The farm-level economics of conservation agriculture for resource-poor farmers

David J. Pannell[a*], Rick S Llewellyn[b] and Marc Corbeels[c]

[a]School of Agricultural and Resource Economics, The University of Western Australia, Crawley, WA 6009, Australia
[b]CSIRO, Adelaide, Australia
[c]CIRAD-Annual Cropping Systems c/o Embrapa-Cerrados, Planaltina, Brazil

*E-mail address: david.pannell@uwa.edu.au

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The farm-level economics of conservation agriculture for resource-poor farmers[1]

David J Pannell[a,*], Rick S Llewellyn[b] and Marc Corbeels[c]

[a] *School of Agricultural and Resource Economics, University of Western Australia, Australia*

[b] *CSIRO, Adelaide, Australia*

[c] *CIRAD-Annual Cropping Systems c/o Embrapa-Cerrados ,Planaltina, Brazil*

*Corresponding author. Tel. +61864884735.

E-mail addresses: david.pannell@uwa.edu.au, rick.llewellyn@csiro.au, marc.corbeels@cirad.fr

Abstract

The farm-level economics of conservation agriculture (zero tillage, mulching and crop rotation) are described, reviewed and modelled. The economics are defined broadly to include not just short-term financial benefits and costs, but also the whole-farm management context, constraints on key resources such as labour and capital, risk and uncertainty, interactions between enterprises, and time-related factors, such as interest rates and the urgency of providing for the farm family. A wealth of evidence shows that these economic factors and variables related to them have significant influences on farmers' decisions about adoption of conservation agriculture. Literature on the farm-level economics of conservation agriculture for resource-poor farmers is reviewed. There is not a large body of high-quality relevant studies. Those that have been published highlight that the economics are highly heterogeneous and need to be considered on a case-by-case basis. Their results tend to indicate that it would be profitable to adopt conservation agriculture or components of it (although not in all cases). This contrasts with disappointing adoption in many of the regions of interest. Potential reasons for this disparity are discussed. A general model of the farm-level economics of conservation agriculture and its components is presented, and used to illustrate influences on the overall economic attractiveness of conservation agriculture. Key factors that would tend to discourage adoption in situations that otherwise look favourable include: the opportunity cost of crop residues for feed rather than mulch, the short-term reduction in yields under zero tillage plus mulching in some cases, combined with short planning horizons and/or high discount rates of farmers, farmer aversion to uncertainty, and constraints on the availability of land, labour and capital at key times of year. Good quality economic analysis should be used more extensively to guide research and extension in this area, particularly in relation to the targeting of effort, and adaptation of the system to suit local conditions.

Keywords: zero tillage, legume rotation, mulching, crop residue retention, risk, uncertainty, adoption of innovations, cropping system, Zimbabwe, maize, groundnuts

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1. Introduction

In response to concerns about food security, farm profitability, and land degradation in agriculture around the world, a range of practices have been developed and promoted to farmers. In developing countries, much attention has been given to a specific combination of measures packaged under the banner of "Conservation Agriculture" (CA) involving the key components of zero tillage (or at least minimum soil disturbance), retention of crop residues for soil cover (mulching), and rotation (or sometimes intercropping) of cereals with legumes (Kassam et al., 2009), or sometimes with other crops. In 2012 it was estimated that 9 per cent of the world's cropland area was being farmed under CA (Friedrich et al., 2012) with the largest areas being in South America. There has been much more extensive adoption of some of the components but not necessarily within the CA 'package'. For example, zero tillage (or no-tillage) has been a major success story in several agricultural systems of North America (Fulton 2010; Horowitz et al., 2010) and Australia (Llewellyn et al., 2012) but not always in association with all other CA components.

The success of these land conservation and soil fertility measures in the countries mentioned above has largely evaded South Asia and Africa. There are certain local success stories, but overall, uptake of CA as a package in these regions has been disappointing (Friedrich et al., 2012; Giller et al., 2009). As noted by Erenstein et al. (2012, p.181), there are "substantial challenges in terms of targeting, adapting and adopting CA—particularly for smallholders in the (sub)tropics". The findings of a meta-analysis of field experiments from around the world (Rusinamhodzi et al., 2011) demonstrate the agronomic challenges for broad adoption. Their analysis shows an increase in maize yield over time with CA practices in low rainfall areas, but results are highly dependent on rainfall, soil type and nitrogen fertiliser inputs. For example, one of the key components of CA, mulching, led to reduced yield in most high rainfall situations but was important for success in dry areas. What is clear is that agro-ecological conditions play a major role in determining the benefits of CA and its components. An additional challenge, potentially even more difficult, is the need for socio-economic considerations that favour successful adaptation and adoption (Giller et al., 2011a; Pannell et al., 2006).

Economics may help us to understand and address these challenges. We define economic drivers broadly to include not only returns from production but consideration of the whole-farm management context, constraints on key resources such as labour and capital, risk and uncertainty, interactions between enterprises, and time-related factors, such as interest rates and the urgency of providing for the farm family. Economic drivers at the farm level have been one of the key factors influencing the adoption of CA practices in Australia (D'Emden et al., 2006, 2008) and the Americas (Gray et al., 1996) and are highly likely to be influential in determining potential adoption in Africa and South Asia. The statement that farmers often respond to the farm-level economics of CA does not imply that farmers respond in a strictly predictable or rational way. Rather, the economics provide insights into trends and tendencies that are likely to be observed across populations of farmers, and can help assess the potential of practices for wide adoption.

In Africa and South Asia, when the farm-level economics of CA are sufficiently favourable, adoption of specific practices can be rapid and extensive. One example is the adoption by smallholders of zero tillage for wheat in parts of the Indo-Gangetic Plains in northern India (Erenstein et al. 2012). On the other hand, there has been little sustained adoption of CA in Sub-Saharan Africa, with local exceptions in Ghana, Zambia and Tanzania (Giller et al., 2009). This can be viewed as a result of economic benefits not currently being large or obvious enough to overcome other existing barriers to adoption.

We note that our concept of the farm-level economics of CA is broader than commonly considered in many mentions of economics in the CA literature, or indeed in many of the published economic analyses we review below. Farm-level economics is not just about immediate financial gain, but should also include, at least: farming systems complexities (e.g. enterprise interactions); long-term comparisons (consistent with the length of the planning horizon of relevant farmers); and personal preferences (e.g. for or against risk). In the case of resource-poor agriculture, the potential trade-off between ensuring the basic immediate-term needs of smallholder farm households and the promise of future improved productivity needs particular recognition (Affholder et al., 2010). Conclusions on the economics of CA should not be reached without consideration of constraints (e.g. on labour or capital) and the potential for acquiring information and skills.

Economic outcomes of CA are likely to be specific to particular people, places and situations (FAO 2001; Uri 1999; Gowing and Palmer, 2008). This is due to heterogeneity between regions (e.g. Erenstein et al., 2012, p. 186) and between farms in a region (Tittonell et al., 2005), and heterogeneity in institutional factors (Stonehouse, 1996), farm sizes, risk attitudes, interest rates, access to markets (for inputs and outputs), farming systems, resource endowments, and farm management skills, driving differences in benefits and costs of CA.

Heterogeneity may also operate within a farm where soil types may result in farmers choosing to adopt CA on some parts of their farm but not others (e.g. Baudron et al. 2012) and different cropping systems suiting some crops and not others (e.g. Erkossa et al., 2006). There may also be heterogeneity in how adoption proceeds. In some cases it may involve step-wise adoption, starting with the component of a 'package' that provides the best returns to the farmer's limiting resources (Byerlee and Hesse De Polanco, 1986) rather than adoption of the full CA package. As a result, the component that is adopted first can vary depending on the situation (Mazvimavi and Twomlow (2009). Chiputwa et al. (2011) found that in a study of CA use by Zimbabwean farmers only 20% had adopted all components of CA and that adoption of each component was affected by a distinct set of factors. CA systems can also diverge through local adaptation to suit farmers' own personal circumstances or preferences (Giller et al. 2011b; Erenstein, 2002).

Reviewing a large number of studies of CA adoption, Knowler and Bradshaw (2007) concluded that the adoption process for CA is highly heterogeneous, and that "there are few if any universal variables that regularly explain the adoption of conservation agriculture across past analyses". In reference to the plethora of individual specific variables that have been related to adoption (e.g. proportion of land devoted to row crops, expenditure on fertilizer, length of growing season), this is not surprising. However, the great majority of factors that have been found to be statistically significant explanators of extensive CA adoption relate one way or another to the farm-level economics of CA; they generally relate to the benefits, costs or risks of CA, the farm's human, financial or land resources, or the farmers' risk and time preferences. The study also highlights social capital as being widely relevant in CA adoption. All this means that it is necessary to consider site-specific conditions in determining the financial attractiveness of CA (FAO 2001) and efforts to promote CA should be targeted to those regions and situations where there is confidence that it generates sufficient benefits to outweigh the costs and the risks. Thus, not just CA itself, but CA extension efforts need to be tailored to reflect the particular conditions of individual locales (Knowler and Bradshaw 2007).

The aim of this paper is to help understand the farm-level economics of CA in smallholder agriculture, typified by those of Africa and South Asia. There are important differences between agriculture in these two regions, with South Asia having more examples of larger and better-resourced farming systems. As will become clear below, some of the advantages and disadvantages of CA are related to farm scale and intensity, so the economic performance of CA should not be presumed to be the same in both regions. Nevertheless, compared with most commercial farmers in developed countries, farmers in these two regions have smaller properties and may face tighter constraints on key resources of labour and capital, have higher levels of aversion to risk and uncertainty, have poorer access to markets for farm inputs and outputs, and may face different time-related pressures through a pressing need to provide for the farm family and/or through high costs of borrowed finance. These factors influence the economics of CA. Relevant questions include, under what circumstances are the farm-level economics of CA likely to be favourable, which factors influence the economic attractiveness of CA (and its components) to farmers, and is adoption of the whole CA package more beneficial than adoption of a subset of the CA components?

In the next section we present a conceptual framework for thinking about the role of the farm-economics of CA. In subsequent sections we use the framework in two ways. First we use it as a prism to review existing literature on the farm-level economics of CA in Africa and South Asia. Secondly, we use it as the basis for development of a quantitative model of the economics of CA adoption, and use that model to explore how the economic performance of CA and its components vary in different circumstances.

2. Conceptual framework

This section provides a conceptual framework for analysis of the farm-level economics of CA. Literature on the adoption of innovations in agriculture is introduced and related to the framework. Put simply, a sound model of the farm-level economics of CA needs to account for: the costs and benefits (broadly defined) of CA relative to the best alternative approach, adjusted for time lags and risk, subject to the need to satisfy resource and other constraints. Our model is essentially a household model, similar in concept to that of Graff-Zivin and Lipper (2008).

2.1 Benefits and costs

The literature on adoption of agricultural innovations highlights that adoption decisions depend on the goals of the farmers (e.g. Pannell et al., 2006). The needs and desires of the household for domestic consumption of agricultural products are uppermost in the priorities of many resource-poor farmers. Thus benefits and costs may need to be assessed in those terms, rather than primarily in cash terms. In that context, certain products may have a higher marginal value to the farmer than their market prices indicate. Potential benefits of shifting from conventional farming systems to CA can include increases in crop yield and, in some cases, decreases in costs (but sometimes the opposite). Specific evidence on these benefits is cited later. Other factors that may influence perceived benefits of adoption of a new practice include farm size (Feder, 1980), human capital, and land tenure (Feder et al., 1985).

Input costs are likely to vary under CA relative to conventional agriculture. As outlined in the literature review later, evidence is mixed about whether they will be higher or lower. In addition to the direct financial cost of inputs, the analysis needs to account for the opportunity costs of resources used in CA. The most prominent example is crop residues, which may have a non-cash value for feeding livestock, or for burning to enhance pest control, that would be lost if the residues are used for soil cover. These lost values (or opportunity costs) are just as relevant to the economics as are financial outlays on fertilizer or herbicide. The farmer's own labour will also have an opportunity cost that needs to be represented despite the fact that superficially the labour may appear to be unpriced. The opportunity cost may be the use of the labour in another farming enterprise or in paid off-farm work and is likely to be particularly high at peak times (White et al., 2005). The opportunity costs of resources (including labour and feed) depend on the farming system and the extent to which it is resource-intensive.

2.2 Risk and uncertainty

Risk and uncertainty mean that benefits of CA are best expressed as probability distributions. The probabilities of different possible benefit levels need to be considered to calculate an expected value of benefits. However, there is another aspect of risk and uncertainty that may need to be considered: the risk aversion of farmers. Resource-poor smallholders, in particular, are likely to be highly risk-averse, meaning that they would be willing to sacrifice some expected income in order to reduce the probability of below-average income. Even in developed countries, risk aversion may be an influence on adoption of CA (Varner et al., 2011).

"Risk" relates to the actual distribution of outcomes. It includes production risk and financial risk. If CA results in lower variation in crop yields or prices from year to year, it would have lower risk, and adoption would be enhanced. However, it is not clear whether the riskiness of CA overall (including production risk and price risk) is generally higher or lower than that of conventional systems. Different risks associated with the technology may be increase or decrease with greater levels of adoption or intensity of use (e.g. Just and Pope, 1979; Pannell, 1991).

"Uncertainty" relates to lack of knowledge or lack of confidence about the performance of a practice. Prior to having experience with CA, farmers will likely have high levels of uncertainty about its performance. Even if the objective riskiness of CA is relatively low, subjective uncertainty about it may be high in the early stages of diffusion and adoption. For farmers who are highly averse to risk and uncertainty, this can be a significant impediment to adoption of new practices (Feder, 1980; Antle and Crissman, 1990; Shively, 1997; Marra et al., 2003; Abadi Ghadim et al., 2005; Koundouri et al., 2006).

2.3 Time

Many resource-poor farmers have pressing needs to provide for their families and so cannot afford to make income sacrifices in the short term even if these would result in greater benefits in the long term. This may be exacerbated by very high interest rates on borrowing in many poor rural areas. Thirdly, some farmers have low confidence in the security of their rights to the resources they use. The risk of losing one's land resource would further reduce willingness to invest in long-term improvements in that resource (Feder et al., 1985).

These considerations can be reflected in economic calculations in two ways: through the discount rate used to compare benefits and costs that occur at different times, and through variation in the planning horizon: the number of years over which benefits and costs will be considered at all. Changing the planning horizon effectively amounts to a judgment that, beyond a certain time in the future, the discount rate becomes infinite. In general, resource-poor farmers have higher discount rates (meaning that future benefits receive a relatively low weight in the present) and shorter planning horizons than other farmers (Tanaka et al., 2010). The higher the farmer's discount rate, the less likely they are to be willing to invest in technologies that have long time lags until their benefits.

2.4 Constraints

The production choices of resource-poor farmers are often constrained by the low availability of key resources. For example, the farming decisions of smallholders are likely constrained by limited availability of labour and/or finance at particular times of year (Feder et al., 1985), reflected in high prices for those resources. The attractiveness of CA to these farmers will be influenced by whether it requires more or less of these limited resources at key times, relative to conventional practices. Greater and smaller resource requirements under CA are both possible, depending on the local circumstances. Failure to reflect this in economic analyses may lead to resource-intensive practices appearing more (or less) attractive than they really are.

The economic decision problem for farmers can be summarised as follows.

Max Σ_s U[Σ_t A×(	Y_g	×	P_g	+	Y_r	×	P_r	−	L	×	P_L	−	K	×	P_K	)×(1+r)$^{-t}$]×Prob(s)
Affected by …																
Crop choice(t)	✓		✓		✓		✓		✓				✓			
Crop choice(t−1)	✓		✓		✓		?						✓			
Zero till(t)									✓				?			
Zero till(t−1,t−2,…)	✓				✓								✓			
Mulching(t)					✓		✓		✓				?			
Mulching(t−1)	✓		?				?						?			
Subject to																
Total L															≤	L_{max}
Total K															≤	K_{max}

where

Y_g is yield of crop in year t

P_g is sale price of crop output (grain or seed) in year t

Y_r is yield of crop residues in year t

P_r is the value of crop residues in year t

L is the amount of family labour used in year t

P_L is the opportunity cost of family labour in year t

K is purchased inputs in year t

P_K is the cost per unit of purchased inputs in year t

For each of the above variables, subscripts for year t and state of nature s (capturing risk and uncertainty) have been suppressed for ease of reading, but it is important to recognise that each of them will vary over time and will be subject to risk and uncertainty.

r is the discount rate

A is area of the farm

U is the farmer's utility function, reflecting his or her attitude to risk

The main set of terms in brackets in the objective function (first line of the problem) represents the net benefits of farm production in year t in state of nature s. These are discounted to present values [(1+r)$^{-t}$], transformed by the utility function to reflect risk attitudes, and weighted by the probabilities of different states of nature to reflect the probability distribution of potential outcomes.

The next set of rows indicates how the variables of the objective function are likely to be affected by decisions made in relation to adoption of CA. For example, these indicate that the crop yield in year *t* will be affected by which crop is grown in year t (cereal or legume), which crop was grown the previous year, over how many previous years zero tillage has been used in the field, and whether residues from the previous year's crop were mulched. Ticks indicate that this aspect of CA is likely to affect the variable in question, and a question mark indicates that it may do so. These rows indicate that the influences of CA on the farm's economic performance are complex and numerous.

The last two rows represent the resource constraints, expressed simply as one constraint for family labour and one for capital used to purchase inputs. In reality there may be a set of constraints for different times of year.

3. Literature on farm-level economics

Here we review existing published research on the economics of CA at farm or field levels, discussing its implications and limitations. The first limitation is that the number of published studies of CA in Africa and South Asia is not large, so it is not possible to develop a comprehensive understanding of how the economics vary between regions, farming systems and farmers. Secondly, many of the existing studies examine individual components of CA rather than the full package. Those that do examine the whole package tend not to compare those results with the economics of partial adoption. Thirdly, most of the studies appear to take very simple approaches, or they provide very little information about the data and assumptions used. Overall, the published literature highlights the high level of heterogeneity and the need for case-specific analysis, but otherwise provides a limited perspective on the issues of interest to us. For that reason, we follow this literature review with results from a model created to provide insights into more of these issues. The review starts with studies that analysed the individual components of CA, and then covers studies of the CA package as a whole.

3.1 Zero tillage

Zero tillage (or at least reduced tillage) involves different practices in different contexts. In mechanised systems, common in parts of South Asia, it involves use of a tillage implement that creates a narrow slot for the seed and does not disturb or turn over the soil in the process of planting the crop. The traditional approach of ploughing for weed control prior to seeding is not used. In non-mechanised systems, more common in Africa, the process involves manual "jab planters" or simply using a stick to make a planting hole, leaving most of the soil surface undisturbed. Planting into prepared basins also minimize soil disturbance.

In some cases, reduced cost of production is the main driver for adopting zero tillage (e.g. Fowler and Rockstrom, 2001; Knowler et al., 2001). For example, farm household surveys in 2003–2004 in the north-west Indo-Gangetic Plains found high levels of adoption of zero tillage in local mechanised rice-wheat production systems. The adoption rate across households was 34% in India's Haryana state and 19% in Pakistan's Punjab (Erenstein, 2010). In this example, the main driver of adoption was found to be a significant, immediate and recurring "cost saving effect" which makes adoption profitable (Erenstein et al. 2008; Erenstein et al., 2012). In this region, reduced tractor time and fuel for land preparation and wheat establishment led to around 15 per cent saving in operating costs. Although undocumented in this case, improved timeliness of seeding (which is related to these savings) was found to be a valued consequence of zero tillage in Australia (D'Emden et al., 2008).

Similarly, Sidhu et al. (2010) estimated economic benefits from reduced tillage in wheat in Punjab, India. The profit increase of 800-2200 Rs/ha/year was attributed to cost savings.

However, reduced costs are not always observed, because reducing tillage can lead to challenges in combating weeds (Erenstein, 2002). For smallholders, CA is more likely to lead to labour savings in cases where herbicides are used for weed control, but less likely where farmers employ manual weeding (Ekboir et al. 2002; Erenstein et al., 2012; Wall, 2007; Ito et al., 2007). In the latter case, CA could even require more labour than conventional agriculture, based on tillage, does. Rockstrom et al. (2009) showed that CA in their southern and eastern African farmer-based trials reduced labour needs for tillage by at least 50%, but labour for weeding needs increased by up to 30%. Use of herbicides is sometimes not an option for resource-poor farmers (Mazvimavi and Twomlow, 2009) due to limited local availability, cash flow problems or lack of farmer knowledge and training. Where herbicides are not used, reduced tillage may increase the weeding burden (Giller et al., 2009).

Zero tillage may also influence crop yields, which has a direct bearing on profits. Evidence on yield effects of zero tillage is highly variable (Giller et al., 2009). Where zero tillage is combined with mulching, a commonly described pattern is for yields to fall initially (Fowler and Rockstrom, 2001; Baudron et al., 2011), and then to increase over the subsequent decade or so, eventually exceeding yields in conventional tillage-based agriculture (Giller et al., 2009 ; Rusinamhodzi et al., 2011). However, trial data also reveal cases where yield is largely unaffected, and some survey data indicate increases and decreases in different cases. For example, Erenstein et al. (2012) report a 4% yield increase in Haryana, India, but a similar yield decrease in Punjab, Pakistan.

Some studies identify both cost savings and yield increases. Erenstein and Laxmi (2008) reviewed a number of studies of the economics of zero tillage in the Indo-Gangetic Plains. Studies included a mix of on-farm trials, field station trials, and farmer surveys. The authors noted that "cost and profitability comparisons of the various studies are sometimes complicated by their site specificity and methodological differences" (Erenstein and Laxmi, 2008, p. 9). Nevertheless, the results consistently showed benefits – both cost savings and increased yields. On average, slightly more than half of the benefits were due to cost savings and slightly less than half were due to yield increases.

It is also possible that CA may reduce the variance of crop yields, although we are not aware of conclusive empirical evidence about this. If it does so, then this would provide an additional benefit to risk-averse adopters.

3.2 Mulching

The economics of mulching are highly context specific, depending on factors such as "human population and livestock density, cropping intensity, access to alternative feed sources, land and markets, and non-agricultural income" (Valbuena et al. 2012, p. 182). There appears to be little published research on the farm-level economics of mulching per se in Africa or South Asia. However, there is research and commentary that provides insights into its economic performance. For a start, there is clear evidence that mulch reduces soil erosion (Giller et al., 2009).

Apart from the long-term yield effect of mulching with zero tillage (described above) mulching can generate higher soil moisture content in the immediate following year, resulting in higher yields, especially in dry years. On the other hand, there is evidence that yields following mulching can be lower in high-rainfall conditions (Rusinamhodzi et al., 2011). Probert (2007), using simulation modelling of southern African cropping systems, concluded that variation in rainfall, soil water and fertility conditions means that crop yield response to residue retention can readily change from positive to negative and that the average effects of retention on maize production are likely to be modest. This is reflected in the variable response to mulching in field trials (e.g. Baudron et al., 2011).

Where retaining adequate mulch over the non-crop period is possible, labour requirements for creating an adequate mulch prior to the next crop can be a further cost for farmers (Lahmar et al., 2012). Affholder et al. (2010) found that this contributed to rice CA systems not always being economically attractive.

More importantly, there are two problems that detract from the viability of mulching in many cases. Firstly, it may not be possible for the farmer to claim exclusive rights to use the crop residues (Mazvimavi and Twomlow, 2009; Sibanda et al., 2011). In many regions in Sub-Saharan Africa, there is a cultural norm that residues may be grazed by any animal in the community (Wall, 2007). In southern Africa, for example, "once the harvest period is over, grazing animals are free to roam and an individual farmer is unable to protect his or her residues" (Erenstein et al., 2012, p.194). The same norm also operates in many regions of West Africa and East Africa. Residues provide an important source of animal feed, so changing this cultural norm is difficult.

Secondly, even if the farmer has exclusive rights to use of his or her stubble, its most valuable use may not be for mulch. The farmer may benefit more by using it for animal feed (Akpala and Ekbom, 2010; Mazvimavi and Twomlow, 2009; Jaleta et al., 2012) or as a fuel for burning for pest control, including weeds and rodents (Giller et al., 2009), or it may be harvested for sale (Valbuena et al., 2012). In a survey of Kenyan farmers, only around 20% retained more than two thirds of their maize residue as mulch, the dominant use being livestock feed (Jaleta et al., 2012).

Where residues are used by the farmer for animal feed, the viability of mulching may be influenced by the volume of biomass produced; only systems with high biomass production compared to the feed demands are likely to have enough surplus residues to mulch (Valbuena et al., 2012). On the other hand, even in the Trans-Gangetic Plains of India, where there is significant biomass production, current crop residue management practices (collection for livestock feed, burning) are largely incompatible with year-round mulch retention (Erenstein, 2011).

There is a lot of literature showing that crop residues can have significant feed value. For example, Magnan et al. (2012) estimated the value of crop residues used for feed in Morocco using household data. They found that residues account for around one quarter of the value of cereal production in a normal rainfall year and three quarters in a drought year.

In a case in Nepal where farmers had few livestock, Pant (2012) found that farmers like to burn their crop residues, despite externalities (smoke and greenhouse gases). It took payments to get most farmers to agree to stop burning, and even then 14% of them would not agree to stop. Farmers benefit from burning residues because it can facilitate establishment of a new crop.

3.3 Rotation

Legumes grown in rotation can provide a range of benefits to the agro-ecosystem, including increases in subsequent crop yields and reductions in input costs due to nitrogen fixation, reductions in crop disease and potentially other factors (Pannell, 1995). On the other hand, sale prices for legume crops may be lower or more volatile in some cases. Just as with zero tillage and mulching, the economics of including a legume phase in the rotation are highly case-specific. Generally, there are yield benefits to the cereal crop, but there may be lower returns (due to lower yield or price) in the legume phase. The economic attractiveness of legume rotations in these cases depends on whether the former outweighs the latter. There are a number of published studies of the economics of legume rotations (without the other components of CA) in the regions of interest, commonly, but not always, with favourable results.

Kaizzi et al. (2007) in semiarid eastern Uganda, based on 142 on-farm trials, found that rotation with legumes (cow pea or mucuna) increased profit. Ebanyat et al. (2010) (on-farm trials in eastern Uganda) found that legume-millet rotations grown with phosphate fertiliser on poor fields provided larger economic benefits than continuous cropping of millet. On better soils, legume-millet rotations without phosphate fertilizer were more profitable than continuous millet.

De Groote et al. (2010) (on-farm trials, western Kenya) found that soybean (legume) rotations and legume fodder intercropping with maize were highly profitable compared with conventional systems. Rotation with the green manure legume crop Crotalaria was clearly not economically attractive.

In Kenya, Rao and Mathuva (2000) found that annual grain legume-based cropping systems (based on cowpea and pigeonpea) were 32–49% more profitable than continuous maize. Maize rotation with gliricidia (a perennial legume) was less profitable than continuous maize.

Sanginga et al. (2003) in Nigeria, found large benefits from two cereal-legume rotations: maize in rotation with promiscuous soybean rotations (a rotation that combines high nitrogen fixation and the ability to kill large numbers of Striga hermonthica seeds in the soil), and millet in rotation with dual-purpose cowpea. These rotations were particularly economically favoured in degraded areas. Continuous maize was still economically attractive in non-degraded areas.

Waddington and Karigwindi (2001) examined the economics of maize-groundnut rotations in Zimbabwe, using data from on-station experiments and on-farm trials. The rotation was more profitable than continuous maize based on experiment-station data, but far less profitable using farm data. Thierfelder et al. (2012) did not do economic analysis but found large yield gains from rotation of maize with legumes in Zimbabwe and increasing benefits over time.

In a statistical study of 1300 farm households in Ethiopia and Tanzania, Asfaw et al. (2012) examined adopters of improved pigeonpea in Tanzania and chickpea in Ethiopia. It was found that adopters had significantly higher household expenditure per person than did nonadopters, even after controlling for all confounding factors.

3.4 The full Conservation Agriculture package

Farooq et al. (2011) plotted the yield difference between CA and conventional treatments against rainfall using results from 25 studies and found a declining trend in yield advantage of CA as rainfall increased, with yields of CA being mostly higher than conventional systems where annual rainfall was below 560 mm. In their meta-analysis of maize production under CA, Rusinamhodzi et al. (2011) found that CA led to no difference in yield stability under conditions of drought or excess rainfall. Given variation in and uncertainty about the benefits, estimates of the expected benefits should consider the probability distribution of outcomes, rather than assuming that the practice will always provide yield benefits. There is some evidence that higher inputs are needed to achieve substantial yield gains (in cases where those are possible) (Baudron et al., 2011; Rusinamhodzi et al., 2011). Ngwira et al. (2012a) also found higher variable costs under CA in Malawi.

FAO (2001) reviewed 40 studies of the financial net present values (NPVs) for CA and related agronomic approaches (intercropping, contour farming, green manure), almost all in developed countries. Of these, 34 studies indicated that the NPV of CA would be positive. However, as discussed earlier, favourable results for CA in other countries does not mean that CA will be profitable in Africa or South Asia. Because of heterogeneity in many factors that influence the economics, we have to assess the economics in the specific context of interest. Knowler and

Bradshaw (2007) reported that 10 out of 11 reviewed studies of the economics of CA for Sub-Saharan Africa found a positive NPV[2].

Kumar et al. (2011) identified significant economic benefits from a variety of CA and related systems, in a number of Indian states. For example, in states of Haryana and Rajathan, conservation tillage in pearl millet was estimated to result in increases of 23% in yield and 1400 Rs ha^{-1} $annum^{-1}$ in profit. In the same context, mulching was estimated to result in increases of 12% in yield and 325 Rs ha^{-1} $annum^{-1}$ in profit. In Madhya Pradesh conservation tillage in soybean increased yield by 15-18% and profit by 4500-5500 Rs ha^{-1} $annum^{-1}$. In Maharashtra, mulching in cotton increased yield by 5-20%, and profit by 2000-12000 Rs ha^{-1} $annum^{-1}$. In all cases, very little information about the analyses was provided.

Silici (2010) studied the system called Likoti in Lesotho. The system is based on use of planting basins for crop plants, and encompasses reduced tillage, mulching and rotation. It has been used for various crops, initially maize and beans, and later sunflowers, sorghum, potato and tomato. Profit per ha was much greater for Likoti than for conventional system in both of the regions studied. Profit/hour labour was greater in one region (highland) but not the other (lowland).

Haggblade and Plerhoples (2010) conducted a detailed economic analysis (using a plot-level linear programming model) of conservation farming versus conventional tillage in Zambia. The conservation farming system studied included: dry-season land preparation using minimum tillage systems; crop residue retention; seeding and input application in fixed planting stations; and nitrogen-fixing crop rotations. Unlike other studies reviewed here, the authors provided separate results for small farmers without access to cash inputs, farmers with enough cash to purchase a modest package of inputs (US$60 per season) and farmers purchasing a high level of inputs of fertilizer, hybrid seeds and herbicides (US$150 per season). All three groups benefited substantially from CA relative to conventional tillage, increasing income by 85%, 100% and 200%, respectively, for the three groups. For the second group, roughly two-thirds of the income gain stems from increased yield, while the remaining one-third comes from area expansion made possible due to labour savings under CA. For the high-cost group, use of herbicides reduced labour inputs for weed control, allowing the farmer to manage as much as 2.7 ha of crop, compared with only 1.1 ha under conventional hand hoe tillage. Like Giller et al. (2009), this study highlights that where capital is limiting, it can have a major impact on the benefits of CA. There is no mention in the study of the opportunity cost of crop residues for livestock feed, so it is possible that this may have been omitted.

Lai et al. (2012) studied the economics of CA in Odisha state, India. They found that legume rotation without minimum tillage was more profitable than legume rotation with minimum tillage, which was more profitable than conventional agriculture.

Ngwira et al. (2012a, 2012b) in a study for Malawi found that maize with pigeonpea intercropping plus minimum tillage was more profitable than minimum tillage in continuous maize, which was more profitable than conventional tillage-based agriculture.

In a different type of study, Mazvimavi et al. (2012) conducted a productivity and efficiency analysis for a sample of 1400 farmers in Zimbabwe over several household surveys since 2008. They found that output was positively related to labour and seed in CA but negatively in conventional farming. Fertilizer had a greater positive response in CA than in conventional farming. There was evidence of technical progress in CA for the three-year period. Technical progress was land-saving

[2] This review and the one by FAO (2001) suffers from a degree of ambiguity as it is not clear what they mean by "positive NPV". They could mean positive relative to doing nothing, or positive relative to the best alternative farming practices. Both criteria need to be met for adoption to be attractive.

but seed and fertilizer-using in CA, while land-using and seed-saving in conventional farming. The study indicated that farmers produced 39% more output in CA compared to conventional farming. However, the requirement for labour was higher under CA, which is likely to present challenges for adoption by resource-poor farmers.

3.5 Explaining non-adoption

Overall, apart from mulching, for which there is very little evidence either way, the majority of published economic results for CA are favourable, indicating that farmers would potentially benefit from adoption. However, the contrast between these favourable results and the low adoption of CA in most parts of Africa and South Asia is striking. There are a number of possible explanations for the disparity:

(a) CA appears financially superior in the results of an economic analysis, but this is misleading because the economic analysis is too simplistic or partial. For example, the analysis may omit agronomic and management factors, such as the opportunity cost of mulching crop residue or the opportunity cost of labour used for weed control.

(b) The economic analysis of CA is based on over-optimistic assumptions about agronomic impacts. For example, data are obtained from field stations under well-controlled conditions rather than from farms. Data may come from trials that use external inputs such as fertilizers, herbicides and/or improved seeds, whereas farmers may lacks these inputs.

(c) The assumptions and data used in the economic analysis are relevant to some farmers but not others. For example, the analysis may use a discount rate that is too low for the majority of farmers in a region.

(d) The analysis is based on an assumption that inputs of capital and labour are available in situations where they are not.

(e) The analysis ignores issues of risk and uncertainty, which have been recognised as important influences on adoption of CA by small farmers (Uri, 1998; Stonehouse, 1996; McNairn and Mitchell, 1992; Erenstein et al., 2012). Depending on whether CA is seen by farmers as being risk-reducing or risk-increasing, it may be more or less likely to be adopted. As a new technology, uncertainty about the performance of CA is likely to be greater than for traditional technologies (Marra et al., 2003).

(f) There is publication bias, such that studies with positive results are more likely to be accepted for publication.

(g) CA actually is financially superior to conventional agriculture but is not adopted for social or cultural reasons.

(h) There are positive net benefits of CA but they are not large enough to outweigh learning and transition costs. Moving from an established farming system to a new one is likely to involve costs of various types, potentially including new machinery, equipment, infrastructure, and time required to learn about the performance of the new system and how to implement it.

Of these explanations, it seems likely that one or more of the explanations related to weaknesses in the economic analysis [(a), (b), (c), (d) and (e)] are relevant in many of the reviewed studies. Without addressing issues (a) to (e), farm-level economic studies are of limited value as guides to the overall merits of CA in the regions of interest.

In many of the reviewed studies, the amount of information provided about the economic framework and the data and assumptions is too little to be able to judge whether any of the above explanations are applicable. In these cases, one's confidence in the quality of analysis cannot be high. Our suspicion is that explanations (a) to (e) are relevant to some degree to many, and probably most, of these studies.

The next section is a description of a comprehensive generic model of the farm-level economics of CA, and this is followed by a range of results from the model applied to a case study.

4. Economic model

There are several reasons for developing a new model of the farm-level economics of CA. Models used in most of the existing studies appear to be simple. Most existing models appear to omit one or more of the potentially important factors we identified in our conceptual framework. Many studies confound the economics of the components of CA; they don't allow the individual and interacting effects to be teased out. Few of the authors provide explicit enough information about the model for a reader to be able to make judgements about its quality and relevance.

The model will be used to provide insights and illustrations of the farm-level economics of CA. To ground the model in a real-world example, the model is parameterised for a case study: Mbire District, part of the Mid-Zambezi Valley in northern Zimbabwe (between 30°00 and 31°45 longitude East and 16°00 and 16°30 latitude South). A team of international researchers has been studying the performance of CA relative to conventional agriculture in this district since 2007 (Baudron et al., 2011, 2012). Assumptions about model parameters were based on estimates by one of this team of researchers (Marc Corbeels), drawing on the results of the research and on his experience observing and interacting with farmers in the district. The parameters for crop residue value were based on an unpublished study for Zimbabwe (Sabine Homann-Kee Tui, pers. comm.)

The study area is Communal Land, consisting of three Wards (2, 3 and 9) of the Rural District Council of Mbire, in the Dande Communal Area. Communal areas are state land that may be used for small-scale farming and residential purposes in accordance with local traditional authority and/or the local Rural District Council regulations. The area is mainly located on former floodplains of the Zambezi river basin, at an average altitude of 400 m above sea level, and is drained by two main rivers: the Angwa and the Manyame. It has a dry tropical climate, with low and very variable annual rainfall (on average between 450 and 650 mm/year) and a mean annual temperature of 25°C. Two seasons are clearly defined: a rainy season from December to March and a long dry season from April to November (Baudron et al., 2011). Because this case study has some important differences from other regions, sensitivity analysis is used to explore the consequences of those differences.

4.1 Model description

The model represents hypothetical, small resource-poor farms growing cereal crops and potentially a legume crop in rotation. It calculates the farm-level economics for a range of management scenarios: (a) conventional agriculture based on continuous cereal production, tillage and open-access grazing of crop residues (or if not open-access, use of crop residues for livestock feed), (b) a rotation of one-year cereal crop, one-year legume crop, (c) zero tillage in the cereal crops, (d) zero tillage in the legume crop, (e) zero tillage and mulching of the cereal crops residues, and (f) zero tillage and mulching of the legume crop residues. Options (b) to (f) can be used in any feasible combination, so there are 12 possible management scenarios in total, including cases where zero till, with or without mulching, is applied to one crop but not the other. Thus, it is not assumed that adoption of CA must be all-or nothing; the consequences of selective partial adoption are also investigated. Only on-farm private benefits and costs are represented in the model. Although the off-farm public benefits and costs of soil conservation (e.g. reduced erosion) can be important from a social perspectives, they are typically not expected to have a significant influence on farmer decision making in a resource-poor smallholder setting (e.g. Das and Bauer 2012).

The model includes many parameters that influence the economic performance of CA. A full list of parameters, including base-case assumptions is provided in the Appendix. Key variables specific to CA include:

- the effect of the legume crop on subsequent cereal yield when grown in rotation;
- the economic performance of the legume crop relative to the cereal (independent of any inter-year effect). As shown in the appendix, the assumed legume grain price is 14% higher than for the cereal, production costs are 30-40% lower, grain yields are lower (less than 50%), there is more residue per tonne of grain, crop residue is more valuable, and labour requirements per hectare are the same;
- the effects of zero tillage on labour costs and input costs;
- the short-term effects of mulching on subsequent crop yields (e.g. due to moisture conservation);
- costs of additional weed control under zero tillage;
- yield losses under zero tillage if extra weeds are not controlled;
- the values of crop residues if used for a purpose other than CA, such as grazing;
- the long-term dynamic pattern of crop yield changes over a decade after zero tillage plus mulching is commenced;
- the cost of fencing to convert open access to private access, to allow mulching (assuming it is socially feasible); and
- the cost of new equipment, or adaptations to existing equipment.

The model is implemented as a simulation model within the Microsoft Excel spreadsheet program. Results are calculated for three lengths of planning horizon: three years (realistic for many resource-poor farmers), 10 years and 20 years (to allow the full long-term benefits to be captured). In addition, three different discount rates are used, representing the opportunity cost of capital and/or the preference that poor farmers have for benefits sooner rather than later: 10%, 20% and 30%.

In the case study, differences in resource availabilities are explored by defining four different farm types (1-4), ranging from 1.5 to 6 hectares in area. These farms vary in yields, input levels, equipment, labour, and weed management (see Appendix for specific assumptions). Parameters provided are expected values of uncertain or risky distributions. Initially, the model is solved deterministically based on those expected values. Later a stochastic version of the model is presented to explore the consequences of farmer aversion to risk and uncertainty.

The smaller farms (types 1 and 2) rely solely on manual labour for seeding, while the larger farms (types 3 and 4) use animal traction, and the largest (type 4) is able to purchase a new direct seeder for the animal to pull. Crops are maize and the legume groundnuts. The rotations grown are either continuous maize or legume: maize (over two years). The larger farms include cattle, which graze mainly on communal grasslands outside the dry season and on the fields during the dry season. Currently, cultural norms determine that crop residues are open-access to the livestock of the village. We investigate the economics of converting to private access, through fencing, as would be required for the mulching component of CA.

4.2 Rotation

Tables 1 shows how a legume rotation performs relative to continuous cereal cropping, assuming that zero tillage and mulching are not practiced. The calculations are for base-case assumptions for all parameters (see Appendix), as they are for all results unless otherwise indicated.

For the base-case assumptions of this case study, the increase in maize yield following legumes is not sufficient to outweigh the reduced net benefits from sale or use of their harvested products relative to maize. The percentage loss of NPV is largest on the smallest farm, and largest for the shortest planning horizon.

This is not to suggest that a legume rotation could never be attractive. Table 2 shows a sensitivity analysis with higher legume crop yields (equivalent to higher sale prices). If legume crops gave yields (or prices) 30% higher than we have assumed for the base case, the legume rotation would be the more profitable option for large farms. (Cases where the conventional system is less profitable than the alternative system are shaded.) Under 50% legume yield (price) increases, legume rotation would be preferred on all but the smallest farms. Agricultural research might attempt to produce varieties or production systems that could achieve these yield increases. The results of Asfaw et al. (2012) illustrate the potential benefits of research to improve the productivity of legume crops in Ethiopia and Tanzania, with adopters of improved varieties gaining significant economic benefits.

Table 1. Net Present Values for continuous cereal and legume rotations across four farm types for three planning horizons (open-access grazing).

Farm type	3-year NPV		10-year NPV		20-year NPV	
	Continuous cereal	Legume rotation	Continuous cereal	Legume rotation	Continuous cereal	Legume rotation
1	679	424	1352	1020	1570	1185
2	1264	950	2515	2226	2922	2585
3	2823	1997	5618	4718	6525	5480
4	4866	3858	9685	8873	11249	10306

Table 2. Net Present Values for non-legume and legume rotations across four farm types for higher crop legume yields (10-year NPVs) (open-access grazing).

Farm type	No legume rotation	Legume rotation		
		Base case crop legume yields	Base case yields +30%	Base case yields +50%
1	1352	1020	1144	1226
2	2515	2226	2500	2683
3	5618	4718	5267	5633
4	9685	8873	10025	10794

4.3 Zero tillage

In Table 3 we focus on zero tillage in a continuous maize system. We assume that zero tillage without mulching has no direct effect on crop yields. Its potential benefit is through cost savings. This benefit is realised on farm type 4, which is able to use herbicides for control of the additional weeds that result from zero tillage. The savings in labour costs on farm type 4 are sufficient to outweigh the increases in input costs (herbicide) and the costs of direct seeding equipment purchase and maintenance. On the other farm types, herbicides are not used, so labour costs for weeding increase (farm types 2 and 3) or yields fall due to an inability to purchase additional labour for weeding (farm type 1).

Table 3. Net Present Values for conventional cultivation and zero tillage across four farm types for three planning horizons (open-access grazing).

Farm type	3-year NPV		10-year NPV		20-year NPV	
	Conventional cultivation	Zero tillage	Conventional cultivation	Zero tillage	Conventional cultivation	Zero tillage
1	679	251	1352	528	1570	618
2	1264	1158	2515	2333	2922	2714
3	2823	2645	5618	5289	6525	6147
4	4866	4910	9685	10076	11249	11753

4.4 Zero tillage with mulching

As noted earlier, conventional practice in the case-study region is for grazing animals to be granted open access to crop residues. If a farm family wished to use its own crop residues for grazing or mulching, it would have to overcome two obstacles: the potential opprobrium of their neighbours, and the lack of fencing around crop fields. In this section we assume that the social aspects can be overcome, provided that the farmer is willing to invest in fencing. Unless otherwise labelled, all subsequent results are for the assumption of private-access to crop residues.

Mulching has two sets of effects on yields. In the short term it may conserve soil moisture, increasing the yield of the next crop. In the long term, it may combine with zero tillage to influence yields through changes in soil fertility. There is wide variation in the reported long-term effect of zero tillage plus mulching on crop yields. Our assumption is consistent with a typically described pattern of yields decreasing slightly in early years[3] and then increasing to a greater extent over the course of about a decade. The assumed dynamic pattern of yield changes is illustrated in Figure 1. We assume that mulching has no effects on labour or input costs other than those associate with zero tillage.

[3] The observed initial decline may be partly due to CA needing, but not receiving, higher nitrogen fertilizer rates due to increased nitrogen immobilization under high carbon: nitrogen ratios in the soil.

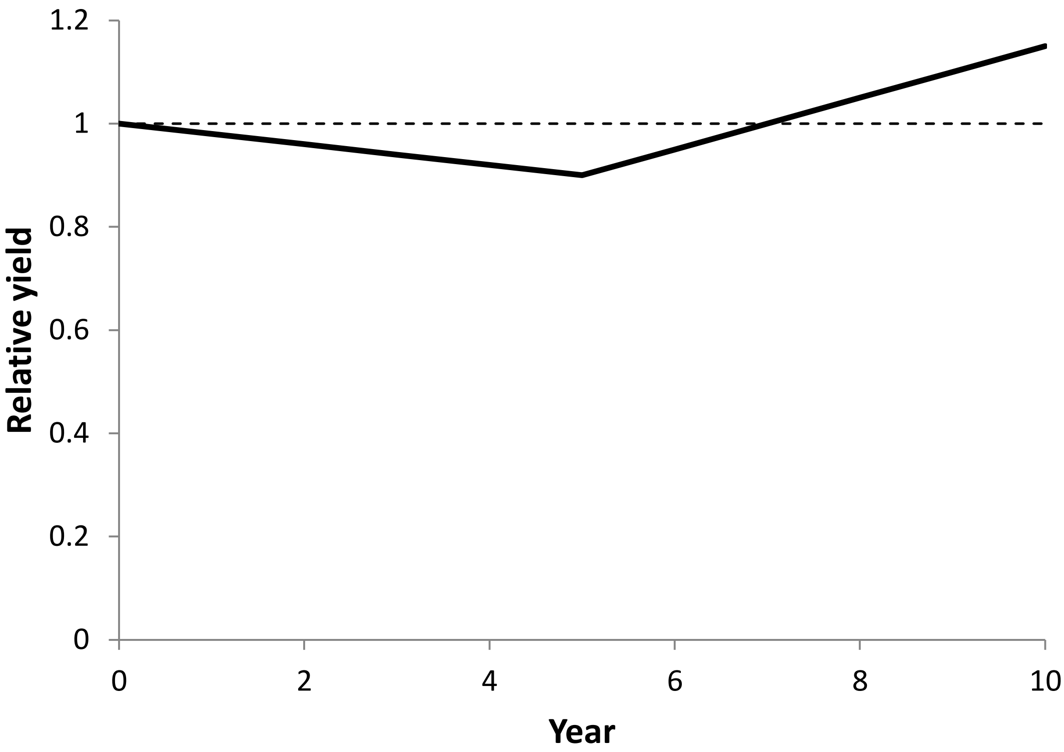

Figure 1. Assumed pattern of yield change following the commencement of zero tillage plus mulching: a fall to 90% of initial yield over five years followed by an increase to 115% of initial yield after 10 years. Yield is assumed to remain at 115% beyond year 10.

Table 4 shows NPV results for zero tillage plus mulching under private access. Before examining the results for zero tillage plus mulching, consider the effect of converting from open access to private access under conventional cultivation. Under private access (Table 4), farmers are able to exploit their own crop residues for livestock feed. However, a comparison of Tables 3 and 4 for conventional cultivation shows that the benefit of this feed is not sufficient to outweigh the cost of fencing. For example, the 10-year NPV for farm 4 falls from $9685 to $9453.

Now consider whether zero tillage plus mulching is superior to conventional cultivation under private access conditions. Table 4 shows that there are four cases where it is superior (shaded grey). These are farm type 4 over 10 years and farm types 2, 3 and 4 over 20 years. However, in only two cases is zero tillage plus mulching under private access superior to conventional cultivation under open access: farm type 4 over 10 or 20 years. For farm types 2 and 3, the cost of fencing to achieve private access outweighs the additional benefits of zero tillage plus mulching, even over 20 years.

Because of the pattern of yield changes (Figure 1), zero tillage plus mulching is more attractive over longer time frames (Table 4) or if lower discount rates are used (not shown). This indicates that zero tillage plus mulching will be relatively more attractive to farmers with secure land property rights, with less urgent food needs, and with access to credit at low interest rates. It is notable that this case study is for a relatively dry area, for which the benefits of mulching are high relative to a wet area. Even so, the practice is not attractive except on the largest farm type or over the longest time frame.

Table 4. Net Present Values for conventional cultivation and zero tillage plus mulching across four farm types for three planning horizons (private-access grazing).

Farm type	3-year NPV		10-year NPV		20-year NPV	
	Conventional cultivation	Zero tillage + mulching	Conventional cultivation	Zero tillage + mulching	Conventional cultivation	Zero tillage + mulching
1	444	-17	1192	358	1435	512
2	984	853	2370	2286	2821	2848
3	2285	2024	5373	5179	6376	6411
4	4128	3946	9453	9861*	11182	12142*

*NPV for zero tillage plus mulching under private access exceeds NPV for conventional cultivation under open access (Table 3).

4.5 The full conservation agriculture package

The previous sections have examined the components of CA individually. This section evaluates the whole package (Table 5). Results are somewhat similar to those for zero tillage plus mulching (Table 4). Under base-case assumptions, conventional agriculture is superior to conservation agriculture except on farm 4 over 20 years. The NPVs of conventional agriculture and conservation agriculture are almost the same on farm 4 over 10 years.

However, it is not necessarily the case that adoption of full CA is superior to partial adoption. Table 6 shows that, if the farmer has not yet installed a fence and can choose whether to do so, the optimal strategy for farm type 4 is zero tillage only, without fencing. (Shading shows the best option for each farm type.) Even if a fence has already been installed, the optimal strategy for farm type 4 is zero tillage plus mulching, not the full CA package, including rotation with a legume crop.

Table 5. Net Present Values for conventional cultivation and the full conservation agriculture package across four farm types for three planning horizons (open access grazing for conventional agriculture, private-access grazing for conservation agriculture).

Farm type	3-year NPV		10-year NPV		20-year NPV	
	Conventional agriculture	Conservation agriculture	Conventional agriculture	Conservation agriculture	Conventional agriculture	Conservation agriculture
1	679	-57	1352	418	1570	571
2	1264	622	2515	2191	2922	2710
3	2823	1372	5618	4678	6525	5767
4	4866	3194	9685	9643	11249	11798

Table 6. 10-year NPV for various strategies across four farm types. For the strategies without mulching, results are shown for the best option out of open access and private access.

Farm type	Conventional agriculture	Legume rotation	Zero tillage	Zero tillage + mulching	Conservation agriculture
1	1352*	1020*	528*	358	418
2	2515*	2226*	2333*	2286	2191
3	5618*	4718*	5289*	5179	4678
4	9685*	9018	10076*	9861	9643

*Open access grazing

4.6 Aversion to risk and uncertainty

The model is adapted to represent risk and uncertainty. Three aspects of the farming system are represented as being risky (for both conventional agriculture and CA): crop yields (both grain and crop residues), grain prices and input costs. Assumed coefficients of variation (CV) for yields are 0.25 for conventional agriculture and 0.15 for CA. Evidence for this difference in CV is thin, but we include it for illustrative purposes. Assumed CVs for grain prices and input costs are 0.2 and 0.1 respectively.

If CA is used, there initially may be high uncertainty about its yield benefits. To represent this high uncertainty, a CV of 1.0 is assumed. In other words, if the expected benefit of CA is a 20% yield increase, the 95% confidence interval ranges from approximately a 20% yield decrease to a 60% yield increase. The distributions of risky or uncertain variables are assumed to be approximately normal. All stochastic variables are assumed to be statistically independent from each other, except for grain yields and crop residue yields which are assumed to be perfectly correlated.

For the illustrative results in Table 7, farmers are assumed to be highly risk-averse, with a relative risk aversion coefficient of 4.0, and a utility function that reflects constant absolute risk aversion as wealth increases (Anderson et al., 1977; Hardaker et al., 2004). Initial wealth for the four farm types is assumed to be \$1500, \$2500, \$5500 and \$10,000 respectively, reflecting the 10-year NPV of conventional systems. The assumed argument for the utility function is the Net Present Value of income (over 3 or 10 years) plus initial wealth. The premium for risk and uncertainty is higher for a shorter planning horizon (relative to expected income) because there is more scope for sample bias when the sample of years is shorter. In other words, the variance of Net Present Value is greater when evaluated over a shorter time frame, because over a longer time frame there is a greater tendency for the ups and downs to cancel each other out.

Results are reported as certainty equivalent values. Each of these represents an expected Net Present Value minus a premium for risk (both price risk and production risk) and uncertainty. The premium depends on the overall variance of net income plus wealth, as well as the degree of risk aversion of the farmer. The variance is simulated for a sample of 100 states of nature that correspond to the above CVs.

To illustrate the potential impacts of risk and uncertainty on farmer choices, we start with a scenario that has the base-case assumptions except that it includes a 30% increase in legume yield (or sale price). In the absence of risk and uncertainty, based on 10-year NPVs, CA is superior to conventional agriculture on farm 4 but not on farms 1, 2 or 3 (Table 7).

Table 7. Certain-equivalent values of 10-year Net Present Values.

Farm type	No risk or uncertainty		Risk only		Risk and uncertainty	
	Conventional agriculture	Conservation agriculture	Conventional agriculture	Conservation agriculture	Conventional agriculture	Conservation agriculture
1	1192	374	1099	351	1099	336
2	2370	2341	2193	2226	2193	2070
3	5373	5111	4996	4885	4996	4609
4	9453	9524	8832	9117	8832	8691

Now examine the results for "risk only" and "risk and uncertainty". First note that, for a highly risk-averse decision maker, risk and uncertainty have negative impacts on the farmer for both conventional and CA systems. There is a large risk premium for "Risk only" in each case (i.e. the certainty equivalents are much lower for "Risk only" than for "No risk or uncertainty"). Interestingly, the risk premiums for the conventional system are slightly greater than for CA, making CA a little more attractive to risk-averse farmers. For these assumptions, farmer 2 would actually switch from preferring conventional agriculture to preferring CA. This is primarily due to the assumed lower CV of grain yield for CA.

However, the effect of uncertainty is unambiguously negative for CA. With the combination of risk and uncertainty, CA is no longer preferred by any of the four farmers. This highlights that, early in the adoption process, while farmers still have high uncertainty about the performance of CA, the expectations about CA need to be more favourable for risk-averse farmers than for risk-neutral farmers. In other words, even if farmers' beliefs were such that CA appeared to be the superior option *on average*, this will not necessarily be sufficient to prompt adoption, due to the negative influence of uncertainty. To counter this, the expected NPV for CA has to be sufficiently high to outperform conventional cultivation *plus* the uncertainty premium. This challenge may be diminished over time if farmers are able to gain greater confidence in CA, such as through observing it perform successfully on a neighbouring farm.

The results show that uncertainty about CA may or may not be the decisive factor determining whether CA is economically attractive. On farm type 4 in the above example, uncertainty about CA is sufficient to change the result from favouring CA to favouring conventional agriculture. However, the occurrence of such a switch depends on other numbers in the model. On farm types 1 and 3, CA is already unattractive without accounting for uncertainty. In other scenarios (not shown) CA was sufficiently attractive that it remains the preferred option even in the presence of uncertainty. Based on these results, it seems likely that explicit representation of uncertainty in economic models of CA will make an important difference to the results in some cases, but often will not, particularly for those farmers who are not highly averse to risk and uncertainty.

5. Conclusion

In the right circumstances, Conservation Agriculture has potential to contribute to the welfare of farmers in developing countries. However, not all circumstances are the right circumstances. It is also possible for CA to be economically unattractive to farmers because its benefits (broadly defined) are not sufficient to outweigh its costs (broadly defined), considering the specific farming context, risk and uncertainty, learning costs, constraints on key resources such as labour and capital, interactions between enterprises, and time-related factors.

Therefore economic analysis helps to explain the adoption and non-adoption of CA as a package. It also provides insights into why farmers often adopt the elements of packages like CA in a selective, partial way, or do so step-wise over a period of time.

Findings of the paper indicate that agricultural research and extension organisations should avoid promoting CA as a one-size-fits-all solution to the economic and natural resource challenges that farmers face. Such an approach is bound to waste agency and farmer resources in those circumstances where CA is not economically attractive to farmers. A more productive approach is to recognise the heterogeneity of farming circumstances, and make efforts to identify (including by economic analysis) those cases where CA, or one or more of its components, are adoptable. Efforts to promote CA should be focused on those cases. This conclusion reinforces the emphasis by Giller et al. (2009) and Erenstein et al. (2012) on the importance of targeting CA. The other key role for research and extension is to assist with adaptation of the package to best suit local circumstances. Again, economic analysis can play an important role in this task.

The economics that is needed for these tasks should be sophisticated enough to deal with the key drivers of and barriers to adoption of CA. Many published studies of the economics have lacked this degree of sophistication.

Key insights from the new economic modelling presented here include that CA is more likely to be economically attractive on larger, better resourced farms; to farmers with longer time horizon and lower discount rates; to farmers whose land is fenced, or at least could exclude livestock without violating local cultural norms; and to farmers who have less uncertainty about the benefits and costs of CA. The results demonstrate that reducing uncertainty can be an important challenge. For some components of CA this will be more difficult than others. For example, reducing uncertainty about the long-term benefits of zero tillage and mulching is likely to be difficult to achieve, especially in shorter-term demonstrations affected by climatic variation. In contrast, demonstrating reduced labour costs during crop establishment due to no-till may be relatively easy for certain farmers. There is an opportunity to focus extension not only where CA benefits may be greatest but also where uncertainty can most readily be reduced.

The model demonstrates that the economic attractiveness of CA depends on the complex interplay of many factors, so that negative aspects can potentially be outweighed by positives (or vice versa) depending on the numbers in specific cases. In the case study analysed, it appears that the potential economic gains from switching to CA are not large, and are primarily realised on larger, better resourced farms. Under many of the scenarios examined, switching to the full CA package results in economic losses, especially on the smaller farms.

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References

Abadi Ghadim, A.K., Pannell, D.J., and Burton, M.P., 2005. Risk, uncertainty and learning in adoption of a crop innovation. Agricultural Economics 33, 1-9.

Affholder, F., Jourdain, D., Quang, D.D., Tuong, T.P., Morize, M., and Ricome, A., 2010. Constraints to farmers' adoption of direct-seeding mulch-based cropping systems: A farm scale modelling approach applied to the mountainous slopes of Vietnam. Agric. Syst. 103, 51–62.

Akpalu, W., and Ekbom, A., 2010. The Bioeconomics of Conservation Agriculture and Soil Carbon Sequestration in Developing Countries, Environment for Development Discussion Paper Series March 2010, EfD DP 10-07, Environment for Development. http://www.rff.org/rff/documents/EfD-DP-10-07.pdf (accessed 23 Sept 2012).

Anderson, J.R., Dillon, J.L., and Hardaker, J.B., 1977. Agricultural Decision Analysis. Iowa State University Press, Ames.

Antle, J.M., and Crissman, C.C., 1990. Risk, efficiency, and the adoption of modern crop varieties: evidence from the Philippines. Economic Development and Cultural Change 38(3), 517-537.

Asfaw, S., Shiferaw, B., Simtowe, F., and Lipper, L., 2012. Impact of modern agricultural technologies on smallholder welfare: Evidence from Tanzania and Ethiopia. Food Policy 37, 283-295.

Baudron, F., Tittonell, P., Corbeels, M., Letourmya, P., and Giller, K.E., 2011. Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. Field Crops Research 132, 117-128.

Baudron, F., Andersson, J.A., Corbeels, M., and Giller, K.E., 2012. Failing to yield? Ploughs, conservation agriculture and the problem of agricultural intensification: an example from the Zambezi Valley, Zimbabwe. Journal of Development Studies 48(3), 393-412.

Byerlee, D., and Hesse De Polanco, E., 1986. Farmers' stepwise adoption of technological packages: evidence from the Mexican Altiplano. American Journal of Agricultural Economics 68(3), 519-527.

Chiputwa, B., Langyintuo , A.S., and Wall, P., 2011. Adoption of conservation agriculture technologies by smallholder farmers in the Shamva District of Zimbabwe: A Tobit application. Paper presented at 2011 meeting of the Southern Agricultural Economics Association, Texas, USA, Feb 5-8 2011.

Das, R., and Bauer, S., 2012. Bio-economic Analysis of Soil Conservation Technologies in the Mid-Hill region of Nepal. Soil and Tillage Research 121, 38–48.

De Groote, H., Vanlauwe, B., Rutto, E., Odhiambo, G. D., Kanampiu, F., and Khan, Z.R., 2010. Economic analysis of different options in integrated pest and soil fertility management in maize systems of Western Kenya. Agricultural Economics 41(5), 471-482.

D'Emden, F.H., Llewellyn, R.S., and Burton, M.P., 2006. Adoption of conservation tillage in Australian cropping regions: An application of duration analysis. Technological Forecasting and Social Change 73, 630–647.

D'Emden, F.H., Llewellyn, R.S., and Burton, M.P., 2008. Factors influencing adoption of conservation tillage in Australian cropping regions. Australian Journal of Agriculture and Resource Economics 52, 169-182.

Ebanyat, P., de Ridder, N., de Jager, A., Delve, R. J., Bekunda, M. A., and Giller, K. E., 2010. Impacts of heterogeneity in soil fertility on legume-finger millet productivity, farmers' targeting and economic benefits. Nutrient Cycling in Agroecosystems 87(2), 209-231.

Ekboir, J., Boa, K., and Dankyi, A.A., 2002. Impact of no-till technologies in Ghana. Economics Program Paper 02-01, CIMMYT, Mexico DF.

Erenstein, O., 2002. Crop residue mulching in tropical and semi-tropical countries. An evaluation of residue availability and other technological implications. Soil Till. Res. 67, 115–133.

Erenstein, O., 2010. Triangulating technology diffusion indicators: zero tillage wheat in South Asia's irrigated plains. Experimental Agriculture 46(3), 293-308.

Erenstein, O., 2011. Cropping systems and crop residue management in the Trans-Gangetic Plains: Issues and challenges for conservation agriculture from village surveys. Agricultural Systems 104(1), 54-62.

Erenstein, O., and Laxmi, V., 2008. Zero tillage impacts in India's rice-wheat systems: A review. Soil and Tillage Research 100(1–2), 1–14.
Erenstein, O., Farooq, U., Malik, R.K., and Sharif, M., 2008. On-farm impacts of zero tillage wheat in South Asia's rice-wheat systems. Field Crops Research 105(3), 240–252.
Erenstein, O., Sayre, K., Wall, P., Hellin, J., and Dixon, J., 2012. Conservation Agriculture in Maize- and Wheat-Based Systems in the (Sub)tropics: Lessons from Adaptation Initiatives in South Asia, Mexico, and Southern Africa, Journal of Sustainable Agriculture 36 (2) , pp. 180-206
Erkossa, T., Stahr,K., and Gaiser, T., 2006. Soil tillage and crop productivity on a Vertisol in Ethiopian highlands. Soil and Tillage Research 85, 200–211
Farooq, M., Flower, K.C., Jabran, K., Wahid, A., and Siddique, K.H.M., 2011. Crop yield and weed management in rainfed conservation agriculture. Soil and Tillage Research 117, 172–183.
Feder, G., 1980. Farm size, risk aversion and the adoption of new technology under uncertainty. Oxford Economic Papers 32(2), 263-283.
Feder, G., Just, R.E., and Zilberman, D., 1985. Adoption of Agricultural Innovations in developing countries: a survey. Economic Development and Cultural Change 33(2), 255-298.
Food and Agriculture Organization of the United Nations (FAO), 2001. The Economics of Conservation Agriculture. Food and Agriculture Organization, Natural Resources Management and Environment Department. FAO Corporate Document Depository. http://www.fao.org/DOCREP/004/Y2781E/Y2781E00.HTM, (accessed 03.02.13).
Fowler, R., and Rockstrom, J. 2001. Conservation tillage for sustainable agriculture: An agrarian revolution gathers momentum in Africa. Soil and Tillage Research 61(1-2), 93-107.
Friedrich, T, Derpsch, R., and Kassam, A., 2012. Overview of the Global Spread of Conservation Agriculture. The Journal of Field Actions, Field Actions Science Reports, Special Issue 6. http://factsreports.revues.org/1941, (accessed 03.02.13).
Fulton, M., 2010. Foreword. In: Lindwall, C., Sonntag, B. (Eds.), Landscapes Transformed: The History of Conservation Tillage and Direct Seeding. Knowledge Impact in Society, Saskatoon, Saskatchewan, pp. ix-xiv. http://www.kis.usask.ca/ZeroTill/LandscapesTransformed_HistoryofCT_Book.pdf, (accessed 03.02.13).
Giller, K.E., Witter, E., Corbeels, M., and Tittonell, P., 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Research 114(1), 23-34.
Giller, K.E., Corbeels, M., Nyamangara, J., Triomphe, B., Affholder, F., Scopel, E., and Tittonell, P., 2011a. A research agenda to explore the role of conservation agriculture in African smallholder farming systems. Field Crops Res. 124, 468–472.
Giller, K.E., Tittonell, P., Rufino, M.C., van Wijk, M.T., Zingore, S., Mapfumo, P., Adjei-Nsiah, S., Herrero, M., Chikowo, R., Corbeels, M., Rowe, E.C., Baijukya, F., Mwijage, A., Smith, J., Yeboah, E., van der Burg, W.J., Sanogo, O.M., Misiko, M., de Ridder, N., Karanja, S., Kaizzi, C., K'ungu, J., Mwale, M., Nwaga, D., Pacini, C., and Vanlauwe, B., 2011b. Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. Agricultural Systems 104(2), 191-203.
Gowing, J.W., and Palmer, M., 2008. Sustainable agricultural development in sub-Saharan Africa: the case for a paradigm shift in land husbandry. Soil Use Management 24, 92–99.
Graff-Zivin, J., and Lipper, L., 2008. Poverty, risk and soil carbon sequestration. Environment and Development Economics 13(3), 353-373.
Gray, R., Taylor, W., and Brown, J., 1996. Economic factors contributing to the adoption of reduced tillage technologies in central Saskatchewan. Canadian J. Plant Sci. 76, 661-668.
Haggblade, S., and Plerhoples, C., 2010. Productivity impact of conservation farming on smallholder cotton farmers in Zambia. Working Paper No. 47, Food Security Research Project, Lusaka, Zambia. http://www.aec.msu.edu/fs2/zambia/wp47.pdf (accessed 03.02.13).
Hardaker, J.B., Huirne, R.B.M., Anderson, J.R., and Lien, G., 2004. Coping With Risk in Agriculture, 2nd Edition. CABI Publishing, Wallingford, UK.

Horowitz, J., Ebel , R., and Ueda, K., 2010. No-till farming is a growing practice. Economic Information Bulletin, Number 70. Economic Research Service, USDA, Washington. http://www.ers.usda.gov/publications/eib-economic-information-bulletin/eib70.aspx, (accessed 03.02.13).

Ito, M., Matsumoto, T., and Quinones, M.A., 2007. Conservation tillage practice in Sub-Saharan Africa: The experience of Sasakawa Global 2000. Crop Protection 26, 417–423.

Jaleta, M., Kassie, M., and Shiferaw, B., 2012. Tradeoffs in crop residue utilization in mixed crop-livestock systems and implications for conservation agriculture and sustainable land management. Selected paper prepared for presentation at the International Association of Agricultural Economists (IAAE) Triennial Conference, Foz do Iguacu, Brazil, 18-24 August, 2012. http://ageconsearch.umn.edu/handle/126282, (accessed 03.02.13).

Just, R., and Pope, R., 1979. Production function estimation and related riskconsiderations. American Journal of Agricultural Economics 61(2), 276-284.

Kaizzi, K.C., Byalebeka, J., Wortmann, C.S., and Mamo, M., 2007. Low inputapproaches for soil fertility management in semiarid Eastern Uganda. Agronomy Journal 99(3), 847-853.

Kassam, A.H., Friedrich, T., Shaxson, T.F., and Pretty, J.N., 2009. The spread of Conservation Agriculture: Justification, sustainability and uptake. International Journal of Agriculture Sustainability 7, 292-320

Knowler, D., Bradshaw, B., and Gordon, D., 2001. The Economics of Conservation Agriculture. Natural Resources Management and Environment Department, Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/DOCREP/004/Y2781E/Y2781E00.HTM, (accessed 03.02.13).

Knowler, D., and Bradshaw, B., 2007. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy 32: 25–48.

Koundouri, P., Nauges, C., and Tzouvelekas, V., 2006. Technology adoption under production uncertainty: Theory and application to irrigation technology. American Journal of Agricultural Economics 88(3), 657-670.

Kumar, S., Sharma, K.L., Kareemulla, K., Chary, G.R., Ramarao, C.A., Rao, C.S., and Venkateswarlu, B., 2011. Techno-economic feasibility of conservation agriculture in rainfed regions of India. Current Science 101(9), 1171-1181.

Lai, C., Chan, C., Halbrendt, J., Shariq, L., Roul, P., Idol, T., Ray, C., and Evensen, C., 2012. Comparative economic and gender, labor analysis of conservation agriculture practices in tribal villages in India., International Food and Agribusiness Management Review 15(1), 73-86.

Lahmar, R., Bationob B.A., Nomaou Dan Lamsoc, N., Guéroc, Y., and Tittonell, P., 2012. Tailoring conservation agriculture technologies to West Africa semi-arid zones: Building on traditional local practices for soil restoration. Field Crops Research (132),158–167.

Llewellyn, R.S., D'Emden, F.H., and Kuehne, G. 2012. Extensive use of no-tillage in grain growing regions of Australia. Field Crops Research 132, 204-212.

Magnan, N., Larson, D.M., and Taylor, J.E., 2012. Stuck on stubble? The non-market value of agricultural byproducts for diversified farmers in Morocco. American Journal of Agricultural Economics 94(5), 1055–1069.

Marra, M., Pannell, D.J., and Abadi Ghadim, A., 2003. The economics of risk, uncertainty and learning in the adoption of new agricultural technologies: Where are we on the learning curve? Agricultural Systems 75(2/3), 215-234.

Mazvimavi, K., and Twomlow, S., 2009. Socioeconomic and institutional factors influencing adoption of conservation farming by vulnerable households in Zimbabwe. Agricultural Systems, 101(1-2), 20-29.

Mazvimavi, K., Ndlovu, P. V., Henry, A., and Murendo, C., 2012. Productivity and efficiency analysis of maize under Conservation Agriculture in Zimbabwe. Paper presented at International Association of Agricultural Economists Conference, August 18-24, 2012, Foz do Iguaçu, Brazil.

McNairn, H.E., and Mitchell, B., 1992. Locus of control and farmer orientation: effect on conservation adoption. Journal of Agricultural and Environmental Ethics 5(1), 87-101.
Ngwira, A.R., Aune, J.B., and Mkwinda, S., 2012a. On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in Malawi. Field Crops Research 132, 149-157.
Ngwira, A.R., Thierfelder, C., and Lambert, D.M., 2012b. Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. Renewable Agriculture and Food Systems, FirstView article. http://dx.doi.org/10.1017/S1742170512000257, (accessed, 03.02.13).
Pannell, D.J., 1991. Pests and pesticides, risk and risk aversion. Agricultural Economics 5(4), 361-383.
Pannell, D.J. 1995. Economic aspects of legume management and legume research in dryland farming systems of southern Australia. Agricultural Systems 49, 217-236.
Pannell, D.J., Marshall, G.R., Barr, N., Curtis, A., Vanclay, F., and Wilkinson, R., 2006. Understanding and promoting adoption of conservation practices by rural landholders. Australian Journal of Experimental Agriculture 46(11), 1407-1424.
Pant, K.P., 2012. Payment experiment for modification of farm practices: a case of rice residue burning in Nepal, Selected Paper prepared for presentation at the International Association of Agricultural Economists Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August, 2012. http://ageconsearch.umn.edu/handle/126195, (accessed 03.02.13).
Probert, M.E., 2007. Modelling minimum residue thresholds for soil conservation benefits in tropical, semi-arid cropping systems. Technical Report No. 66, Australian Centre for International Agricultural Research, Canberra.
Rao, M.R., and Mathuva, M.N., 2000. Legumes for improving maize yields and income in semi-arid Kenya. Agriculture, Ecosystems and Environment 78(2), 123-137.
Rockstrom, J., Kaumbutho, P., Mwalley, J., Nzabi, A.W., Temesgen, M., Mawenya, L., Barron, J., Mutua, J., and Damgaard-Larsen, S., 2009. Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. Soil and Tillage Research 103, 23-32.
Rusinamhodzi, L., Corbeels, M., van Wijk, M.T., Rufino, M.C., Nyamangara, J., and Giller, K.E., 2011. A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. Agronomy Sust. Development 31, 657–673.
Sanginga, N., Dashiell, K.E., Diels, J., Vanlauwe, B., Lyasse, O., Carsky, R.J., Tarawali, S., Asafo-Adjei, B., Menkir, A., Schulz, S., Singh, B.B., Chikoye, D., Keatinge, D., and Ortiz, R., 2003. Sustainable resource management coupled to resilient germplasm to provide new intensive cereal-grain-legume-livestock systems in the dry savanna. Agriculture, Ecosystems and Environment 100(2-3), 305-314.
Shively, G.E., 1997. Consumption risk, farm characteristics, and soil conservation adoption among low-income farmers in the Philippines. Agricultural Economics 17(2), 165-177.
Sibanda, A., Homann-Kee Tui, S., van Rooyen, A., Dimes, J., Nkomboni, D., and Sisito, G., 2011. Understanding community perceptions of land use changes in the rangelands, Zimbabwe. Experimental Agriculture 47, 153–168.
Sidhu, R.S., Vatta, K., and Dhaliwal, H.S., 2010. Conservation Agriculture in Punjab – Economic implications of technologies and practices. Indian Journal of Agricultural Economics 65(3), 413-427.
Silici, L., 2010. Conservation Agriculture and Sustainable Crop Intensification in Lesotho. Integrated Crop Management, Vol.10-2010, FAO, Rome.
Stonehouse, P.D., 1996. A targeted policy approach to inducing rates of conservation compliance in agriculture. Canadian Journal of Agricultural Economics 44, 105-119.
Tanaka, T., Camerer, C.F., and Nguyen, Q., 2010. Risk and time preferences: linking experimental and household survey data from Vietnam. American Economic Review 100(1), 557-571.

Thierfelder, C., Cheesman, S., and Rusinamhodzi, L., 2012. A Comparative analysis of conservation agriculture systems: benefits and challenges of rotations and intercropping in Zimbabwe. Field Crops Research 137, 237–250.

Tittonell, P., Vanlauwe, B., Leffelaar, P.A., Rowe, E.C., and Giller, K.E., 2005. Exploring diversity in soil fertility management of smallholder farms in western Kenya: I. Heterogeneity at region and farm scale. Agriculture, Ecosystems and Environment 110, 149-165.

Uri, N.D., 1998. The role of public policy in the use of conservation tillage in the USA. Science of the Total Environment 216: 89-102.

Uri, N.D., 1999. The economic benefits and costs of conservation tillage. Journal of Sustainable Agriculture 15: 5–26.

Valbuena, D., Erenstein, O., Homann-Kee Tui, S., Abdoulaye, T., Claessens, L., Duncan, A.J., Gérard, B., Rufino, M.C., Teufel, N., van Rooyen, A. and van Wijk, M.T. 2012. Conservation Agriculture in mixed crop-livestock systems: Scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. Field Crops Research 132, 175-184.

Varner, B.T., Epplin, F.M., and Strickland, G.L., 2011. Economics of no-till versus tilled dryland cotton, grain sorghum, and wheat. Agronomy Journal 103(5), 1329-1338.

Waddington, S.R., and Karigwindi, J., 2001. Productivity and profitability of maize + groundnut rotations compared with continuous maize on smallholder farms in Zimbabwe. Experimental Agriculture 37(1), 83-98.

Wall, P.C., 2007. Tailoring conservation agriculture to the needs of small farmers in developing countries: An analysis of issues. Journal of Crop Improvement 19, 137–155.

White, D.S., Labarta, R.A., and Leguía, E.J., 2005. Technology adoption by resource-poor farmers: considering the implications of peak-season labor costs. Agricultural Systems 85, 183–201.

Appendix

Table A.1. Parameters of the economic model that are consistent across farm types.

Maize crop price	350	$/tonne
Legume crop price	400	$/tonne
Cost of fencing (zero if open access)	250	$/ha
Effect of mulching on bought labour cost that year	0	$/ha
Effect of mulching on subsequent input cost	0	$/ha
Positive interaction between zero till+mulch and rotation	0	t/ha
Discount rate	0.2	
Maize residue ratio	0.9	t residue/t grain
Legume residue ratio	1.35	t residue/t grain
Maize residue value if not mulched (zero if open access)	30	$/tonne
Legume residue value if not mulched (zero if open access)	60	$/tonne
Dynamic changes in yield due to zero till + mulch		
Phase 1		
Change in yield	-0.1	t/ha relative to initial yield
Time until change finished	5	years of zero till
Phase 2		
Change in yield	0.15	t/ha relative to initial yield
Time until change finished	5	years of zero till

Table A.2. Parameters of the economic model that vary across farm types.

Farm type		**1**	**2**	**3**	**4**
Maize crop yield	tonne/ha	0.9	1.2	1.3	1.5
Legume (groundnut) crop yield	tonne/ha	0.3	0.5	0.5	0.7
Maize production cost	$/ha	100	120	120	140
Legume production cost	$/ha	60	80	80	100
Maize					
Share of cost: labour bought		0	0.2	0.2	0.35
Share of cost: labour own		0.8	0.6	0.6	0.35
Share of cost: inputs		0.2	0.2	0.2	0.3
Legume					
Share of cost: labour bought		0	0.2	0.2	0.35
Share of cost: labour own		0.8	0.6	0.6	0.35
Share of cost: inputs		0.2	0.2	0.2	0.3
Cost of fencing (zero if open access)	$/ha	250	250	250	250
Effect of legume crop on subsequent maize yield	t/ha	0.2	0.4	0.4	0.5
Effect of zero tillage on bought labour cost that year	$/ha	0	18	18	-44
Effect of zero tillage on input cost that year	$/ha	0	0	0	15
Effect of zero tillage on yield that year due to uncontrolled weeds	proportion	0.6	1	1	1
Zero tillage up-front equipment costs, year 1	$/farm	35	35	30	375
Equip extra maintenance cost if zero tillage, years 2-20	$/farm	0.7	0.7	0.6	7.5
Effect of mulching legume on subsequent maize yield	t/ha	0.2	0.3	0.3	0.3
Effect of mulching maize on subsequent legume yield	t/ha	0.1	0.2	0.2	0.2
Area	ha	1.5	2	4	6