or discourage/limit CA adoption. While some studies have shown that farm operations located within regions of steep slopes and erodible soils have a greater tendency to use CA practices, other studies have found these variables to be insignificant.

Social factors

CA adoption is seldom strictly a function of individual profit maximization alone, but also can reflect non-individual or societal interests. More specifically, Lynne (1995) argues that farmer decision making usually reflects a compromise between private economic utility and collective utility. Producers often identify this latter interest as 'the right thing to do', at least in those places where stewardship is part of the cultural norm. The argument runs that for many producers the pride associated with stewardship makes up for limits in financial rewards (Campbell *et al.*, 1999). Examples of such stewardship motives governing land management arrangements include the Landcare movement in Australia (Sobels *et al.,* 2001). In contrast, Van Kooten *et al*. (1990) modelled the trade-offs between stewardship and net returns on wheat-fallow farms in Saskatchewan, Canada. Their study found that farmers make improvements in agronomic practices to benefit soil quality only under extreme degrees of concern (e.g. stewardship). This result holds despite such practices representing no more than a 5 percent sacrifice in net returns.

In addition to stewardship motives, collective action may be necessary to implement CA on a regional basis. Cooperative arrangements govern numerous activities within village agricultural systems. Although the discussion usually focuses on common property resources, even private land use may overlay with cooperative arrangements governing various aspects of farm management (Pretty, 1995). For example, contour ploughing, stone lines and other structural works require cooperation amongst several or many farmers in order to be effective conservation strategies. Many dimensions of CA fit the cooperative model, including the formation and operation of farmers' groups, dissemination of information, pest control and the purchase of agrochemical inputs. Box 3 provides a more general discussion of collective action in relation to sustainable agriculture.

If CA requires collective action or high levels of social organization to help it gather momentum, then widespread adoption may be related to a society's social capital. The role of social capital in fostering or retarding the collective action needed in promoting new conservation technology is of growing interest (Box 3). In the broadest sense, social capital refers to the interconnectedness among individuals in society and considers relationships as a type of asset. Several studies have examined the influence of social capital on technology adoption in either developed or developing countries. For example, kinship, or more exactly 'connectedness to others', can influence the adoption of

Box 3
Collective action and social capital in soil and water conservation

Collective action can have benefits over individual decision making when the tasks at hand require coordinated group activity (e.g. various agricultural and conservation practices). For example, it may reduce the costs of repeated transactions amongst many individuals by establishing a single set of rules and avoiding individualized negotiation and transaction. However, collective action is not automatic in the diffusion of improved technologies such as CA, especially where information is lacking or the underlying physical processes of land degradation are slow and barely perceptible. Additionally, some individuals may benefit from collective action without contributing, and this may result in a lack of collective incentives. Using game theory to model behaviour in collective action situations, researchers have tried to understand what factors may foster collective behaviour. For example, if repetition and observability characterize group activities, the result may well be cooperation, but only if:

- other individuals are able to retaliate in the future if one individual does not cooperate, i.e. by reducing the benefits the defector can obtain in the future; ·
- retaliatory threats are credible and not too costly to implement - thus, retaliation can be viewed as a collective action in itself; and,
- future benefits are substantial enough and sufficiently longstanding to provide an inducement to cooperate in the present - in this case, face-to-face encounters prove important as these ensure that aspects of reputation and trust enter into the incentives structure.

In general, the key variables influencing the potential success of collective action are: the number of decision-makers, especially the minimum number required to attain a collective benefit; discount rates, which influence the magnitude of future benefits from collective action; a similarity of interests among agents; and the presence of some individuals with leadership or other assets. In part, the behaviour needed to foster collective or socially responsible actions may hinge on the level of social capital in a community. The World Bank (1998) reviewed various definitions of this term and found they ranged from a fairly narrow view relating to the interconnectedness among individuals, via associations, societies, etc., to a much broader view encompassing the entire social and political environment. In simple terms, if conservation activity requires cooperation, then the degree of interconnectedness and the enabling social environment may be a critical determinant. The various indicators of a community's or nation's level of social capital include the number and type of associations, homogeneity within communities, levels of trust in others, reliance on networks of support, presence of natural leaders, etc.

conservation technology. Some studies have shown that the expectation of farmland inheritance can have a bearing on conservation behaviour amongst farmers, although other studies testing for this have not shown a positive correlation. Similarly, higher levels of social capital help explain the adoption of fertilizer and soil conservation practices in Peru (Isham, 2000; Swinton, 2000), while one study has related the success of peasant committees in Paraguayan villages to the level of social capital in these communities (Molinas, 1998). Such institutions at the local level have been an important catalyst in the adoption and diffusion of CA.

In conclusion, the inconsistent and sometimes contradictory results obtained from studies of the adoption of CA-type practices tend to suggest that the decision-making process is highly variable, and that outcomes may be specific to particular people, places and situations. This makes the task of developing a policy framework to promote CA adoption particularly challenging.

Chapter 3

Conservation agriculture and the role of policy

The preceding analysis of the financial and other factors associated with the adoption of CA and related practices has already captured many of the effects of policy, or more generally government action, on adoption. Governments use macro-economic policy, trade regulations, input subsidies, or education and extension to alter the decision-making environment in which farmers choose one practice over another (Figure 3). This chapter examines the actual and potential roles of policy in the adoption of CA.

The influence of policy on the adoption of conservation agriculture

Agriculture has been subject to considerable state interest and intervention over the past half-century, perhaps more than any other economic sector (Robinson, 1989; Gardner, 1990). While it is possible to overestimate the influence of policies in farmer decision making (Winter, 2000), there is increasing recognition that the provision of public support in the form of guaranteed output prices, input subsidies, deficiency payments, cheap credit, or disaster relief has encouraged and facilitated massive investment by farmers in production capacity expansion. Some authors have characterized the resulting dominant form of agriculture, at least in the developed world, as industrial. This is because of its continuing trend towards larger and fewer units of production, regional and enterprise specialization, more intensive soil tillage, increased reliance on agrochemicals, and in many locations, surplus output (Troughton, 1985). Given its associated effects upon the quality of soil, water and wildlife habitat, various authors have implicated agriculture policy as a contributing cause of environmental degradation (Libby, 1985; Pierce, 1993; OECD, 1989; Lewandrowski *et al*., 1997).

It is in this context that many governments have introduced a variety of programmes to encourage the adoption of CA-type practices. With extension services, subsidies and taxes, these initiatives have achieved some important results. For example, the success in promoting CA practices in certain developing regions, particularly Latin America, is noteworthy, and policy has played an important role. Box 4 discusses the key factors cited in the expansion of CA in the Mercosur countries of Latin America. Many of these stem not from government policy but from extraneous factors and local traditions. Indeed, many programmes promoting CA throughout the world have been relatively ineffective because of contradictory signals and incentives from existing subsidy programmes. For example, policies designed to promote sustainable agriculture can be undermined by other, typically richer, policy measures in support of highly erosive row crops such as groundnuts and tobacco, or by weak or slow-to-respond research and extension efforts.

Some studies have shown government-financed extension to have a positive impact on adoption (e.g. Logan, 1990), although Agbamu (1995) cautions that not all forms of extension will achieve such an end. In the case of state financial assistance, Napier and Camboni (1993) identify a positive, albeit weak, correlation between participation in such programmes and conservation tillage adoption. More specifically, based on a model cash crop farm in southwest Ontario, Stonehouse and Bohl (1993) show that a one-time subsidy covering 20 percent of the outlay costs would induce a farmer to convert from conventional tillage to no-till. However, the study suggests that conversion to permanent cover crops such as alfalfa would require excessively high subsidies. Finally, with respect to the use of taxes, Aw-Hassan and Stoecker (1994) determined that if the off-site damages from conventional practices were taxed as high as US$2.25 per tonne of soil loss, the area of high-yielding/high-erosion land under conservation tillage would increase significantly, while lower-yielding land would be converted to pasture. However, in a similar study, Stonehouse and Bohl (1993) show that meaningful levels of soil erosion prevention via taxation are difficult to achieve and result in significant reductions in net returns.

Beyond the confines of conservation tillage, reviews of new conservation schemes in Europe can provide some insight into the effect of policy on conservation behaviour among farmers. These schemes have developed through a gradual conversion of the European Union's extensive subsidy regime from supporting production to supporting environmental practices such as set-aside (Potter and Goodwin, 1998). Based on surveying in Scotland, Wynn *et al.* (2001) show that compensation alone does not ensure conservation programme success as a lack of awareness of such programmes can limit participation. Once aware, farmers were more likely to participate, as long as there was a good fit with the farm situation and the costs of compliance were low. Compliance costs are often an obstacle to adoption (Wilson, 2000). Even with full compensation for foregone agricultural income resulting from participation, administrative or

Box 4

Two cases of contrasting policy roles in promoting sustainable agriculture

Several studies have examined the reasons for successful promotion of CA (zero tillage) in the Mercosur region of South America, arguing that an efficient innovation system developed around the promotion of zero tillage. This system included a number of policy elements along with extraneous elements that contributed to its success. As an example of the latter, agrochemical companies helped initiate the programmes recognizing their own self-interest in promoting zero tillage. Farmers benefited significantly as well, as the benefits from zero tillage were especially pronounced for the key soybean crop and were available to mid- and larger-sized farms. In terms of government's policy role, traditional research and extension services were weak and slow in responding to the perceived needs of farmers. However, this opened the way for others such as pioneer farms, NGOs and foreign aid agencies to fill the gap. In addition, farmers could readily recognize and understand the underlying problem and experiment with solutions, aided with information supplied by associations of zero-tillage farmers. Local traditions also helped: although there was no precursor knowledge of zero tillage, there was a tradition of innovating with commercial crops. Moreover, a mismatch between extension and research targeting of small and medium-sized farms in some countries (e.g. Paraguay) may have limited an otherwise successful CA programme.

In New Zealand, the government removed virtually all support, including environmental grants, to the dominant pastoral agriculture sector in the post-1984 period. This action provides a unique opportunity to assess the implications of subsidy removal for farm-level resource use and environmental stewardship. The evidence suggests that the response to subsidy removal, at least in the short term, is a decrease in farming intensity as manifested in: (1) reduced use of marginal lands; (2) decreased and more selective fertilizer use; and (3) reduced livestock numbers and stocking rates. At the same time, increased insecurity among farmers has shortened planning horizons and stifled certain environmental investments. While farmers still undertake practices such as planting trees for erosion control because of a recognized need or a conservation ethic, the termination of grants and other subsidies has generally reduced the propensity and ability of farmers to undertake many stewardship activities, especially during periods of financial distress. Therefore, many regional governments have filled the void left by the removal of national support by funding new programmes to encourage farm-level stewardship.

Sources: Bradshaw and Smit, 1997; Bradshaw *et al*., 1998; Blunden and Bradshaw, 1999; Sorrenson, 1997.

transaction costs equal to just 5 percent of total compensation can inhibit farmer participation (Falconer, 2000). This evidence from Europe suggests that financial support alone is not sufficient to encourage the adoption of CA-type practices.

It is necessary to combine such support with other efforts directed at the specific needs of farm operations.

How policy can enhance the adoption of conservation agriculture

Given the perceived environmental impacts over the past half-century, some have argued that the decoupling of agricultural support from production decisions would represent the most effective means by which governments could alleviate environmental degradation (OECD, 1989 and 1998). There is debate concerning the means, both direct and indirect, by which governments can promote conservation in agriculture effectively. Table 9 summarizes the many approaches adopted by governments in the developed world to achieve various conservation objectives.

In promoting CA, a key concern for policy-makers is whether CA provides a positive or negative net return to potential adopters. Once this uncertainty is rectified, Uri (1998b) recommends:

- education and technical assistance where conservation is profitable but the farmer is not aware of the technology or its profitability, or does not have the skills to implement it;
- financial assistance where conservation is not profitable to the individual farmer but would provide substantial public benefits;
- long-term research and development;
- land retirement; and

Table 9
A summary of policy approaches to promote conservation agriculture

Category	Sample approach
Voluntary compliance	stewardship agreements, education/ extension services, research and development, resource centres, etc.
Economic/trade controls	cross-compliance requirements, export bans, etc.
Financial incentives	grants/subsidies, tax rebates, etc.
Regulations	statutes, fines, zoning, taxes, etc.
Direct ownership/management	public purchase, trusts, etc.

Source: Pierce, 1996.

- regulation and taxes where conservation behaviour is required of all farmers, or for those participating in related income support programmes (e.g. a cross-compliance measure).

With respect to the first approach, McNairn and Mitchell (1992) argue that encouraging the adoption of conservation practices requires assurance of long-term benefits from adoption; unambiguous, easily understood and accurate information; and the promotion of multiple economic and non-economic benefits. Education plays a key role in motivating adoption and requires tailored, credible, and appropriate information and experience that is communicated through the proper channels. Extension services to provide information and assistance can be highly effective, especially in the case of new or emerging technologies, although public agents need not be the exclusive providers of such services.

Financial assistance for the adoption of various conservation practices is well established in Europe and, to a lesser degree, North America. Assistance can take a variety of forms, such as tax credits on equipment, machine rentals, cost-sharing programmes and direct subsidies. Assistance is most suitable to help overcome significant initial investments and transition costs, and in cases where adoption is unprofitable from the individual farm perspective. Box 5 presents an analysis of policy options for encouraging soil conservation on farms in Ontario, Canada, highlighting the role such analyses can play when government assistance is needed. However, Nowak (1987) suggests that financial assistance may also be important where the adoption of a technology results in positive net returns for farmers. The author argues that institutional support tends to reduce the risk faced by farmers in adopting an 'unknown technology' and thereby reduces their need for detailed information prior to adoption. That is, to overcome non-adoption because of onerous information demands, state support is useful.

A less interventionist policy approach might focus on research and development to enhance the benefits of CA adoption by improving performance or reducing costs. This approach relies on voluntary adoption and aims to increase the odds of this occurring by making the practice more attractive. However, research and development is a long-term policy strategy with an uncertain probability of success.

Land retirement is only suitable in instances where soil erosion concerns are so significant as to warrant conversion to permanent cover crops. Typically,

Box 5

Policies for encouraging soil conservation: cash crops in Ontario, Canada

One study examined the impacts of public policies on farmland use, soil conservation, farm-level economics and the public budget to assess the effectiveness of the policy alternatives for combating soil erosion. The objective was to estimate the anticipated effectiveness of government actions designed to regulate soil erosion losses. The study used a multi-period linear programming model to model a typical cash-crop farm operation producing soybeans, maize and cereal grains in southwest Ontario. The goal was to maximize the NPV of farm net returns over a 20-year period. It considered ten production system alternatives, representing various crop sequences and soil tillage techniques (conventional tillage, conservation tillage and zero tillage). In addition, six policies were modelled: (i) a regulated limit on soil loss from farm operations per year; (ii) a tax on soil erosion losses per year; (iii) a tax on material inputs associated with conventional tillage systems; (iv) a one-time subsidy for conservation tillage equipment purchases; (v) an annual subsidy to encourage the incorporation of alfalfa into production or to adopt conservation tillage; and (vi) a direct subsidy on production prices for alfalfa. In the absence of any public policies, the most profitable system is the maize-soybean-winter-wheat sequence with conventional tillage. Other policies showed the following:

- Meeting a soil loss regulation required changes in the production system; as the regulation became increasingly restrictive, the farmer moved from conventional to conservation to zero tillage and the farm's net cash flow decreased by a maximum of 57 percent.
- A modest level of soil loss taxation (0.20 t/year) is required to reduce soil erosion by 20 percent and is achieved with a relatively small loss in net cash flow (6 percent). However, raising the taxation level achieves little in terms of reduced soil losses, but severely erodes net cash flow.
- The effectiveness of the material input tax depends on the crop sequence selected by the farmer.
- A one-time, 20 percent subsidy for zero tillage equipment would be sufficient to raise net cash flow over a four-year period above conventional and conservation tillage.
- An annual, direct production subsidy of 20 percent would be sufficient for zero-tillage continuous maize production to exceed the net cash flow from maize-soybean with conservation tillage.
- A very high subsidy for alfalfa would be necessary to induce farmers to shift to a less erosive system.

In conclusion, public policy measures that require the farmer to bear the burden of reducing soil erosion are unlikely to be implemented because of the adverse financial effects imposed on farm operations. Public policies that require taxpayers to bear the burden would be effective in terms of cost per unit of controlled erosion, but could become a fiscal problem, especially during an era of government budget deficits and rising debt.

Source: Stonehouse and Bohl, 1993.

this approach requires significant public financing to compensate farmers, and it is infeasible in areas highly dependent on a limited land base for the production of foodstuffs.

Finally, although tried in some locations, regulating soil erosion limits is not a common approach (Libby, 1985). This situation probably arises from political awkwardness and onerous enforcement/compliance demands. This is especially so where meeting a soil loss regulation through use of no-till results in significant declines in net returns (Box 5). A more common regulatory approach involves cross-compliance measures whereby eligibility for a support programme depends on the adoption of certain conservation practices. Because compliance is by choice, programme implementation is liable to be more politically feasible and economically efficient. With respect to the use of taxes on soil erosion, it is possible to induce CA adoption and even pasture conversion. However, meaningful levels of soil conservation involve significant revenue losses (Box 5). Hence, although possible, taxation is politically infeasible.

The inconclusive nature of empirical studies, and obvious site-specific nature of many results, suggests that a universal approach is not possible. In order to accommodate differences between farms, farmers and economic circumstances, a targeted policy approach may be preferable. In other words, policy mechanisms such as grants or extension services could be geared to the particulars of a location or, preferably, to individual farmers and their farm operations (Box 6). While a targeted policy approach places a heavy administrative burden on policy-makers, it could achieve greater efficiencies than a more uniform approach, and may represent the most effective means of encouraging CA adoption.

Although a targeted policy approach may be most appropriate for the design of programmes directly promoting CA, there are some alternative policy prescriptions that may be more universally applicable. For example, Isham (1999) points out that parallel investments in social capital may be necessary to create a sufficiently enabling environment for the adoption of desirable project activities, and this may apply strongly in the case of CA. Some authors argue that social capital is a product of a learning process. Fostering discussions about the community and seeking consensus decision making can help achieve such learning. A key question is whether governments can foster social capital, as top-down efforts may not be able to promote bottom-up social capital. However, Sobels *et al*., (2001) suggest this is not so, citing Landcare in Australia as an example of successful government support contributing to social capital. Indeed, to a certain degree, the success of Ontario's Environmental Farm Plan

Box 6
Ontario's Environmental Farm Plan Programme

Ontario's Environmental Farm Plan (EFP) Programme represents an innovative approach to environmental conservation on the farm through the voluntary participation of farmers to assess environmental risks and raise environmental awareness on their farms. The EFP Programme began in 1992, helping farmers develop a practical plan for operating their farms in a way that is environmentally responsible. Individual farmers work through a series of 23 modules covering such issues as water quality and wildlife habitat, and submit their individualized plans for peer review (i.e. to fellow farmers). It began and remains a farmer-driven process, although government provides some technical expertise and funds. Compliance and interest among farmers is high, especially relative to traditional government-led regulatory approaches. While some funding is available (a maximum C$1 500 per farm for those farmers who complete, implement, and secure approval of their participation in the EFP, plus winners of environmental contests receive C$1 000), the programme primarily draws on farmers' pride and their desire to garner respect with colleagues, neighbours and consumers. As one programme participant stated: "The EFP is an excellent way to mark our own report card and rate all our farm activities environmentally....We need to inform our urban neighbours that we are concerned about the environment".

Sources: Grudens-Schuck, 2000; Klupfel, 2000; Stonehouse, 2000; Ontario Soil and Crop Improvement Association, 2001.

programme is ascribable to farmer pride and interest in 'doing the right thing' (Box 6). Both pride and peer pressure may be important forms of motivation for CA adoption, and government policies may be able to contribute on this front.

Implications for economic and policy analysis

Specialized policy and economic analyses are prerequisites for the appropriate design and correct targeting of CA policies. Policy analysts and economists interested in CA can make use of numerous new techniques and ways of thinking. Sustainability indicators are one example. These capture changes in farming practices that alter the sustainability of the farming system in some quantifiable way that conventional analysis may fail to capture. Therefore, sustainability indicators help describe the evolution of soil productivity over time or present its status in terms that better contrast conditions under CA and conventional management. Sustainability indicators are applicable at the local farming-

TABLE 10
Tillage and soil surface management effects on indices of agricultural sustainability

Level of sustainability	Indices of sustainability influenced by soil tillage
Plant/crop	Agronomic yield
Cropping system	Productivity
Farming system	Profit, income, resource and environmental quality
Region/community	Supply, off-farm income, comparative advantage, environmental quality
National	GNP, resource sustainability, trade status
International	Per caput calorie intake

Source: Lal, 1999.

systems level, at intermediate levels such as the community or region, or at higher levels. Table 10 shows some of the component indicators that changes in tillage practices affect at each of these levels. To the extent that more comprehensive sustainability measures incorporate these indicators, changes in farming practices will cause changes in the accompanying measures.

At the village and farm level, sustainability indicators assess the sustainability of specific farming systems and, by inference, the sustainability of soil tillage within a given farming system (Tisdell, 1996). Table 10 suggests several variables at the farm level that could serve as such indicators. Indicators that are more comprehensive define sustainability in an operational sense, using concepts such as sustainable income. This is the potential income that can be derived from resource use in perpetuity. In some cases, the indicators that accompany these definitions link farm-level soil degradation with national accounting techniques.

At the macroeconomic level, the system of national accounts has integrated soil degradation through formal green accounting initiatives such as the United Nations System of Integrated Environmental and Economic Accounting. In keeping with standard national accounting practice, green accounting measures disinvestment or investment in soil natural capital and then adjusts NNP/GNP accordingly. Other national indicator approaches include the World Bank's calculations of genuine savings rates. These adjust net domestic savings for changes in the value of resource stocks and pollution damages while the Pearce-Atkinson indicator incorporates elements of the genuine savings idea. Indicators such as this can convey the message powerfully to decision-makers that soil degradation is resulting in a loss in national wealth, and so encourage greater efforts to promote more sustainable practices such as CA.

Analysts who have to assess the attractiveness of projects involving CA or competing farming practices can adopt a number of measures. Such efforts are important because some of the benefits of adopting CA do not show up in conventional cost-benefit type analyses, or in comparisons of CA and alternative practices in narrowly-defined financial terms.

Non-market valuation techniques

It is common practice to use non-market valuation techniques to incorporate the benefits and costs of farming practices that are not priced in markets. Examples include downstream siltation from soil erosion, or loss of organic fertilizer where dung is used as a fuel instead of on farm fields. The valuation practices most appropriate to comparisons of CA and conventional farming practices include replacement cost, changes in productivity, direct and indirect substitute approaches, preventive or mitigative expenditures, and hypothetical or constructed market techniques (IIED, 1994).

Depletion of soil as natural capital

Economic analyses at the project level can incorporate the depletion of soil as a form of natural capital under conventional tillage practices, so enabling fairer comparisons with CA. This depletion constitutes a cost of non-sustainable cropping in addition to normal production costs. It is a user cost as it yields short-term gains at the expense of future income (Daly, 1996). Omitting user costs results in an overstatement of the net economic benefits of current cropping practices that deplete soils. Several techniques are available to calculate the user cost of depleting natural resource stocks. Two common approaches are the net price method and the marginal user cost method.

Whole-farm budgeting

Proper environmental analysis requires the assessment of changes in environmental conditions in terms of the full range of behavioural responses that occur (Freeman, 1993). When farmers adopt CA, numerous ancillary changes can be expected, such as crop switching, changes in pest control measures, shifts in cropping duties for household members (by gender), etc. For this reason, comparative analyses of CA and alternative practices should adopt a whole farm approach to capture the full range of these behavioural changes (Sorrenson, 2001). Diebel *et al*. (1993) argue that analysis of individual practices in isolation can even provide misleading results when certain factors combine synergistically to raise barriers to adoption that are not otherwise evident.

Alternative project evaluation techniques

While project work makes universal use of cost-benefit analysis, other project evaluation techniques hold promise for the appraisal of CA projects or technologies. These include multi-criteria analysis (MCA), cost-effectiveness analysis, decision analysis, environmental impact assessment and participatory methods. MCA recognizes that government decision-makers and smallholders have many objectives in mind when deciding about agricultural project viability and on-farm management practices, respectively; more than a cost-benefit analysis alone can capture. In addition, various trade-off techniques, such as trade-off curves or more sophisticated analytical techniques, can help assess the trade-offs amongst competing objectives. For example, Van Kooten *et al.* (1990) use such a method to examine the trade-offs between net returns and stewardship motivations amongst farmers in Saskatchewan, Canada, in adopting soil conservation practices.

Chapter 4

Conclusions

The benefits of CA range from supporting basic agricultural production and meeting food security needs in a sustainable manner, to supporting globally important terrestrial and soil-based biodiversity, culminating in carbon sequestration. This review of current thinking about these benefits suggests that the expansion of CA across many different agro-ecological zones makes good sense from a social perspective.

However, the financial profitability of CA is uncertain. Although there appears to be a small cost advantage over conventional practice in general terms, results are liable to fluctuate widely from site to site, with many studies showing CA as less profitable. There are also differences in analysing cases in developed versus developing countries, with tropical hilly examples from the latter group demonstrating distinct advantages for CA because of its more comprehensive approach and better agroclimatic conditions. In contrast, caution is warranted in temperate areas, as the CA approach promoted is less intensive and any cost advantage is likely to be insufficient for bringing about the levels of adoption and diffusion justified from a social perspective. In part, this situation occurs because farmers cannot capture the many national and global benefits from CA.

Given this divergence between private and social interests, interventions promoting more sustainable farming techniques are justifiable in a social sense, and at both the national and international levels. However, CA is not the only soil and water conservation technique that can generate the benefits cited above. Thus, it is necessary to situate CA within a broader range of alternatives to conventional farming practices. Encouragingly, CA is representative of a group of improved agronomic practices that are generally more profitable than competing soil and water conservation technologies that are more structural or purely vegetative in nature.

If CA-type approaches are preferable to the alternatives, then providing monetary compensation to induce adoption might seem an appropriate policy response. However, such an exercise is unlikely to bridge the gap between socially desirable levels of adoption and actual farmer behaviour on its own. Other factors affect adoption as well. For example, numerous such influences are statistically significant in models that attempt to explain actual adoption behaviour (as opposed to general discussions lacking empirical support). These other factors stem from different farmer management objectives, stewardship motives and fundamental barriers or constraints that inhibit a response to profit signals. In some cases, it is the collective rather than the private dimension that is critical to adoption success. There appears to be a correlation between higher levels of social capital and success in these situations. Thus, promoting CA must start with the identification of all factors that impeded adoption and not just a lack of financial net returns.

Policy has also been an important determinant in explaining past CA adoption or non-adoption. Policy stances have sometimes been weak and ineffective in promoting CA. Much of the successful diffusion of the technology has occurred because of support from private corporations, the formation and operation of farmers' groups and other non-governmental pathways. Moreover, conflicting policies have often operated at cross-purposes, encouraging and discouraging CA at the same time. Despite these shortfalls, examples of successful policy measures include green decoupling programmes in Europe and farmland stewardship programmes such as Landcare in Australia.

The above analysis contains implications for policy-makers. On the one hand, an assumption that CA will spread on its own in some desirable fashion is not appropriate. On the other hand, a uniform policy prescription to fit many locations is not realistic either, whether it consists of direct interventions or more indirect incentives stemming from research and development, or some mix of both. Designing successful policies to promote CA is likely to start with a thorough understanding of farm-level conditions. This understanding needs to include management objectives, attitudes to risk, willingness to make trade-offs between stewardship and profits. The next step is the careful design of location-sensitive programmes that draw on a range of policy tools. Flexibility is liable to be a key element in policy design to promote CA.

One area where policies of a more uniform nature might be useful is in the development of social capital and the promotion of the precursor conditions for collective action. For example, the social capital benefits of group extension approaches probably are under-appreciated. Given the demonstrated importance of farmers' groups and information dissemination in the successful diffusion of

CA, efforts to strengthen the enabling conditions that foster these activities can pay large dividends.

In devising appropriate policies relating to CA and, more generally, sustainable agriculture, there is a need for improved policy analysis and information for decision making. Developing sustainability indicators that can more clearly show the benefits of CA over its alternatives is one step. Similar improvements are achievable at the economic-analysis level. For example, incorporating the depletion of natural capital in studies of conventional farming practices can help evidence the limitations of these techniques. Ultimately, a whole-farm systems approach may be the most appropriate basis for financial analyses of CA, as this can capture the full range of responses that farmers make when choosing to adopt a new technology such as CA. Moreover, it can incorporate the many options available to farmers in making such choices, something which is not possible in a simplistic comparison of conventional tillage and CA.

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Appendix 1
A summary of financial analyses of conservation agriculture

Study	Location	Crops grown	Returns/costs	Comments
Kelly, Lu and Teasdale (1996)	U.S.	Maize, winter wheat, wheat straw, soybean and hay	Total Gross Margin (US$/ha): - conventional, US$306 - no-till, US$331 - cover crop, US$ 117-169 - manure-based, US$256-305	Total gross margin is total revenues minus variable costs.
Uri (2000)	U.S.	Maize and soybeans	Total expenses (US$/ha): - chisel mouldboard plough, US$182-227 - disk chisel/disk, US$137-212 - no-till chisel, US$165-197 - no-till, US$142-205 - ridge till, US$140-227	Includes costs for machinery, labour and herbicides. Comparisons are made between chisel mouldboard plough (conventional technique) and all the others.
Stonehouse (1997)	Ontario, Canada	Maize, soybeans, alfalfa, winter wheat and oats	Change in total return/year (C$): - full width no-plough, C$260 719 - no-till, C$1 840 553	Costs are for change from conventional till to semi- or full no-till system. Includes on-farms costs and social costs associated with fishing, ditch-cleaning & dredging.
Govindasam *et al.* (1995)	Arkansas, U.S. (2 sites)	Cotton	Net revenues (1993 US$/acre): - conventional, US$306 & (US$138) - no-till, US$261 & (US$161) - ridge-till, US$305 & (US$182)	Net revenues include costs of: seed, labour, chemicals, fuel, repair and maintenance, interest, machinery and fixed expenses.
Sijtsma *et al.* (1998)	Prince Edward Island, Canada	Potato-barley-forage, barley-soybean	Tillage cost savings (C$): - chisel plough, C$5 890-7 860 - disc harrow, C$7 779-11 007 - power harrow, C$2 736 - roto-tiller, C$2 458 - cultivator-seed, C$11 012	Comparison to mouldboard plough costs. Tillage costs include machinery replacement costs & maintenance over life span.
Hernanz *et al.* (1995)	Spain	Winter wheat, winter barley, spring barley & vetch	Incremental net returns (1993 US$/ha): - minimum till, US$80-114 - no-till, US$46-154	Comparison of minimum and no-till to conventional tillage. Net returns equal gross margin minus production cost.
Zentner *et al.* (1991)	Saskatchewan, Canada	Spring wheat with fallow crop rotations	Net returns (1989/90 C$/ha): - conventional, silt loam (C$84)-C$40 - minimum, (C$21)-C$24 - no-till, (C$108)-C$5	Net returns are revenues less cash costs, labour and machine overhead (interest and depreciation included). No allowance for land investment.
Mueller *et al.* (1985)	Wisconsin, U.S.	Maize	Total costs (US$/acre): - conventional, US$295 (no & with fixed) - chisel plough, US$301 (no fixed), US$297 - till-plant, US$314 (no fixed), US$287 - no-till, US$320 (no fixed), US$292	Total costs include: variable costs in short-run calculation, plus fixed costs (including land) in long-run calculation.

Study	Location	Crops grown	Returns/costs	Comments
Stonehouse (1991)	Canada	Maize	Expected return to management (C$/ha): - conventional, C$416 - reduced conventional, C$405 - full-width no plough, C$411 - no-till, C$340	Expected return is gross revenue minus total production costs, defined as: fuel, agrochemicals, seed, machinery repairs & maintenance, capital costs, labour, land rental, insurance and miscellaneous.
Ehui *et al.* (1991)	Southwest Nigeria	Maize & cassava	To be completed	PVINR (Naira/ha).
Kirby *et al.* (1996)	Northern Australia	Sorghum	Gross margin (1996 US$/ha): - conventional till, US$190 - no-till, US$271	Gross margin, variable costs and grain returns are not defined.
Sorrenson (1997)	San Pedro and Itapua, Paraguay	Oats, soybean, sunflower, maize, wheat, oats, oilseed radish, oats, crotalaria & vicia	Net farm income (1995/6 US$): - conventional till, (US$3 013) & US$ 1095 - no-till, US$31 142 & US$33 703 Financial rate of return on marginal investment: medium farm 39 to 49 percent, large farm 100 to 151 percent	Net farm income is total farm income minus total variable & fixed costs after 10 years.
Sorrenson (1998)	Edilera and San Pedro, Paraguay	Various	Net farm income (1998/9 US$): - conventional US$567 & US$1 400 - no-till US$1 000-2 900 & US$1 090-1 350 Increase in net farm income when switching from conventional to no-till 35 to 236 percent	Net farm income is total farm income minus total variable & fixed costs.

Notes: negative values shown in brackets.

Appendix 2

A review of empirical studies of the adoption of soil conservation and conservation agriculture

Study/country	Crop or soil management practice adopted	Variables with significant positive influence on adoption	Variables with significant negative influence	Insignificant variables
Tanzania (Nkonya *et al*., 1997)	Nitrogen fertilizer	Area planted with improved maize seed	Farm size	Education, age, family labour, extension visits, livestock numbers, off-farm activities
Nigeria (Okoye, 1998)	Traditional soil erosion control practices (tree trunks, cover crops, diversion pits, mulching, mounds & ridging)	Input prices, interest rate, age	Off-farm employment, innovativeness index, income, education	Farm size, output prices, conservation attitude, risk bearing index
	Recommended soil erosion control practices (zero & minimum tillage, contour strip cropping, no burning & tree planting)	Input prices, age, income	Off-farm employment, output prices, innovativeness index, education	Input prices, interest rate, farm size, conservation attitude, risk bearing attitude
Rwanda (Clay *et al*., 1998)	Conservation investments (grass strips, ditches, hedgerows, terraces)	Sector-level conservation investments	Lower location on slope, size of parcel, distance from residence, leased land, landholdings owned	Agricultural profitability index, non-agricultural wage, output prices, distance to market/road, holdings under fallow/woodlot/pasture, slope, plot fragmentation, years farming, rainfall, price variation, income and wealth variables, demographic and socio-economic variables, other sector-level variables
	Organic inputs (composting, manure, green manure, mulch)	Parcel size, years farming, value of livestock, knowledge of conservation/production technologies, sector-level use of organic inputs	Non-agricultural wage, banana price, distance to paved road, share of holdings under fallow & pasture, slope, lower location on slope, distance from residence, leased ,land price variation, landholdings owned, age of household head	Agricultural profitability index, other output prices, distance to market, holdings in woodlots, slope, plot fragmentation, rainfall, other income and wealth variables, other demographic and socio-economic variables, other sector-level variables
	Chemical inputs (fertilizer, pesticides, lime)	Share of holdings in woodlots, parcel size, distance from residence, sector-level use of chemical inputs	Share of holdings under pasture, slope, lower location on slope, years farming, leased land	Agricultural profitability index, non-agricultural wage, output prices, distance to market/road, share of holdings under fallow, plot fragmentation, rainfall, price variation, income and wealth variables, demographic and socio-economic variables, other sector level

Notes: significance is measured at the 5 percent level or higher, except Caveness & Kurtz, which is at the 15 percent level or higher, and Westra & Olson, Shortle & Miranowski and Gould *et al*., which are at the 10 percent level or higher; Rahm & Huffman do not state to what level they measure significance; Nowak 1987 is not clear on level of significance; de Harrera and Sain, which is at the 10 percent level.

Study/country	Crop or soil management practice adopted	Variables with significant positive influence on adoption	Variables with significant negative influence	Insignificant variables
	Land use erosivity (erosiveness of crop mix – higher value, more erosive)	Share of holdings under fallow/woodlot/pasture, plot fragmentation, parcel size, cash crop income	Lower location on slope, distance from residence, rainfall, landholdings owned, sector-level land use patterns & chemical inputs	Agricultural profitability index, non-agricultural wage, output prices, distance to market/road, slope, years farming, price variation, other income and wealth variables, demographic and socio-economic variables, other sector level variables
Ethiopia (Shiferaw & Holden, 1998)	Conservation practices (retention of level bunds & graded fanya juu bunds)	Perception of problem, positive adoption attitude, technology awareness, land/person ratio, slope, parcel size, perceived technology productivity	Age, family size, altitude of plot	Education, household consumer-worker ratio, plot location in group area, land security, farm size, livestock holdings, house type, other technology characteristics, off-farm income, land use
Senegal (Caveness & Kurtz, 1993)	Agroforestry (live fences, windbreaks & home gardens)	Number of plots owned, adult males, male children, groundnut yield	Number of horses, female children	
Minnesota (Westra & Olson, 1997)	Conservation tillage	Farm size, concern for erosion, recent major farm investment, other farmers used as primary source of information, management skills, fit with production goals and the physical farm setting	Ease of finding information, degree of control in decision making	Long-term viability of the farm, age, experience, debt level, availability and ease of obtaining information, availability of support
Iowa, United States (Rahm & Huffman, 1984)	Conservation tillage	Area of maize planted, ratio of soybean acreage to maize acreage, soil characteristics (rolling, lighter and better drained soils), experience, formal education, attendance at courses, conferences and meetings at Iowa State, media sources used for information	Health	Rainfall, length of growing season, tenure, vocational training, completion of agricultural college, attendance at extension service demonstrations
Iowa, United States (Nowak, 1987)	Conservation tillage (ecological factors forced)	USDA contact, extension service contact	Land-use intensity, erosion rate, maize suitability rating	Number of field days, field demonstration and tests plots visited per year, gross farm income, non-farm income, farm size, access to credit, tenure, use of hired labour
Nigeria (Agbamu, 1995)	Eleven soil management practices, including minimum and zero tillage	Knowledge of innovative practices	Extension service contact	Farm size, education level, leadership status

Study/country	Crop or soil management practice adopted	Variables with significant positive influence on adoption	Variables with significant negative influence	Insignificant variables
Iowa, Unites States (Shortle & Miranowski, 1986)	Conservation tillage	Education, field type (hilly)	Farm size	Experience, tenure, crop rotation, perceived incremental risk, expected incremental yield
Wisconsin, United States (Gould *et al*., 1989)	Perception of soil erosion	Slope of land, education, experience, extension service contact	Acres planted	Farm-related training, full/part time operator
	Conservation tillage	Acres planted, proportion of total crop area devoted to row crops, precipitation and temperature, household income, age, off-farm work, whether farm will be transferred to family member, perception of soil erosion	Dairy/grain farm, slope of land, debt ratio, education, age, off-farm work	Proportion of total crop area devoted to small grains/hayland
Maine, United States (Marra & Ssali, 1990)	Conservation tillage/soil conserving practices	Education, experience		Farm size, soil erodibility, extension service contact, age, health
Tanzania (Isham 2000)	Fertilizer			
Ontario, Canada (Warriner & Moul, 1992)	Conservation tillage	Education, age, kin partners, connectedness, belief in the effectiveness of conservation tillage	Integration	Farm size, net income, outside sources of information, diversity
Azuero, Panama (de Harrera and Sain, 1999)	Conventional tillage, minimum tillage and zero tillage (large farms)	Plot size, importance of livestock, availability of machinery	Slope, ownership of conventional tillage machinery	Tenure, availability of information
	Conventional tillage, minimum tillage and zero tillage (small farms)	Availability of information	Plot size, importance of livestock	Tenure, availability of machinery, ownership of conventional tillage machinery, slope
United States (Uri, 1997)	No-till	Farm type, low soil productivity, slope, rainfall, expenditure on fertilizer and pesticides	High productivity soil, expenditures on fuel, expenditure on custom fertilizer	Tenure, temperature, age, education, soil texture, farm size, no. of acres in acreage reduction programme, proportion of hectares with no pesticides, hired labour, part/full time operator, proportion of hectares irrigated, water applied, seeding rate, yield per hectare
	Mulch tillage	Farm type, low soil productivity, slope, rainfall, expenditure on pesticides	High productivity soil, expenditures on fuel, expenditure on custom fertilizer	Tenure, temperature, expenditure on fertilizers, age, education, soil texture, farm size, no. of acres in acreage reduction programme, proportion of hectares with no pesticides, hired labour, part/full time operator, proportion of hectares irrigated, water applied, seeding rate, yield per hectare

Conservation agriculture is an innovative approach for improving resource use in sustainable production. Its benefits include reduced inputs, more stable yields, improved soil nutrient exchange and enhanced long-run profitability. This study examines the financial and non-financial factors that affect the adoption and success of conservation agriculture at farm, national and global levels. Conscious of the possible divergence between private and social interests, it highlights the importance of farmers' objectives and motives, the collective dimension and the role of policy. In calling for improved policy analysis and information for decision-making, it recommends the development of sustainability indicators and a whole-farm approach to analysis.