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RESEARCH INTO CONSERVATION TILLAGE FOR DRYLAND CROPPING IN AUSTRALIA AND CHINA

Projects LWR2/1992/009 and LWR2/1996/143

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The Australian Centre for International Agricultural Research (ACIAR) operates as part of Australia's international development cooperation program, with a mission to achieve more-productive and sustainable agricultural systems, for the benefit of developing countries and Australia. It commissions collaborative research between Australian and developing-country researchers in areas where Australia has special research competence. It also administers Australia's contribution to the International Agricultural Research Centres.

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Foreword

ACIAR's impact assessment reports provide information on project impacts which helps to guide future research and development activities. While the main focus of these commissioned reports is on measuring the dollar returns to agricultural research, emphasis is also given to analysing the impacts of projects on poverty reduction.

Crop yields are limited by moisture availability across large areas of China's northwest provinces. Traditional tillage methods for optimising use of moisture employ labour-intensive techniques and are no longer economic. The ACIAR projects evaluated in this report explored the suitability of Australian conservation cropping techniques for China, aiming to maximise wheat and maize yields while conserving moisture and reducing soil degradation. In Australia, scientists examined the controlled traffic systems used in conservation tillage, focusing on soil and crop response under a range of tillage intensities.

The focus of both projects was on the underlying problem of optimising sustainable dryland grain production in environments where moisture is limiting, soils are vulnerable to degradation, and large inputs of energy, capital or labour are undesirable.

Before the ACIAR-funded projects, there was widespread resistance to the concept of conservation tillage in China due to the popular belief that frequent and deep tillage was essential for high-yielding crop production.

The projects generated convincing evidence that conservation tillage can provide significant improvements in productivity and economics.

The general outcome of both projects was the demonstration of practical controlled-traffic farming and conservation tillage systems for more-sustainable dryland grain production in Australia and China.

This report estimates that the projects have the potential to deliver substantial long-term benefits. As well as economic benefits, important capacity-building benefits from the projects are identified. Conservation tillage also benefits rural women by reducing the labour and time required for farming.

This report is Number 33 in ACIAR's Impact Assessment Series and is also available for free download at <www.aciar.gov.au>.

Peter Core
Director
Australian Centre for International Agricultural Research

Contents

Figure

Acknowledgments

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Any omissions or errors of interpretation in this assessment are the responsibility of the author.

Details of projects evaluated

ACIAR projects LWR2/1992/009 and LWR2/1996/143	Conservation/zone tillage research for dryland farming Sustainable mechanised dryland grain production
Collaborating organisations	University of Queensland Farm Mechanisation Centre, Gatton; China Agricultural University, Beijing
Project leaders	Dr J. Tullberg (University of Queensland); Professor Gao Huanwen (China Agricultural University)
Principal researchers	Dr J. Tullberg; Professor Gao Huanwen
Duration of projects	Project LWR2/1992/009–January 1993 to December 1996; Project LWR2/1996/143 – July 1997 to June 2003.
Total ACIAR funding	$1.429 million
Project objective	To develop and evaluate improved reduced or conservation tillage technologies for sustainable dryland grain production in Australia and China.
Location of project activities	Gatton, Queensland, Australia; Shanxi Province, China.

Summary

This report contains an economic impact assessment of two ACIAR-funded projects: LWR2/1992/009, Conservation/zone tillage research for dryland farming (1993–1996); and LWR2/1996/143, Sustainable mechanised dryland grain production (1996–2003). The projects focused on the development of improved technologies for controlled-traffic farming (CTF) in dryland crop production in Australia, and on reduced or conservation tillage (CT) for similar purposes in China. This research was undertaken by the Farm Mechanisation Centre of the University of Queensland in collaboration with the Agricultural Engineering College of the China Agricultural University in Beijing.

Conventional tillage practices in dryland crop production are recognised as being major contributors to the problems of soil erosion, soil surface crusting, impaired hydrology and reduced soil organic matter and biological activity. In Australia, there are well-established links between conventional tillage and the degradation of soils, an expression of the failure to manage land in a way that is consistent with the sustainable use of the soil resource. Similar problems have been experienced in the dryland cropping regions of northwestern China, where traditional tillage practices have been identified as the primary cause of severe dust pollution in the major cities.

The principle of CT is to reduce the tillage requirements of dryland crop production by retaining a protective surface residue that conserves soil and water. CT research in Australia has produced technologies that have been widely adopted in many areas. The research has demonstrated that regular tillage is not necessary to grow good crops and that the retention of crop residues results in long-term productivity gains with increased profits and enhanced economic sustainability. CTF is an extension of that research and aims to reduce the soil-compaction problems associated with the use of heavy tillage equipment. It has been a longstanding research issue in Australia. Before the ACIAR-funded projects, CT had not been as well accepted in China. It was considered to be unsuitable for Chinese cropping systems because of the perceived potential for yield reductions, the herbicide requirements and the incompatibility of western CT equipment for China's small-scale farms.

The main objective of project LWR2/1992/009 was to develop and evaluate CTF and CT technologies for sustainable, dryland grain production in Australia and to establish the potential for the application of

CT under Chinese conditions. On its completion, the project was reviewed and a one-year extension recommended. In addition to work in the extension period, research on reduced-tillage technologies continued in a follow-on project, LWR2/1996/143, in which the researchers were able to capitalise on the achievements of the earlier project and the strong cooperative relationship developed between the Australian and Chinese scientists.

The general outcome of both projects was the demonstration of practical CTF and CT systems for more-sustainable dryland grain production in Australia and China. In Australia, there was a 16% grain yield increase in crops grown under CTF. Over a five-year period, CTF with stubble retention reduced water run-off by 46% and increased rainfall infiltration by 18%. In China, CT increased the mean yields of the wheat and maize in plots established in 1993 by 22% and 15% in comparison to wheat and maize sown under traditional cultivation. The clear yield superiority of CT in winter-wheat production in dry years was an important factor in demonstrating the value of CT to Chinese farmers. In China, the projects resulted in a reversal of the previously negative attitude to CT, so much so that the expansion of CT in northwestern China is now being actively promoted and funded by the Chinese Government. Further official recognition of the outstanding achievements of the projects has come in two prestigious awards made to the Australian and Chinese project leaders by the Chinese Government.

Using the methods of economic surplus and stochastic benefit–cost analysis for a 30-year period, the projects are estimated to have the potential to deliver substantial long-term benefits. The Australian benefits are estimated as increments to the past volume of CTF research. The net present values and benefit–cost ratios estimated are deemed to be the ‘most likely’ (the median in the case of net present value). For wheat production, the net present value of project benefits is estimated to be $79.5 million and the benefit–cost ratio 4.9:1. The benefits to China are also incremental and are estimated to be much larger than those for Australia, because of the greater volume of wheat and maize produced in China. Also, the innovative nature of the CT research during the projects in China means that its benefits are more readily attributable to the ACIAR-funded projects. Considering Chinese wheat production, the net present value of project benefits is estimated to be $408.5 million and the benefit–cost ratio 25.7:1, while the values for maize production in China are $90.6 million and 5.7:1. The estimated total economic benefits of the project are a net present value of $578.6 million and a benefit–cost ratio of 36.3:1. This estimate of returns to research might seem large but, based on the price and quantity data used in this assessment, it amounts to only about 1.3% of the average annual gross value of the relevant crop production in Australia and China between 2000 and 2003.

Other important capacity-building and gender benefits from the projects, captured mainly by China, are also identified. Some of the Chinese scientists who visited Australia are now in prominent teaching positions in national universities and are contributing expertise to their government's CT policies. Many university students are now studying for careers in CT in response to the growing demand for people trained in its techniques. At the advisory level, the various tiers of the agricultural mechanisation bureaus are developing expertise in CT and are providing CT training to extension staff and farmers in many districts. These agencies are also administering the government subsidies for the purchase of CT equipment. The gender implications of the projects relate mainly to the women in rural China who supply the bulk of farm labour in many regions. CT benefits rural women by reducing the labour and time required for farming. This has flow-on implications for their health and welfare and that of their children.

Reasons are detailed for optimism about the realisation of the project benefits estimated.

1 Introduction

The long-term use of conventional tillage for seedbed preparation in dryland cropping systems is recognised as being a major factor in soil and landscape degradation. Soil degradation is a composite term that embraces the soil-based problems of erosion, compaction, surface crusting and decline in organic matter, biological activity and soil water movement. It results from the failure to use land-management systems that are consistent with the long-term sustainable use of the soil resource (Pratley and Cornish 1987). In Australia, there are well-established links over long periods between conventional tillage and soil degradation (Southorn et al. 2004) that became most evident in the 1960s when the expansion of cropping areas and intensities and the use of larger machinery resulted in more frequent cultivation (Scott and Farquharson 2004). The visual evidence of soil degradation in terms of gully erosion, vegetation decline and, more recently, dryland salinity, is a consequence of what are considered to have been inappropriate soil-management practices (Lawrie et al. 2004).

Research into 'conservation farming' in dryland crop production based on various reduced-tillage technologies has been undertaken throughout Australia over many years. Much of the developmental research into these tillage practices was completed over the 1960s and 1970s. This research demonstrated that conventional tillage was unnecessary to grow crops and that heavy tillage equipment contributed to soil degradation. A major research emphasis has been on the benefits of preserving soil moisture by increasing the volume of crop residue on or near the soil surface. It has been established that reduced tillage provides effective protection against soil erosion and gives crop yields that are at least equal to, and at times better than, those from conventional cultivation (Holland et al. 1987). In New South Wales and Queensland, reduced-tillage practices incorporating the retention of crop residues have resulted in long-term productivity gains in dryland crop production through reductions in soil erosion and loss of organic matter. Such benefits have translated into increased profits and the enhanced economic sustainability of dryland cropping systems (Thomas et al. 1997).

Conservation tillage remains an active research area in Australia. A recent economic evaluation of the benefits of such research by NSW Agriculture between 1970 and 2002, determined net present values between $78 million for no-till research to $205 million for no-till plus reduced-tillage research, with corresponding benefit–cost ratios between 4:1 to 9:1 (Scott and Farquharson 2004). Much larger benefits resulted when the evaluation was projected to 2020 on the basis of an expected mean adoption rate of the research outcomes of 30%. It was also considered that there were likely to have been substantial environmental benefits. For example, an estimated annual saving of 18 million tonnes of soil was estimated to result from the adoption of reduced tillage compared with conventional cultivation in northern New South Wales.

Before the early 1990s, most Chinese agricultural scientists considered that reduced-tillage technologies had little relevance for dryland farming in China. Despite the widespread adoption of these practices in numerous other countries, including Australia, Brazil, Canada and the USA, the Chinese were wary of the potential for yield reductions, the high costs of herbicides and the unsuitability of large, western tillage equipment for China's small-scale farms. There was also concern about changing tillage practices that had been followed for over 4000 years, particularly the removal of stubble, a practice considered to indicate good farming and clean fields. Research into conservation tillage at the China Agricultural University at that time was undertaken without government funding and with minimal interest from the agricultural bureaucracy. Farmers were supported financially by the university to trial conservation-tillage systems to enable the research to proceed.

The reduced-tillage research undertaken in the two ACIAR-funded projects that are the subject of this economic impact assessment were both a continuation of the longstanding Australian research investment and an investment in largely new research in the dry regions of northwestern China. Both projects were based at the University of Queensland at Gatton and conducted in collaboration with the China Agricultural University in Beijing. Their focus was on the underlying problem of optimising sustainable dryland grain production in environments in which moisture is limiting, soils are vulnerable to degradation and large inputs of energy, capital or labour are undesirable— conditions that characterise Australian dryland grain production. A central part of the objective was to investigate the potential for applying Australian reduced-tillage technologies under Chinese dryland conditions. Although there are large differences between Australia and China in the physical and technological features of dryland crop production, particularly in terms of farm mechanisation, the problems with moisture retention and soil degradation are common to both countries.

2 Background to the projects on conservation tillage

This impact assessment concerns two ACIAR-funded projects: LWR2/1992/009, Conservation/zone tillage research for dryland farming (1/1/1993–31/3/1997); and LWR2/1996/143, Sustainable mechanised dryland grain production (1/7/1997–31/12/2003). For both projects, the commissioned organisation was the Farm Mechanisation Centre of the University of Queensland at Gatton (UQG). The Chinese collaborator was the Agricultural Engineering College, China Agricultural University (CAU), East Campus, Beijing.

Much of the material in this section is drawn from various project documents, including proposal statements, annual and termination reports, reports by management on visits to the project sites and the reviews by Smith et al. (1995) and AACM International (1998) of project LWR2/1992/009. The use of this material is collectively acknowledged here. Other information is derived from interviews in China and Australia (Appendix 1) and through correspondence with the Australian project leaders and is acknowledged as personal communications.

The terms ‘conservation tillage’, ‘controlled traffic farming’ and ‘zone tillage’ are used to describe different methods for reducing the tillage requirements for dryland crop production. Conservation tillage (CT) is a generic description of soil-management systems that attempt to conserve soil, water and energy by the retention of a protective surface residue. Controlled-traffic farming (CTF) is a system in which the crop production zone and traffic lanes are distinctly and permanently separated to manage soil compaction. Estimates of wheel-track coverage from the Darling Downs are 82% for conventional tillage, 46% for zero tillage and 14% for CTF (Radford and Kelly 2003). The use of heavy tillage equipment for seedbed preparation can compact soil to depths of up to one metre. Soil compaction causes restricted plant growth and significant yield loss within a crop. CTF systems are based on the maintenance of crop production zones (comprising about 15% of the crop area) that optimise plant root growth and reduce the negative impact of wheeled traffic on the soil. Zone or precision strip tillage describes systems in which soil manipulation is confined to narrow strips to reduce energy requirements, optimise soil moisture and minimise soil compaction. These distinctions specify different approaches to the problem of achieving sustainable crop production, and elements of each approach are usually necessary for optimum crop production. Since some aspects of the land-degradation problem are related to the scale and weight of field equipment, the control of field traffic has become important in reducing both structural damage to the soil and the energy inputs into dryland crop production. Unless otherwise indicated, the terms CT and CTF are used to refer to reduced-tillage technologies and to controlled-traffic farming in this impact assessment.

CT systems are common in Australia and vary from the use of non-inverting tillage in a near to conventional cropping program, to zero-till systems in which the only soil disturbance occurs at planting. CT research at UQG, and CTF research in particular, has been into systems that restrict heavy, wheeled equipment to defined pathways so that crops can be grown in undisturbed rootbeds. The potential for reduced energy use during cropping operations has also been investigated. The outcomes of this research have indicated the nature of the economic and environmental benefits that can result from the adoption of these technologies. These benefits include reduced tractor sizes and fuel costs, spatial selectivity for weed control, reduced soil-structural degradation, improved water infiltration and reduced erosion and nutrient loss. It has also demonstrated the potential for more precise fertiliser and chemical application.

The reduced-tillage research at UQG provided the technical basis for the ACIAR-funded projects. As in Australia, crop yields in China are limited by moisture availability across large areas of the northwestern region, where wind erosion is a critical problem. This region comprises 13 provinces and annually produces about 70% of China's wheat and 56% of its maize (Table 1). Before the ACIAR-funded projects, there was widespread resistance to the CT concept in China due to the popular belief that frequent and deep tillage was essential for high-yielding crop production. CT was recognised as having beneficial environmental effects but no yield advantages. The small tractors and tiny land areas of most Chinese farms made the CT technology largely irrelevant, and farmers were reluctant to trial CT because it lacked government support. Increased agricultural mechanisation is now a policy priority for the various levels of government in China. Mechanisation is being forced on farmers because the declining rural workforce is eroding the economic feasibility of the traditional methods of crop production. Coupled with this issue is the major environmental problem of increased dust pollution in the major cities, to which agriculture is acknowledged as being the main contributor. In a substantial attitudinal change by the Chinese Government, CT is now seen to be an effective solution to both these problems.

The (pre-project) research at UQG demonstrated the positive effects of CTF in reducing water run-off and adding to surface residue. It was considered that the innovative feature of this research was the recognition of the pervasive effects of field traffic in creating and intensifying tillage requirements. Controlling field traffic and minimising soil disturbance were seen to provide opportunities to enhance the productivity and sustainability of dryland crop production in both Australia and China. This proposition was the unifying feature of the ACIAR-funded projects.

Table 1. Recent Chinese crop production statistics for the 13 northwestern provinces

Province	Wheat production ('000 tonnes)				Maize production ('000 tonnes)			
	2000	2001	2002	Average	2000	2001	2002	Average
Beijing	669	366	243	416	587	539	461	529
Gansu	2,661	2,961	3,121	2914	2,105	1,990	2,192	2,096
Henan	22,360	22,997	22,484	22,614	10,750	11,514	11,898	11,387
Heibei	12,080	11,227	10,995	11,434	9,945	10,595	10,350	10,297
Inner Mongolia	1,818	1,271	1,215	1,435	6,292	7,570	8,215	736
Liaoning	358	155	115	209	5,511	8,187	8,580	7,426
Ningxia	745	836	961	847	820	948	1,043	937
Qinghai	439	513	452	468	12	12	12	12
Shandong	18,600	16,552	15,471	16,874	14,675	15,324	13,160	14,386
Shaanxi	4,186	4,066	4,053	4,102	4,137	3,528	3,745	3,803
Shanxi	2,152	2,274	2,432	6,858	2,548	3,099	4,353	3,333
Tianjin	595	451	441	496	410	752	711	624
Xinjiang	3,995	3,708	3,827	3,843	2,685	2,938	3,329	2,984
NW region	70,658	67,377	65,810	67,948	60,477	66,996	68, 049	65,174
Total China	99,637	93,876	90,290	94,601	106,000	114,090	121,310	113,800
NW region/China (%)	71	72	73	72	57	59	56	57

Source: China Agricultural Press (2001, 2002).

Project LWR2/1992/009, Conservation/zone tillage research for dryland farming

Project LWR2/1992/009 arose from a joint interest in CT research between UQG and CAU. In 1990, Professor Gao Huanwen of CAU inspected the CT research at UQG and identified complementary research interests in the broader effects of soil preparation in dryland farming. Professor Gao is widely recognised as being the primary instigator of CT research in China and recently received a prestigious national award from the Chinese Premier in recognition of his efforts. The project was successfully developed and funded by ACIAR following a visit in mid-1992 by Dr J. Tullberg of UQG to CAU and to various proposed experimental sites in Shanxi Province in the northwestern region.

Professor Gao's interest was in the potential for Australian-developed CT systems to be applied in northern China.

The main objective of project LWR2/1992/009 was to develop and evaluate CT techniques for sustainable dryland grain production in Australia and to establish their potential for application under Chinese conditions. The Australian component investigated the conservation and cost-saving benefits of CTF, its interaction with CT, and its extension into zero-traffic crop production. The emphasis was on reducing the inputs needed for effective fallow management and crop establishment without compromising weed control and seedbed preparation, with a focus on soil and crop response to the technologies under a range of tillage intensities. The specific Australian objectives were to: (i) develop a low-power, controlled-traffic CT system for wheat production, (ii) evaluate traffic effects on soil and crop performance under three surface-management regimes, (iii) develop grain production technology to minimise inputs of energy and herbicides, and (iv) assess the potential for the use of controlled-traffic zero-tillage systems based on 'gantry' units or modified conventional equipment in sustainable crop production systems that lead to long-term resource conservation. Gantry farming systems in which tractors are replaced by an implement-width power unit have many theoretical advantages. The availability of a gantry tractor at the beginning of the project appeared to provide an attractive option for experiments, but the practical and economic difficulties of using this unit could not be overcome.

The specific Chinese objectives were to: (i) assess the suitability of a range of Australian equipment and residue treatment methods for CT in northwestern China, (ii) identify appropriate CT systems for wheat and maize production and to develop assessment techniques, (iii) evaluate CT systems in terms of energy requirements, residue retention, soil moisture storage and crop yields, and (iv) assess the effects of deep tillage and traffic on soil moisture storage capacity. Australian planting, tillage and spraying equipment (components rather than machines) were introduced and contributed to the development of effective CT systems. The Chinese component also involved the development by CAU of CT planters for adaptation to the small tractors (17–20 horsepower; 13–15 kW) that are commonly used in Chinese agriculture.

The Australian experimentation was done at UQG using a controlled-traffic plot layout in which all equipment wheels were restricted to fixed, permanent lanes. These experiments demonstrated an overall 16% increase in mean grain yield in crops grown under the system with no negative impacts from tractor wheeling. Run-off were reduced by controlled traffic and by crop residue, with apparent additive effects. The China field experiments were based in Shanxi Province—wheat near Linfen and maize near Shouyang—where the outcome was assessed in terms of the effect on wheat and maize yields and the impact on sustainability and costs. This component of the project demonstrated the feasibility of CT planting in wheat and maize and the economic and productivity benefits of the system. Despite some problems with experimental design, the advantages of CT were confirmed by many positive results over a range of sites and seasons, particularly under drought. Tests demonstrated the decrease in run-off that results when residue protects the soil surface from rainfall impact, and indicated that the field traffic effects on run-off and tillage energy requirements were similar to those found in Australia. The summary result was that grain yields and sustainability indicators improved with CTF in Australia and with CT in China.

A review of project LWR2/1992/009 concluded that it had been successful in machinery development and in the demonstration and initial assessment of CT in northwestern China despite the difficulties encountered because of local inexperience with CT machinery, drought and other factors (Smith et al. 1995). The project was seen to be innovative in the development of mechanised CT systems that were relevant to wide areas of China. It attracted strong support from academics and from the national and provincial levels of government. The emphasis on the importance of the work by the Chinese participants was a major outcome because of the high national priority that is now given to agricultural mechanisation and sustainable resource management by the Chinese Government. Further, the work in China in exposing and solving practical problems with CT was considered to be beneficial to the design of more-effective CT machinery for use in both China and Australia. An example was given with the problem of CT equipment in both countries in coping with large amounts of straw, a problem that was resolved under Chinese conditions.

The review recommended a one-year extension to make further progress towards the objectives, particularly in assessing appropriate CT technologies for wheat and maize production (objective ii), in evaluating CT systems in terms of energy and other stated requirements (objective iii), and in assessing the effects of deep tillage and traffic on soil moisture storage capacity (objective iv). It was also recommended that a replacement project proposal be developed based on the knowledge gained and the knowledge gaps revealed in project LWR2/1992/009. General recommendations were made about machinery comparisons, improved experimental designs, additional sites in different climates, the involvement of a wider range of agencies to ensure all the skills needed were available and a strong training component with a major training workshop.

Project LWR2/1996/143, Sustainable mechanised dryland grain production

Project LWR2/1996/143 built on the earlier project and capitalised on the cooperative relationship developed between UQG and with Professor Gao and staff at CAU, in association with the Shanxi Provincial Agricultural Machinery Bureau. This project's broad objective was to develop more-sustainable technology for mechanised crop production that combined CFT and CT for application in Australia and China. The Australian component of the project investigated the conservation and cost-saving benefits of CTF and its impact on sustainable crop production. Here, the focus was on soil and crop response to traffic and tillage under a range of tillage intensities. This work was undertaken in an experimental area that allowed valid comparisons to be made of energy input, soil hydrological properties and crop performance. The specific objectives were to: (i) measure soil and crop response to wheel traffic within different tillage systems, and use these data to calibrate a field-plot-scale simulation model, (ii) investigate wheel track persistence in cropped soil, and examine soil deformation under wheels, to provide a basis for modelling random traffic effects, and (iii) assess cropping system developments made possible at varying levels of machine/crop precision.

The main objective of the China component was to assess—using replicated trials and personnel trained during project LWR2/1992/009—the impact of those aspects of CT that are modified by machine input. The specific objectives for China were to: (i) assess the effects of crop residue, soil tillage and wheel traffic on soil properties and the growth of wheat and maize in Shanxi Province, and the scope to generalise findings via simulation modelling, (ii) further develop CT equipment and systems and assess their potential for incorporation into economically and socially viable farm-scale systems, and (iii) develop a pilot program to build local capability and expand research to sloping land in the water-erosion-affected areas of western Shanxi, and to the more arid regions. The typically small scale of field operations in China required that the project work there was directed to developing and assessing low-powered equipment and systems of CT. This was distinct from the Australian focus of reducing the impact of wheel traffic from the much heavier tillage equipment.

Joint objectives for both China and Australia were to: (i) assess the scope for simulation models to examine and generalise the impact of mechanised CT, by the process of modifying, calibrating and validating existing models using data from both countries, (ii) assess the operation of CT–CTF systems to determine their effect on labour/machine operating costs, ownership (fixed) costs and timeliness, and (iii) compare the economic advantages of precision CTF systems involving fewer, less-energy-intensive operations, with conventional crop-production systems, within a benefit–cost framework using results from crop simulation modelling, appropriate soils and management information, and long-term weather data.

Because project LWR2/1996/143 was a follow-on to LWR2/1992/009, it is appropriate to consider the outcomes jointly rather than separately. The projects demonstrated practical CTF and CT systems for more-sustainable grain production in areas of Australia and China where moisture is limited and soil erosion is problematic. There was convincing evidence that these technologies could generate significant improvements in productivity and economics. In Australia, there was a 16% grain yield increase in crops grown under CTF, without the negative effects of tractor wheeling and tillage. Over a five-year period, CTF–ZT with stubble retention reduced cumulative run-off by 46% and increased rainfall infiltration by 18%. Mean yields of winter and summer crops improved by 15% and 12%, respectively, compared with stubble-mulch wheeled treatments.

In China, in over 10 years of continuous trials with winter wheat and spring maize cropping, CT increased the mean yields of the plots established in 1993 by 22% and 15% relative to crops sown under traditional cultivation. The trials at Linfen demonstrated the yield superiority of CT in winter wheat over the five dry years that occurred in the trial period. Under severe drought conditions in 2000, wheat yields from the CT trials were 3.75 tonnes per hectare compared with minimal yields for conventionally sown wheat on many Linfen district farms. This result was considered to be a major outcome of the trials as it clearly demonstrated to farmers the value of CT in dry years. It also justified the one-year extension of project LWR2/1992/009 and the initiation of project LWR2/1996/143 a year later, since its initial three-year term was too short to effectively demonstrate the benefits of CT under widely different seasonal conditions. As a result, large areas committed to wheat and maize production have been or are now being converted to CT in the most erosion prone areas of the Loess Plateau in China.

A major outcome of the projects has been to reinforce the benefits of CT farming to the various levels of government in China. Before project LWR2/1992/009, no funds were allocated to CT research, because experts in the Ministry of Agriculture (MoA) considered that the technology had little relevance. This attitude changed following a visit to the trial sites in 2002 by a high-level national delegation, including the vice Minister for Agriculture, that resulted in a directive to the Ministry of Agriculture (MoA) to prepare a national CT extension plan. This plan was drafted by

Professor Li Hongwen of CAU who is now the chief consultant to the Department of Agricultural Mechanisation in the MoA. The plan has been approved by the MoA but is still being considered by the central government because of the very large budget request of $1.6 billion (10 billion yuan). It is expected that $80.6 million (500 million yuan) will be allocated for agricultural mechanisation by the central government in 2005, and that half of this funding will be spent on further developing and promoting CT throughout China. Also, the current Chinese Premier (Wen Jaibao) has recently stated that CT is a good technology for China. Much of this change in attitude and government funding can be directly attributed to Professor Gao's research and to the ACIAR-funded projects (Li Hongwen, pers. comm.).

3 Methods for economic impact assessments

It is possible to define three broad components to the economic benefits that could result from an ACIAR-funded project. The first results from completely new research that would not have been undertaken without the ACIAR investment. The second results from enhanced research outputs that have a greater impact on the target industries than those emanating from alternative research programs that may be undertaken by the same agencies but without ACIAR involvement. The third is the result of the extension to the target industries of improved information that can be legitimately attributed to the ACIAR-funded project. For any particular project, the assessment task is therefore to measure the incremental benefits that can be ascribed to that project. It requires the measurement of the benefits that are net of ongoing benefits from past research activities and net of any expected benefits that could come from other independent research.

The impact assessments of the two ACIAR-funded projects were undertaken in an ex-ante benefit–cost context in which the project costs were known and the benefits were projected estimates of the expected project returns. The projects were assessed jointly rather than separately because the second project was a direct outcome of the first, particularly in relation to the work in China. The following sections indicate the major issues that were considered and the methods used in undertaking the assessments.

Defining the impact-assessment scenarios

The first requirement was to define realistic *with*- and *without-project* scenarios to enable the incremental benefits to be estimated as the difference in economic impacts from the projects (the *with-project* scenario) and those that would have resulted if the projects had not been initiated (the *without-project* scenario).

CT in its various forms has been a longstanding topic of research in Australian dryland farming. Work on the topic has been and is likely to continue to be undertaken independently of the ACIAR-funded projects. It can therefore be expected that, without the ACIAR-funded projects, CT research in Australia will continue, but at a lower level of funding. This means that there will be future productivity improvements in Australian dryland grain production that can be attributed to improved CT practices resulting from non-ACIAR-funded research.

A feature of the UQG research that distinguished it from other CT programs was its focus on the use of CTF to reduce the inputs required for crop establishment and to mitigate the problem of soil compaction that results from the use of heavy tillage equipment. Over a five-year period, this research found that CTF increased winter wheat yields by an average 15% compared with yields derived from other CT systems. The project documents note that these projects did not claim to have originated the CTF systems that were investigated. CTF research had been under way in Australia well before the projects and had been widely adopted in the Australian cotton industry. Nevertheless, problems with machinery standardisation made CTF adoption more difficult for dryland crop producers and initially its use was not encouraged. That situation changed with the decision of the Queensland Department of Primary Industries to promote the use of CTF for dryland crop production following the outcomes of a successful project on the technology. The results of project LWR2/1992/009 were also considered to have been an important factor influencing that decision. The projects do claim to have developed and demonstrated practical CTF technologies and 'a significant share of the credit for mainstream acknowledgement of the productivity, sustainability and practicability' for CTF farming in Australia.

The use of CTF was considered to have wider application in Australia than in China because of the much larger tillage equipment used in Australia. This assessment considers the benefits that could be attributed to the ACIAR-funded projects in the development of improved CTF systems for dryland wheat production in northern New South Wales and southern Queensland. It estimates the benefits to the use of CTF compared to standard

CT systems in dryland wheat production. Based on these considerations, the *Australia with-project* scenario recognises that the main direct effect of the ACIAR-funded projects was to intensify CTF research in the project area through the provision of additional research funds, and to bring forward by three years the delivery of the research outcomes. Because the ACIAR-funded projects were jointly assessed, the *Australia with-project* scenario is defined as being the difference between the benefits to both of the ACIAR-funded projects and the benefits to other non-ACIAR-funded CTF research.

The assessment scenarios for China were more difficult to define. It was recognised that, while there had been some previous CT research undertaken at CAU and earlier projects such as one funded by the Canadians (that had no links to CAU) from which a *China without-project* scenario might be based, there had been little adoption of CT practices in northwestern China before the ACIAR-funded projects. The CAU research had attracted little official support for the reasons previously given. Further, the outcomes of the Canadian project had not been widely promoted because its CT technology was based on the heavy tillage equipment that is commonly used in Canadian crop production but is unsuitable for Chinese conditions. Moreover, the project was centred in wetter areas quite unlike northwestern China. As this past research had resulted in negligible adoption of CT in the northwestern project area, it therefore seemed logical to attribute all the benefits of the Chinese CT research to the ACIAR-funded projects. That presumption, however, would have ignored the likelihood that CT would have eventually been introduced into the country had the projects not occurred, and possibly during the time when they ran. It is reasonable to expect that the outcomes of the large volume of CT research that continues to be undertaken internationally would eventually have spilled over into China. Also, it is probable that some local CT research would have continued (presumably at CAU) irrespective of the ACIAR-funded projects, but at a much lower level than took place under those projects. Some level of CT adoption could therefore be expected to have eventually occurred for both crops when the proven economic and environmental benefits of the technology could no longer be ignored. The outcomes of CT research from both sources could be expected to have had an initial level of adoption that would have accelerated over time as the benefits of CT became increasingly apparent. It is most likely that this latter effect would have been expedited by increased government recognition of the benefits of CT in relation to soil erosion and mitigation of dust pollution. On the basis of these expectations, it is assumed that the main impact of the ACIAR-funded projects was to expedite the delivery and adoption of CT into China for dryland wheat and maize production in the northwestern provinces by three years (the *China with-project* scenarios) over the *China without-project* scenarios.

Methods

Estimating benefits

Based on the considerations and the assessment scenarios outlined in the previous section, the benefits of the ACIAR-funded projects were measured in terms of the differences in the impacts of research and adoption lags for the CTF and CT technologies. In Australia, it is considered that the main economic effect of the projects was to generate shorter lags in delivering the outcomes of CTF research and higher levels of adoption of the outcomes by grain producers, recognising that there continues to be a body of similar research that attempts to deliver similar outcomes. The benefits to the ACIAR-funded projects are the differences between the benefit levels that are generated by the research and adoption lag structures for research supported by ACIAR and that supported by other institutions. In China, the main effect of the ACIAR-funded projects has been to bring forward the introduction of the CT technology into the country.

The benefit-assessment methods are based on the partial equilibrium measures of economic surplus or welfare change that result from the adoption of a production-increasing technology in an industry. The approach follows the conclusion of Alston et al. (1995) that the partial equilibrium–economic surplus model is the best available method to evaluate returns to research. It is the most appropriate method to evaluate production level gains where differences in production costs from the technology's adoption can be determined. Benefits are measurable in (price × quantity) value terms which, with various parameter values, can be translated into estimates of economic welfare changes. These benefits include the potential welfare gains to producers from adopting the technology and the corresponding gains to consumers from the lower commodity prices that typically result from an industry-wide production increase. Benefits are distributed between producers and consumers according to the relative values of the supply and demand elasticities. Details of the model used to estimate the benefits in terms of economic welfare changes are given in Appendix 2.

Accommodating uncertainty

The main factors that influence total benefit levels are the effect of the technology on yields and production costs (the supply shift), the timing and level of adoption of the research outcomes and commodity prices. Values for these factors are based on the best available information, but are uncertain. The effect of uncertainty is incorporated in the assessments by treating the main benefit determinants as random variables and by simulating their value ranges within probability distributions using a stochastic Monte Carlo routine. Stochastic simulation models were developed in which the supply shifts, the research and adoption lags, the adoption ceiling and the relevant commodity prices were treated as random variables. Triangular probability distributions were used to define each variable in terms of value ranges (Table 2).

Table 2. Probability distributions for the random variables

Random variable	Triangular distribution parameters		
	Maximum	Median	Minimum
Supply shifts (%)			
Australian wheat	11.6	9.7	7.7
Chinese wheat	21.0	10.5	5.3
Chinese maize	22.8	11.4	5.7
Adoption ceilings (%)			
Australian wheat with project	50	37	20
Australian wheat without project	47.5	35.2	19
Chinese wheat with project	25	10	7.5
Chinese wheat without project	20	8	6
Chinese maize with project	25	10	7.5
Chinese maize without project	20	8	6
Total research and adoption lag[a]			
Australian wheat with project	14	13	12
Australian wheat without project	17	16	15
Chinese wheat with project	20	14	7
Chinese wheat without project	23	17	10
Chinese maize with project	20	14	7
Chinese maize without project	23	17	10

Note: The adoption parameters for Chinese wheat and maize are assumed to be the same.
[a] The research lag in each *with-project* scenario instance was the total 11-year term of the two projects

Stochastic simulation provides a transparent means of determining the expected benefits to the ACIAR-funded projects by enabling the main benefit–cost criteria—net present value (NPV) and benefit–cost ratio (BCR)—to be given in terms of a probability distribution. It obviates the problem of using single values for variables that are likely to be uncertain because of the ex-ante nature of the assessments, and particularly where such values have to be elicited from the researchers. An important output from this simulation approach are the cumulative distribution functions for each project's range of possible NPVs and BCRs. Cumulative distribution functions indicate the likelihood of obtaining a particular benefit–cost outcome by giving the probabilities of the project generating a NPV or a BCR of a given value. Ignoring the 100th and zero percentiles, the maximum values are represented by the 95th percentile, the median (most likely) values by the 50th percentile and the minimum values by the 5th percentile of the probability distributions. This stochastic simulation process is based on sampling from probability distributions for a large number of iterations (set at 10,000 for these assessments). The median value can be interpreted as being the value of the NPV or the BCR that the project is most likely to deliver, given the range of possible values that have been specified for the variables whose values were sensitised.

Defining supply shifts

The extent of the supply shift from the adoption of a project's technology is a critical determinant of the total benefits. Alston et al. (1995) note that the supply shift comprises both the change in yield and the change in production costs. Relative increases in yield translate into an equal outward shift of the supply curve in the quantity direction (the *J*-shift component). Where the technology generates a reduction in unit production costs, this equates to a percentage shift down the supply curve in the price direction (the *K*-shift component). Both components are linked by the supply elasticity (ε), where $K = J/\varepsilon$.

Defining supply shifts for CTF compared to conventional CT for Australian wheat production is complicated by the trade-off between improved yields and usually higher machinery and herbicide costs. Gross margin and partial budgets for northern New South Wales indicate both these elements in the returns from CTF compared to conventional CT systems for long-fallow wheat production (Scott 2003). Crop budgets for the Moree area of northern New South Wales were used to estimate a supply shift of 9.7% relative to the farm wheat price ($228.40 per tonne) from the use of the CTF system. The 10% yield increase for CTF was consistent with other recorded yield advantages reported by Scott (2003) that were derived under commercial farming conditions in northern New South Wales and southern Queensland. Because this supply-shift estimate was based on comparative data for wheat crops sown under commercial rather than experimental conditions, it was considered to be the median value and was varied by ±20% to derive the maximum and minimum values of the probability distribution that enabled an appropriate sensitivity analysis to be undertaken. These bounds approximated the increased wheat yields that resulted from the use of CTF in other areas that were noted by Scott (2003).

The supply-shift values for the Chinese component were calculated from published data from the trial sites over the period 1993–2004. These data indicated both yield-increase and cost-reduction advantages from CT. Gao et al. (2004) reported an average yield increase of 17.7% and an average cost reduction of 17% for wheat sown under CT compared to conventional tillage. The wheat cost change (0.9 cents per kilogram) was a reduction of 3.9% when expressed as a proportion of the assumed wheat price ($228.40

per tonne). These additive effects gave a wheat production supply shift of 21.01%. The Chinese maize supply-shift values were similarly calculated from trial data reported in Hongwen et al. (2004) over the same period. The average maize yield increase (12.3%) and average production cost reduction of 1.9 cents per kilogram gave a supply shift value of 22.8% based on the assumed maize price of $161.30 per tonne. There were no comparable data from other areas of China on which to scale the probability distributions for the calculated supply-shift values.

As the China supply-shift estimates are based on experimental data, their values are held to be the upper bounds and are heavily scaled back by 50% and 75%, respectively, to represent the median and minimum values in recognition that experimental outcomes are typically larger than those derived under commercial farming. [Alston et al. (1995) refer to this divergence as the 'yield-gap' phenomenon.] This attrition scaling of the China supply shifts is considered to be appropriate, following observations that farmers are taking different approaches to implementing CT in the northwestern provinces (it is much larger scaling than for the Australian supply shift, which was estimated from commercially grown crop data). Farmers have been observed removing parts of the crop residue for sale or for household fuel or for livestock feed (C. Roth, pers. comm.). The reality of total or partial crop-residue removal means that the experimental yields derived under full crop-residue retention cannot be replicated on the farm, but the reduced soil disturbance that is now being widely practised enabled part of the experimental yield increases to be achieved. These supply-shift estimates are recognised as being large relative to those which typically result from technology adoption in modern agricultural industries. They result from the large (experimental) yield increases and production cost reductions that can be attributed to the CT technology in China, both of which are incorporated in the supply-shift calculation (Table 2).

Industry relevance of projects

This consideration defines the part of the Australian and Chinese grains industries in which the projects are expected to have their greatest impact; a definition that is usually made in terms of proportions of total production. Difficulties can be encountered in ex-ante project assessments in realistically determining the output proportion that could be attributed to the adoption of a project's technology. This is because the *without-project* scenario recognises that there is often similar research that has been and remains independent of the project being assessed, and that this research has resulted in productivity gains in the target industries.

In this assessment, the wheat industry is held to be the relevant industry in Australia and the wheat and maize industries the corresponding Chinese industries. The CTF technology is also relevant to Australian maize production, but this crop was not included in this assessment because of its low volume of production relative to wheat.

The review of project LWR2/1992/009 noted that, because various types of CT/CTF had been practised in Australia since the 1970s, it is difficult to determine the extent to which the project could be claimed to be responsible for the (more recent) adoption of the technology. While the project confirmed the scientific basis of the technology in its region, the proportion of on-farm benefits that can be attributed to it was unclear, particularly in the major grain-growing areas of Western Australia (AACM International 1998). In New South Wales, CT and CTF research has been conducted by various agencies for many years and three-quarters of wheat growers in the northeastern areas were practising some form of CT by the late 1990s (Scott and Farquharson 2004).

It is logical to consider that the CTF research undertaken in southern Queensland would have most of its application relevance there and in northern and perhaps other parts of New South Wales where production systems and growing seasons were similar. It would be less relevant in Western Australia (AACM International 1998) and in the rest of Australia. During 2000 to 2003, including the drought-affected crops of 2002–03, the average Australian wheat production proportions between the States were 34%, 32% and 6% for Western Australia, New South Wales and Queensland, respectively. The relevant regional proportion was about 40% for New South Wales and Queensland combined, and this was defined as the Australian wheat-growing region for the adoption of the CTF technology resulting from the ACIAR-funded projects. The rest of Australia was defined as the non-adopting region. Although average Australian wheat production was less than 4% of world production over the same period, the rest of the world was also defined as a non-adopting region as in normal growing seasons about 70–75% of Australian wheat is exported (ABARE 2004).

Chinese wheat production averaged 95 million tonnes over the same period which is 17.5% of world production and about five times the average Australian output. The northwestern provinces annually supply about 70% of the Chinese wheat crop (Table 1). Wheat is also grown in central and southern China, but there is less scope for promoting CT in these areas. Relative to northern China, wind and water erosion is not a problem in central China because the land is continually under crop, yields are already high and environmental problems are not as great. Hence, there is little incentive for CT on these grounds, but there is interest in investigating its potential role in arresting watertable decline. Watertables have dropped rapidly in some central regions at the rate of one metre per annum. Another 10 years of research is required to develop appropriate CT equipment to address this problem (Gao Huanwen, pers comm.). There is little interest in CT in southern China because there is abundant water for cropping. For these reasons, the northwestern region is defined as the adopting region in China for the CT technology, while the rest of China is the non-adopting region. No international region is defined for the China component because Chinese wheat exports have been negligible at less than 1% of production since 1998. This means that all the impacts of the projects on the international wheat market price result from the Australian components.

Chinese maize production averaged about 114 million tonnes from 2000 to 2002, 57% of which came from the northwestern provinces (Table 1). This area is defined as the Chinese adopting region and the rest of China is the non-adopting region for maize production. Because average annual maize exports from China were 11.5% of the world trade between 1998 and 2003 (ABARE 2004), the rest of the world is also defined as a non-adopting region for maize. All regions and production levels defined for the economic surplus change calculations are given in Table 3.

Table 3. Regional production levels for impact assessments

Region	Production ('000 tonnes)[a]		
	Adopting region	Non-adopting region 1	Non-adopting region 2
Australia wheat			
SQLD and NNSW	3,450		
Rest of Australia		20,272	
Rest of world			462,137
China wheat			
NW provinces	67,948		
Rest of China		26,653	
Rest of world			–
China maize			
NW provinces	65,174		
Rest of China		48,626	
Rest of world			486,277

[a] Based on three-year averages 2000–02; from Australian and Chinese grain statistical sources.

Adoption profiles for the project outcomes

There are three aspects of the expected adoption profile of a project's outcomes. The *research and development lag* is the time taken for the project's outcomes to become available for adoption by the target industry.

This is usually, but not always, the term of the project for which cost estimates have been provided. Development is a component of this lag because it often occurs after the project has been completed, e.g. in the case of new plant varieties or chemicals being tested by appropriate government authorities before their release. The *adoption ceiling* is the maximum anticipated adoption level of the project's outcomes by an industry, while the *adoption lag* is the time taken from when the project's outcomes are first adopted until the maximum level of adoption is reached. These aspects are closely linked to the process of diffusion that drives the uptake of a new technology across a population of potential adopters rather than adoption by an individual. For an agricultural technology such as CT, the speed of its diffusion is an important factor in determining the full realisation of the benefits to investment in its development (Lindner 1986).

Adoption data for northern New South Wales indicate that the use of reduced tillage in wheat and other cropping (no-tillage and mulching) increased from 1% in 1985 to 37% in 2003 and is projected to reach 50% by 2020. These estimates incorporate the three-year agricultural census data issued by the Australian Bureau of Statistics. The corresponding reductions in conventional tillage are from 84% in 1985, to 53% in 2003 and to a projected 24% by 2020 (Scott and Farquharson 2004). Over the period of the ACIAR-funded projects, the annual rate of growth in CT adoption was about 4%. Because similar estimates for Queensland could not be located, the northern New South Wales data are held to represent both regions. Since CTF is an extension of CT, its adoption profile can be expected to be similar to that for CT. Hence, the probability distribution bounds for the CTF adoption ceiling under the *Australia with-project* scenario are taken from Scott and Farquharson's estimates as a 50% maximum (the 2020 value), a 37% mean (the 2003 value) and an arbitrarily set minimum of 20%. These are the adoption ceiling values for the total volume of Australian CTF research that are assumed to include the effects of the research completed under the ACIAR-funded projects, since their period is part of the period of the Scott and Farquharson estimates. The adoption ceiling values for the *Australia without-project* scenario are set as small (5%) reductions to recognise the volume of Australian CTF research that has been undertaken independently of the ACIAR-funded projects (Table 2).

For the *China with-project* scenario, the minimum ceiling adoption level for CT in wheat and maize production is set at 10% because this is the target number of farms that the MoA expects to be using CT by 2010 in the northwestern region. The maximum level is 25% since that level of adoption might reasonably be expected to follow over the remainder of the 30-year assessment period given the active government CT support programs. A mean ceiling adoption of 17.5% is set as a midpoint of these value bounds.

The total research, development and adoption lag includes the full 11-year term of the ACIAR funding (1993–2003) plus the time taken to attain the expected adoption ceilings. Because of the past and ongoing nature of overall CT research in Australia, CTF adoption is considered to be a continuous process. Thus, the research completed under the ACIAR-funded projects enhanced the body of knowledge on CTF and facilitated its adoption by wheat growers. For the *Australia with-project* scenario, this is assumed to have reduced the adoption lag by a maximum of four years, a three-year mean and a two-year minimum. An additional three years is added to each of these values to establish the probability distribution for the total adoption lag under the *Australia without-project* scenario (Table 2).

For China, CT adoption was also considered to be a continuous process, some of which would have occurred from an approximate midpoint in the full project term following the extension of project LWR2/1992/009. Before then, it was considered that the projects had not delivered a CT technology that was ready for adoption. The review by Smith et al. (1995) stated that the first project had insufficient time to achieve its objectives on the development of CT technologies for China. This observation was also confirmed in discussions with project staff and farmers during this author's visit to the Linfen trial sites in late 2004. Accordingly, the minimum value of the adoption lag required to attain the 10% CT target by 2010 under the MoA plan is seven years from the completion of the projects' term, on the basis that some adoption was achieved during the projects' term. The maximum adoption ceiling (25%) is to take 20 years to attain from 2003, and a midpoint of 14 years is specified as the mean for the *China with-project* scenarios. These lags were extended by three years to represent the *China without-project* scenarios for both Chinese wheat and maize (Table 2).

The adoption profile values were the most difficult to define. Every attempt was made to base these values on the information available and reliable opinions. Some of the values for the probability distributions were arbitrarily specified. However, it should be recognised that the values that define the (triangular) probability distributions for the adoption variables need only be approximate since they are used to define the distributions' shapes, including the upper and lower bounds. From this procedure, a large number of random values are drawn from the probability distribution to simulate the stochastic outcomes of the benefit–cost analysis.

Models used

The initial assessments are made using the DREAM (Dynamic Research EvaluAtion for Management) model developed by Alston et al. (1995) and refined and promoted for use by the International Food Policy Research Institute and ACIAR. DREAM has a rigorous theoretical base and requires well-defined values for the major parameters such as supply shifts, elasticities, industry contexts, adoption rates and lags. One of the market specifications represented in DREAM is the horizontally disaggregated multi-region option that (represented by equations 1–6 in Appendix 2) can be used to model the project impacts for the regions defined in Table 3. This option is used with the parameter values given in Tables 2, 3 and 4 to make an initial assessment of the potential regional welfare changes that could be attributed to the ACIAR-funded projects.

Table 4. Supply (ε_i) and demand (η_i) elasticities

	Supply		Demand	
	Wheat	Maize	Wheat	Maize
Australia national	0.25	–	–0.20	–
Australia regional	0.30	–	–0.15	–
China national	0.42	0.50	–0.28	–0.27
China regional	0.25	0.26	–0.28	–0.25
World	0.30	0.18	–0.20	–0.10

Sources: Australian and world wheat elasticities from Brennan and Quade (2004); regional Australian wheat elasticity for the wheat–sheep zone from Griffith et al. (2001); Chinese national crop elasticities are the means of those reported in Mullen (2004); Chinese regional elasticities from Mullen (2004); world maize elasticities are from the IFPRI website <www.ifpri.org>.

As previously indicated, the effects of uncertainty about some of the parameter values needed to be incorporated in the impact assessments. Because the DREAM model cannot simultaneously simulate parameter value ranges, stochastic (Monte Carlo) simulation models were developed to allow this value uncertainty to be directly incorporated in the assessments using the R statistical package (R Development Core Team 2003) and simulated from the probability distributions for the values of the random variables. To calculate the probability distributions for the NPVs and BCRs, the benefit estimates derived from this simulation process were matched against the total project costs that commenced in 1993 and continued to 2003.

Costs are modelled as the full funding for the projects including the ACIAR contributions (Table 5). Costs are treated as being the same for each project component as there was no basis for disaggregating these costs according to country or commodity, e.g. it was not possible to reasonably allocate the project costs to the wheat and maize parts of the China component (costs may therefore be overstated in the benefit–cost analysis). In addition, a cost allowance is made for extension of the CT technology in northwestern China to recognise the importance of government promotion of the technology in the realisation of the potential benefits. As indicated in section 5, various government agencies have allocated funds for CT extension in addition to the annual allocation of $0.15 million per county in the northwestern region made by the central government. These costs totalled about $0.8 million per annum and are assumed to incur over the 20-year period from the onset of the benefits in 2004 to the end of the benefit–cost period in 2023.

Table 5. Project costs (A$)

	Contributions				
	ACIAR	Commissioned organisation (UQ)	Chinese collaborator (CAU)	Other	Total funds from all sources
Project LWR2/1992/009 initial					
1–6/93	58,298	39,850	30,150		128,298
93–94	173,722	80,200	60,300		314,222
94–95	137,391	81,200	61,500		280,091
7–12/95	82,882	40,850	31,350		155,082
Total	452,293	242,100	183,300		877,693
Project LWR2/1992/009 extension					
1–6/96	34,756	45,671			80,427
7–12/96	22,956	43,067			66,023
Total	57,712	89,738			146,450
Total project LWR2/1992/009	510,008	330,838	183,300		1,024,143
Project LWR2/1996/143 initial					
97–98	291,826	168,124	123,148	22,503	605,601
98–99	260,512	168,124	101,491	22,503	552,630
99–00	243,228	168,124	95,835	22,503	529,690
Total	795,566	504,372	320,474	67,509	1,687,921
Project LWR2/1996/143 extension					
00–01	48,820	10,600	22,850		82,270
01–02	49,795	10,600	18,000		78,395
02–03	24,955	6,900	7,000		38,855
Total	123,570	28,100	47,850		199,520
Total project LWR2/1996/143	919,136	532,472	368,324	67,509	1,887,441
Total ACIAR funds					
Project LWR2/1992/009	598,743				
Project LWR2/1996/143	947,236				
Total funds all sources	1,429,141	863,310	551,624	67,509	2,911,584

The net benefits that can be attributed to the ACIAR-funded projects are the difference in the benefits from the *with-* and *without-project* scenarios based on the separate scenario definitions. The benefit–cost specifications follow ACIAR's requirements with a start year in 1993, a 30-year benefit time horizon to 2023, and a real discount rate of 5%. All values are given in Australian dollars. Table 6 contains a summary of the main parameter values that were used in the economic surplus change and benefit–cost calculations.

Table 6. Summary of parameter values used in impact assessments (mean values)

	Australia wheat	China wheat	China maize
Yield increase (%)	10	17.7	12.3
Cost saving ($/ha)	–4.0	26.6	93.6
Supply shift estimate (%)	9.7	10.5	11.4
Supply elasticity (regional)	0.30	0.25	0.26
Demand elasticity (regional)	–0.15	–0.28	–0.27
Adoption ceiling with project (%)	37	10	10
Adoption ceiling without project (%)	35.2	8	8
Adoption lag with project (years)	13	14	14
Adoption lag without project (years)	16	17	17
Discount rate (real %)	5	5	5

4 Results of impact assessment

Table 7 contains the estimates of the annual economic surplus changes from the adoption of the improved CTF and CT technologies resulting from the ACIAR-funded projects in Australia and China. The country estimates are given separately and represent the benefits that are measured in terms of the potential economic surplus or welfare changes for producers and consumers of the two commodities. For the Australian component, the projects generated annual gains to wheat producers who adopted the new CTF technology (in New South Wales and Queensland) with a median value of $93.1 million. Wheat producers in other Australian regions (ROA) and the rest of the world (ROW) suffer welfare losses from the wheat price reductions caused by the regional supply shift because they are unable to adopt the CTF technology and lower their production costs. All Australian and international wheat consumers benefit from the lower wheat prices. The welfare losses to other Australian wheat producers (–$174.9 million) outweigh the gains to producers in the adopting region because of the price reduction spill-over from the adopting region and the large residual proportion of the Australian wheat crop (60%) that comes from the other States. The total economic surplus change for Australia is the sum of the regional changes and represents the measure of potential economic benefit from the projects. It should be recognised that the values of the total benefit are also derived under the stochastic simulation procedure and are not the sum of the corresponding regional values. The simulated median value ($315.1 million) is equal to the actual sum, but the maximum and minimum values are the extremes for each simulation of the regional changes and do not approximate the sums of the separate economic surplus changes.

Table 7. Annual change in economic surplus

	Value of annual economic surplus change ($A million)		
	Maximum 95th percentile	Median 50th percentile	Minimum 5th percentile
Australia wheat – producers' surplus change			
New South Wales–Queensland	133.6	93.1	57.9
Rest of Australia (ROA)	–180.7	–174.9	–251.2
Rest of World (ROW)	–3526.0	–5674.8	–8144.1
Australia wheat – consumers' surplus change			
New South Wales–Queensland	34.6	24.1	14.9
Rest of Australia (ROA)	52.9	36.9	22.9
Rest of World (ROW)	8622.9	6010.8	3736.7
Total surplus change (Australian wheat)	488.8	315.1	197.8
China wheat – producers' surplus change			
Northwestern China	2064.8	1016.4	372.5
Rest of China (ROC)	–130.7	–357.6	–728.3
China wheat – consumers' surplus change			
Northwestern China	1753.9	862.9	316.1
Rest of China (ROC)	816.5	401.7	147.1
Total surplus change (Chinese wheat)	3906.8	1923.5	705.0
China maize – producers' surplus change			
Northwestern China	1399.5	697.5	254.2
Rest of China (ROC)	–198.0	–545.9	–1100.3
Rest of World (ROW)	–1950.9	–5401.1	–10823.6
China maize – consumers' surplus change			
Northwestern China	1285.9	641.1	233.7
Rest of China (ROC)	960.5	478.6	174.4
Rest of World (ROW)	9063.9	4531.7	1656.9
Total surplus change (Chinese maize)	785.8	401.9	150.4
Total economic surplus change	5181.4	2640.1	1053.2

The median values of the economic surplus changes resulting from CT adoption in Chinese wheat production exceed those for Australia because of the much larger production scale and the closed-economy characteristics (negligible exports) of the wheat industry in China. The annual median change in wheat producers' surplus in the northwestern CT adopting region is $1016.4 million while wheat producers in other regions lose $357.6 million annually from the international spill-over effect of the reduced Australian wheat price. Ignoring the possibility that there may be internal taxes and subsidies that prevent the wheat price from falling with the increased supply, all Chinese wheat is assumed to be disposed of on the domestic market and this translates into an annual benefit to local consumers of $862.9 million, and a corresponding benefit value to consumers in other parts of China of $401.7 million. The median value of the total annual economic surplus–welfare change for wheat is $1923.5 million which is about 7.5% of the average value of Chinese wheat production between 2000–03.

CT adoption in Chinese maize production also generates substantial annual benefits to local producers and consumers. The value of the maize producers' surplus change in the adopting region is $697.5 million annually, while maize producers in the rest of China lose $545.9 million. Losses to the non–adopting Chinese maize producers are greater than those for wheat producers because of the greater proportion of maize (43% on average) that is produced in other parts of China. These large changes result from the high value of the maize supply shift compared to wheat which generated a greater price reduction and regional price spill-over for maize relative to wheat. Maize consumers in China gained an annual consumers' surplus of $1119.7 million from CT adoption, while the median value of the total economic surplus-welfare change is $401.9 million.

The overall results for each of the three regions are consistent with the theory of a spatially disaggregated economic-surplus model in which the adoption of a technology such as CT in one region benefits local producers, while producers in other regions suffer welfare losses from price spill-overs.

The estimates of economic surplus change provided the benefit estimates for the 30-year project impact assessment (Table 8). The benefit–cost criteria indicate that the CTF and CT technologies resulting from the ACIAR-funded projects have the potential to generate large levels of economic benefits over the range of expectations concerning the adoption of those technologies in Australian and Chinese dryland crop production. The benefit–cost outcomes for the Australian component are the simulated differences between the *Australia with-* and *without-project* scenarios that are defined in section 3. This incremental benefit can be attributed to ACIAR-funded CTF research in the Australian wheat industry that has expedited the delivery of the improved CT technology and its adoption by wheat producers. Such a benefit results because the benefits under the *Australia with-project* scenario are larger than without the project, they occur earlier in the benefit–cost period at higher adoption levels and are less reduced by the discounting. For Australia, the NPV of the incremental benefit is represented by a probability distribution with a median value of $79.5 million, and maximum and minimum values of $126.7 million and

$43.6 million, respectively. The simulated values of the BCR were a median of 4.9:1, a maximum of 7.9:1 and a 2.4:1 minimum.

Table 8. Stochastic 30-year benefit–cost analysis results for the projects: estimates of incremental benefits attributable to the projects

	Maximum 95th percentile	Median 50th percentile	Minimum 5th percentile
Australian wheat benefits from project			
Net present values ($m)	126.7	79.5	43.6
Benefit–cost ratios ($:1)	7.9	4.9	2.4
China wheat benefits from project			
Net present values ($m)	1668.6	408.5	–529.3
Benefit–cost ratios ($:1)	116.6	25.7	–43.1
China maize benefits from project			
Net present values ($m)	347.4	90.6	–112.4
Benefit–cost ratios ($:1)	23.3	5.7	–9.1
Total benefits from project			
Net present values ($m)	2142.7	578.4	–579.9
Benefit–cost ratios ($:1)	142.8	36.3	–49.8

Note: Calculations based on the total annual economic surplus change (Table 6) using a stochastic simulation model developed within the R statistical package (R Development Core Team 2003); discounted at 5% real interest rate over 30 years.

The benefit–cost outcomes for China are much larger than for Australia because of the greater annual increases in total economic surplus enabled by the adoption of CT in Chinese wheat and maize production. Like the Australian component, the results for China represent the incremental benefits between the *with-* and *without project* scenarios. The median NPV for Chinese wheat is $408.5 million with a median BCR of 25.7:1. The benefit–cost criteria for maize were a median NPV of $90.6 million and a median BCR of 5.7:1.

The aggregate benefit–cost outcomes are derived by adding the simulated totals of the annual economic surplus changes for the three country components. The median NPV of the total incremental benefit is $578.4 million and the median BCR was 36.3:1. While these benefit–cost outcomes are large, they are small when considered in the context of the annual values of the cropping industries. Based on the average production levels and prices used in the economic surplus change calculations, the median NPV of the total incremental benefit estimate is about 1.3% of the gross value of crop production in the two countries ($45.4 billion), of which the Chinese share is 88% ($40 billion). The benefit–cost results (median values) for various years in the assessment period are summarised in Table 9.

Table 10 contains the cumulative distribution function results that indicate the probabilities of the projects delivering a particular benefit–cost outcome based on the benefit–cost differences between the *with-* and *without project*

Table 9. Summary of benefit–cost outcomes (median values)

Region	Australia wheat	China wheat	China maize
NPV at year 15 ($millions)	30.5	103.9	20.9
NPV at year 20 ($millions)	53.7	263.2	55.9
NPV at year 25 ($millions)	72.0	373.1	78.1
NPV at year 30 ($millions)	79.5	408.5	90.6
BCR at year 15 ($:1)	2.9	9.0	2.1
BCR at year 20 ($:1)	4.3	21.2	4.4
BCR at year 25 ($:1)	4.6	24.3	5.4
BCR at year 30 ($:1)	4.9	25.7	5.7

scenarios. For the Australian wheat component, the minimum NPV of $43.6 million and minimum BCR of 2.4:1 are represented by the 5th percentile. The median (50th percentile) results are a NPV of $79.5 million and a BCR of 4.9:1. There is zero probability that the projects will deliver a negative return. The cumulative distribution function results for both the Chinese crops and for the total benefit indicate high probabilities of the projects achieving large benefit–cost outcomes in the higher percentiles of their probability distributions. The negative NPV and BCR values that occur in the lower percentiles of the cumulative distribution functions for these crops result from the assumption of full independence between the *with-* and *without-project* scenarios. This implies zero correlation between the input data for the project benefit and adoption lags. Under the Monte Carlo stochastic simulation routine that was used, it is possible that any randomly selected value for a benefit or lag can be greater for the *without-project* scenario than for the *with-project* scenario and this will generate a negative difference or incremental benefit at that point for the NPV and the BCR between the two scenarios. This could occur in a real project situation if, for example, another agency established a similar project that was better resourced than the project being assessed. However, the estimated cumulative distribution functions indicate that the probability of such a result is low for either of the Chinese crops and zero for the total project benefits (an alternative would be to impose correlation between the input distributions for the *with-* and *without-project* scenarios but this was not attempted in these assessments). A useful way to consider these results is to determine an acceptable benefit–cost outcome from a project, say a NPV ten times greater than the total project cost, and to recognise the probability of obtaining that result. Considering the Australian example and the total project cost of $1.4 million, the probability of obtaining that benefit–cost outcome would be 100%. Similarly, for the China wheat component, that probability is between 75 and 80%.

Table 10. Cumulative distribution functions for 30-year benefit–cost outcomes: incremental benefits attributable to the projects

	Australia wheat	China Wheat	China maize	Total project[a]
Net present value ($ million)				
5%	43.6	–529.3	–112.4	–579.9
10%	49.5	–289.7	–63.1	–303.3
15%	53.4	–163.4	–33.8	–143.8
20%	57.3	–0.7	–1.4	55.2
25%	60.9	64.8	14.2	139.9
30%	64.6	129.5	29.6	223.7
35%	68.3	192.3	42.9	303.5
40%	71.8	268.3	59.1	399.2
45%	75.4	334.1	75.9	485.4
50%	79.5	408.5	90.6	578.4
55%	82.4	482.4	105.7	670.5
60%	86.0	563.5	122.8	772.3
65%	89.4	644.7	140.6	874.7
70%	93.2	738.5	158.1	989.8
75%	97.6	836.5	179.6	1113.7
80%	102.4	954.1	206.4	1262.9
85%	108.2	1114.8	237.9	1460.9
90%	115.9	1310.5	280.2	1706.6
95%	126.7	1668.6	347.4	2142.7
Benefit–cost ratio (BCR $:1)				
5%	2.4	–43.1	–9.1	–49.8
10%	2.8	–25.9	–5.4	–28.5
15%	3.0	–16.7	–3.2	–16.9
20%	3.3	–6.6	–1.3	–4.6
25%	3.5	–3.2	–0.6	–0.3
30%	3.8	5.3	1.2	10.3
35%	4.1	8.8	2.0	14.9
40%	4.3	14.8	3.4	22.5
45%	4.6	19.7	4.5	28.8
50%	4.9	25.7	5.7	36.3
55%	5.0	29.9	6.6	41.5
60%	5.3	35.3	7.8	48.4
65%	5.5	41.2	9.0	55.7
70%	5.7	47.4	10.3	63.4
75%	6.0	54.3	11.7	72.0
80%	6.3	62.6	13.6	82.5
85%	6.7	73.6	15.8	96.1
90%	7.3	86.9	18.7	112.9
95%	7.9	111.6	23.3	142.8

[a] The total project benefits are the sum of the simulated values of the components.

5 Discussion and conclusions

Economic benefits

This impact assessment presents estimates of the potential economic benefits of an 11-year research program sponsored by ACIAR into the development of new CTF and CT technologies in dryland cropping in Australia and China. CTF has been a longstanding research issue in Australia and the ACIAR-funded projects represented a continuation of that research. Since it is not possible to determine the full costs of all CTF research that has been made by the Australian research institutions over time, the known research costs under the ACIAR-funded projects are used to estimate the change in benefit that could result from the projects under a range of adoption assumptions.

The benefits attributed to the ACIAR-funded projects are additional benefits estimated to have resulted from the role of the projects in expediting the development and release of improved CTF technologies in wheat production in Australia, and of improved CT in wheat and maize production in China. Although there had been some previous research into CT in China by staff at the CAU before the initiation of the ACIAR-funded projects in 1992, the technology was then considered to have little relevance under Chinese dryland farming conditions and to be contrary to long-used conventional tillage practices. Although this scenario suggested that most of the benefits from CT research in China could be legitimately attributed to the ACIAR-funded projects, it is likely that China would have experienced some spill-over effects from the continuum of CT that is undertaken internationally. Hence, the role of the ACIAR-funded projects in bringing forward the release of the CT technologies is also held to be relevant in China. The assessment has a clear bias to China because the innovative nature of the CT technology there has the potential to generate relatively large levels of benefits. The long history of CT research in Australia means that the benefits to the new research under the projects are smaller in comparison.

The main benefits of CT and its CTF extension are that they increase crop yields and can reduce the costs of production and the labour inputs into cropping. These technologies also lead to important environmental benefits where the retention of surface residues reduces soil degradation and dust pollution. The results of this assessment indicate the potential of the ACIAR-funded projects to generate very large, long-term economic benefits. This is particularly so in China where the acceptance of CT has gone from being negligible to being an integral part of the official five-year agricultural plans of the Chinese Government. Under the current (10th) five-year plan, the expansion of CT in northwestern China is being promoted with substantial government funding.

The incremental NPV of the benefits of CTF in Australia has a median value of $79.5 million and a median BCR of 4.9:1 when compared to the total project costs. The corresponding China-level benefits from CT adoption were larger because of the much greater scale of the cropping enterprises there and the relative magnitudes of the supply shifts. The median values of the NPVs and the BCRs are $408.5 million and 25.7:1 for wheat in China, and $90.6 million and 5.7:1 for Chinese maize. However, in both countries the economic welfare gains to producers in the adopting regions have to be balanced against welfare losses to crop producers in other regions.

CT is now being actively promoted in the 13 northwestern Chinese provinces under the MoA program that was initiated in 2002 to establish CT demonstration sites across that region. Funds have been allocated to establish these sites with the help of the local agricultural mechanisation bureaus and leading farmers. Each site is to achieve a target area of 1300 hectares. In 2004, the CT sites totalled 220,000 hectares of wheat and maize production in 94 counties in the northwestern provinces (Gao Huanwen, unpublished data). This area change represents a substantial extension effort for CT since only 38 counties had demonstration sites in 2002. Funding from the MoA for CT demonstration is $0.15 million (0.9 million yuan) annually per county. The total area of the CT sites is expected to be about 400,000 hectares when the current MoA plan is fully implemented by 2005 (Li Hongwen, pers. comm.)

The national MoA plan is being complemented by further CT initiatives at the provincial level. An additional 200,000 hectares are now under CT demonstrations in sites that are supported by county and provincial governments independently of the MoA. It is expected that these additional demonstrations will eventually gain MoA funding to enable further expansion in the overall CT area. The MoA plan is to have 2 million hectares of government-supported CT in north China over the next decade. In a further initiative, the provincial government of Beijing, through the Beijing Agricultural Commission and the Beijing Agricultural Bureau has allocated $0.81 million (5 million yuan) per annum to prepare a CT extension plan, and the Beijing Environment Bureau has allocated $1.13 million (7 million yuan) per annum to support the Agricultural Mechanisation Bureau in implementing CT. The aim of this initiative is to achieve a 100% conversion of cropland around the city to CT in time for the Beijing Olympic Games in 2008, the main drivers being to reduce dust-storm pollution and improve farmer welfare. CT is listed as one of 10 key environmental protection strategies to achieve the environmental improvement plan of the Beijing government.

The realisation of the estimated benefits to China appears to be promising on several grounds. CT is a central element in the agricultural component of the 10th five-year plan (2002–05), and has a much greater importance than under the previous plan. The agricultural plans are monitored by the Ministry of Science and Technology and the MoA, and are reviewed on completion by an independent panel of experts. The CAU on behalf of the MoA is the main agency monitoring CT under the current plan. Staff are confident that CT will remain a major emphasis in future plans.

As previously indicated, the MoA objective is to have 2 million hectares of CT operating in northwestern China by 2010, or a conservative 10% of all farms. The government recognises that the success of this policy can be assured only if farmers are willing to adopt the CT technology. Government policy is a critical factor in this expansion but it is also dependent on active extension programs. In the latter regard, the MoA organises two training courses each year in Beijing with teaching materials and some lectures provided by CAU. Attendees are usually staff from the agricultural extension and mechanisation bureaus. They receive accreditation certificates. Participants in a 2003 workshop in Shanxi Province received an ACIAR certificate in CT competency. The local agencies have the responsibility for instructing farmers in CT procedures. While the current extension effort is directed to the northern region, it is expected that the government will support CT extension elsewhere given the success of CT in the current program.

The limited availability of CT equipment remains an important constraint on the expansion of CT in China. Under the MoA plan, selected farmers purchase CT machinery from the local mechanisation bureau with a two-thirds cost subsidy from the government on the understanding that the machinery will be used to help plant the crops of other farmers. For example, in the Yaodu district around Linfen city, 250 farmers have successfully applied to the district mechanisation bureau for subsidies to purchase CT equipment in the past five years. This process is considered to be a better and less costly system that benefits all farmers in the locality since most farmers do not have to purchase their own equipment. However, government finance is limited, which means that there is insufficient CT equipment available to satisfy the demand in all regions.

Other benefits

The ACIAR-funded projects generated other important benefits that could not be quantified in the impact assessments.

Capacity-building implications

The main capacity-building aspects of the ACIAR-funded projects concerned the training of Chinese scientists and the development of appropriate CT equipment for China. Younger Chinese scientists were invited to spend periods of 3–5 months working with the project team at UQG, where they gained direct experience with the scientific approaches and application of the CT technologies in Australia. This was a beneficial experience for the visitors who were able to make useful contributions to the projects. Further, the visiting scientists each made significant contributions to the projects in China and all remain working in CT and related areas. One of the scientists, Li Hongwen, has succeeded Professor Gao as Director of the Agricultural Engineering College at CAU and, as previously indicated, is the expert consultant to the MoA on CT policy in China.

The projects, in association with the Crawford Fund Scholarship scheme, provided financial support to three PhD students. One Australian student contributed to the project work in China but the other two did not return to their own countries and contribute to future projects. The Australian project leaders considered that modifications to the scholarship system were necessary so that students spent shorter periods in Australia at the beginning and end of their candidature, and undertook most of the field work in their home countries with increased supervisory visits. This system is used by Wageningen University in the Netherlands.

CT is regarded as being one of the great achievements of CAU, which was the first agency in China involved in that research. The capacity-building benefits of the projects are highlighted by Professors Gao and Li having been able to capture most of the government funds for CT research to date. The university remains the main centre of CT research and continues an active teaching program in CT to meet the demand for this expertise in China. At least 10 PhD and Masters students are involved in CT research each year and up to 20 undergraduates study some aspects of CT for their degree requirements. Other provincial universities such as those in Heibei and Shanxi are also involved in CT teaching and research. Most of the teachers at these universities are former students of the CAU. There is a great demand for this expertise in China and it will be a long time before the supply of CT-trained students can satisfy it.

In addition to the universities, the various tiers of the agricultural mechanisation bureaus have developed a strong appreciation for and expertise in CT. These agencies are now providing CT training to extension staff and farmers in many districts, as well as administering the government subsidies for the purchase of CT equipment. Engineers at the bureaus have been able to solve local problems that have emerged with CT application. An example was observed in which the chief engineer for the mechanisation bureau of the Yaodu district successfully modified a planter to prevent fertiliser from burning the seed.

Chinese CT developmental research is now focused on larger machinery for use on bigger tractors (50–70 horsepower; 40–50 kW). The MoA has allocated funds to subsidise the purchase of larger CT equipment. While it is expected that the small tractors will eventually be phased out, the CAU still has to develop small tractor equipment to ensure that the CT technologies remain relevant to the typical farmer. This process is now evident as there are now six medium-size (50–70 horsepower) tractors and 200 sets of CT equipment operating in the Yaodu district (a set of equipment includes a slasher, a sub-soiler and a seeder). A further dimension of this issue is the flow-on benefits of CT expansion that are already in evidence in China. The MoA's subsidisation of CT machinery purchases through the agricultural machinery bureaus has created a heavy demand for this equipment. There has been an upsurge in the commercial manufacture of CT machinery in response to this demand. Supporting evidence for this growth comes from Wu (2004) who stated that, before 2001, there were only two no-till seeder manufacturers in the north of China. Three years later there were 20 such factories, some of which had developed into large-scale specialist manufacturers.

Such achievements have been officially recognised in two prestigious awards made to the project leaders by the Chinese Government. Professor Gao was awarded a National Science and Technology Progress Award that was presented in the Great Hall of the People in January 2003 by the then Premier Zhu Rongji. Dr Tullberg received a Friendship and Cooperation award from the Foreign Experts Bureau of China that was presented by the Mayor of Beijing in November 2001. Both awards recognise the outstanding contributions of the project leaders to the development and promotion of CT in China. The awards emphasise the success of the projects in achieving a complete reversal in attitude to CT by Chinese officials. They are also indicative of the rapport amongst the members of the project teams wherein the Chinese scientists emphasised the continuing value of the strong research relationship that was developed under the projects with their Australian counterparts.

An important practical aspect of the capacity-building outcomes of the projects is the joint research into the design of CT equipment for Chinese conditions. In Australia, the challenge of sowing through crop residues has usually been solved with heavier planting equipment with high-powered tractors. This solution is inappropriate in China because the very small tractors that are commonly used do not have the lift capacity for heavy equipment. Because CT requirements vary with soils and residue treatment, there is no single solution to this problem. The cooperative work has continued since the inception of project LWR2/1992/009 and covers many aspects of machinery design, development and field assessment. It has resulted in a range of effective CT equipment now being available in China, as well as the establishment of a valuable human resource with experience in the equipment options and system consequences.

Gender implications

Women make a major contribution to traditional agricultural production in China. They supply the bulk of farm labour since many men work off-farm, often in distant areas. In some regions, women comprise 70% of the rural workforce and perform most of the labour-intensive tasks of land preparation, removing crop residues and weeding. Project LWR2/1996/143 provided funds for a baseline survey of household labour allocation to identify the potential gender effects of CT. The Chinese component of this research was undertaken by Liu Feng-qin of the Rural Women's Studies Group at the CAU who conducted a field study over 1998–99 at two locations in Shanxi Province to further investigate the socioeconomic status of rural women and the effects of CT on those women. Using a combination of participatory observation, focus group interviews and questionnaires, the ACIAR-funded projects were found to have generated major and permanent benefits to rural women and children (Feng-qin 1999).

CT is found to have positive influences on Chinese rural women in several aspects. The main impact of CT is to reduce the labour and time demands on women for farming. This results in improved health for women, enabling them to take better care of themselves, their children and the elderly. Reductions in labour and time inputs from CT also enable women to obtain more off-farm work. Higher household incomes result in improved educational opportunities for children and for rural girls in particular, many of whom (68%) had previously been denied an education when limited household funds favoured the schooling of boys. In this regard, the Feng-qin study noted that, as rural women were traditionally house-bound, CT created another gender benefit by enabling them to become more involved in farm decision-making. It was the women who assumed the leading role in appreciating the benefits of the CT technology. Exposure to CT through the project created opportunities for women to obtain information on the technology, to observe and evaluate it and to consequently practise it. This aspect increased women's awareness of environmental protection by learning how to make more effective use of the land, water and crop residue resources.

Other gender benefits identified are better clothing for children and improved child health and hygiene, and women being more confident and able to influence household expenditure decisions. One interesting aspect of the latter benefit was that 70% of the women surveyed indicated that education is their foremost spending priority, whereas this demand ranked much lower with men. Some limitations are also identified that mainly related to limited public funding. The gender benefits determined for the Shanxi areas in which the CT research is centred could also be expected to result in other provinces but limited government funding is preventing their realisation. Also, the CT training opportunities provided by the mechanisation bureaus are limited by machinery availability, and men are typically given priority for this training. Women indicated that they want to be much more actively involved in CT training because they recognise the income potential of the technology and tend to be more farm-based that the men. In summary, the study by Feng-qin (1999) concluded that the ACIAR-funded projects produced a very good technology that has resulted in major permanent benefits for rural women and children in China. It is not considered that such gender issues are as significant in Australia and no parallels are drawn.

6 References

AACM International 1998. Conservation tillage and controlled traffic. Canberra, ACIAR, Impact Assessment Series No. 10, 29p.

ABARE (Australian Bureau of Agricultural and Resource Economics) 2004. Australian commodity statistics 2003. Canberra, ABARE (electronic version).

Alston, J.M., Norton, G.W. and Pardey, P.G. 1995. Science under scarcity: principles and practice for agricultural research evaluation and priority setting. Ithaca and London, Cornell University Press.

Brennan, J.P. and Quade, K.J. 2004. Analysis of the impact of CIMMYT research on the Australian wheat industry. Orange, NSW Department of Primary Industries, Economic Research Report No. 25.

China Agricultural Press 2001, 2002. China agricultural year books for 2001 and 2002. Beijing, China Agricultural Press.

Davis, J.S. 1994. Disaggregation rather than mathematical manipulation for incorporating research impacts on supply. Canberra, ACIAR, Working Paper Series No. 3.

Feng-qin, Lui 1999. Examination of the effects of conservation tillage on women. Paper presented at an ACIAR project review workshop, Beijing.

Gao Huanwen, Luo Hongqi, Cao Liansheng and Jing Xisen 2004. Continuous experiment of no-tillage system for 12 years in north of China. In: Proceedings of the international conference of conservation, tillage and sustainable farming. Beijing, China Agricultural Science and Technology Press, 32–39.

Griffith, G.R., I'Anson, K., Hill, D.J. and Vere, D.T. 2001. Previous supply elasticity estimates for Australian broadacre agriculture. Orange, NSW Agriculture Economic Research Report No. 6.

Holland, J.F., Doyle, A.D. and Marley, J.M. 1987. Tillage practices for crop production in summer rainfall areas. In: Cornish, P.S. and Pratley, J.E., ed., Tillage: new directions in Australian agriculture. Melbourne and Sydney, Inkata Press, 48–71.

Lawrie, J.W., Packer, I.J., Chewings, R.A. and Farrow, C.A. 2004. Encouraging farm management change to improve soils in central NSW Australia. In: Proceedings of the International conference of conservation, tillage and sustainable farming. Beijing, China Agricultural Science and Technology Press, 521–527.

Li Hongwen, Gao Huanwen, He Jin and Wang Xiaoyan 2004. A comparison of subsoiling and zero tillage on soil properties and crop yield. Proceedings of the International Conference of Conservation, Tillage and Sustainable Farming, China Agricultural Science and Technology Press, Beijing, 85–88.

Lindner, R.K. 1986. Adoption and diffusion of technology: an overview. In: Champ, B.R., Highley, E. and Remenyi, J.V., ed., Technological change in postharvest handling and transportation of grains in the humid tropics. Canberra, ACIAR Proceedings No. 19, 144–151.

Mullen, J.D. 2004. Impact assessment of ACIAR-funded projects on grain-market reform in China. Canberra, ACIAR, Impact Assessment Series No. 26, 92p.

Pratley, J.E. and Cornish, P.S. 1987. Responsible land use: the role of government. In: Cornish, P.S. and Pratley, J.E., ed., Tillage: new directions in Australian agriculture. Melbourne and Sydney, Inkata Press, 420–434.

R Development Core Team 2003. A language and environment for statistical computing. Vienna, R Foundation for Statistical Computing <http//www.R-project.org>.

Radford, B. and Kelly, R. 2003. Precision farming in the northern grains region 2. Soil compaction and controlled traffic. Brisbane, Queensland Department of Primary Industries, DPI Note (August).

Scott, F.J. 2003. Partial budgets: conventional no-till versus controlled traffic no-till in dryland crop rotations in the Moree district. Presentation at Western Farming Systems Field Day, Moree, 2 September 2003.

Scott, F.J. and Farquharson, R.J. 2004. An assessment of the economic impacts of NSW Agriculture's research and extension: conservation farming and reduced tillage in northern NSW. Orange, NSW Department of Primary Industries, Economic Research Report No. 19.

Smith, G., Tao Ding Lai and Liu Xunhao 1995. Conservation zone tillage research for dryland farming. Canberra, ACIAR Project Review.

Southorn, N.J., Packer, I.J. and Murphy, B.W. 2004. Future directions for dryland soil management under direct seeding techniques—an Australian perspective. In: Proceedings of the international conference of conservation, tillage and sustainable farming. Beijing, China Agricultural Science and Technology Press, 295–302.

Thomas, G.A., Felton, W.L. and Radford, B.J. 1997. Tillage and crop residue management. In: Clarke, A.L. and Wylie, P.B., ed., Sustainable crop production in the sub-tropics. Brisbane, Queensland Department of Primary Industries, 195–213.

Wu Chuanyun 2004. Conservation tillage in China makes positive progress. In: Proceedings of the international conference of conservation, tillage and sustainable farming. Beijing, China Agricultural Science and Technology Press, 518–520.

Appendixes

1 Persons interviewed

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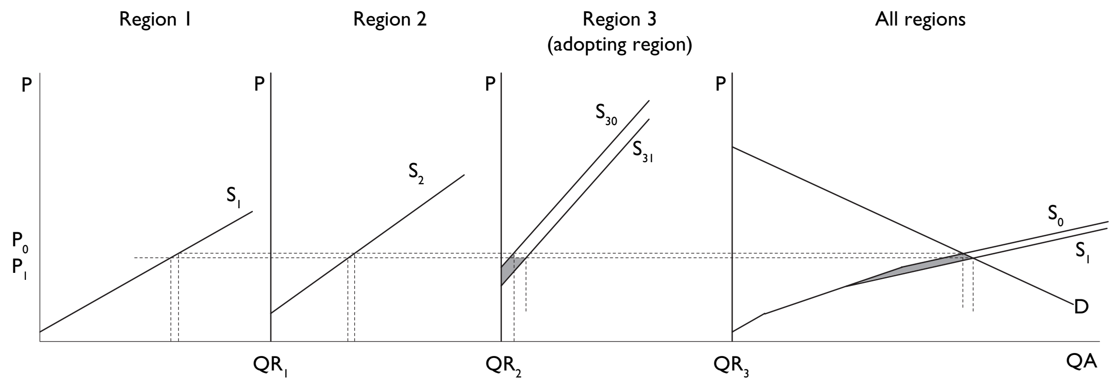
Jing Xisen, manager of the project trial plots, Linfen district, Shanxi Province.

Several farmers in Changhuang village, Xiandi district, Linfen City, who were involved in the Linfen trial sites and who have since converted to conservation tillage practices.

2 Economic basis of the regionally disaggregated model for benefit estimation

For a production-increasing, cost-reducing technology, the standard economic-surplus model incorporates a parallel supply shift that implies that the cost reductions are uniform across the industry. However, this is considered to be unrealistic if the technology has a regional rather than an industry-wide relevance and so production costs are likely to vary between regions. Where a technology is location-specific, it is necessary to disaggregate the level of analysis to more accurately assess the technology impact (Davis 1994). Such a disaggregated model is illustrated in Figure 1 (after Davis) in which three production regions vary sufficiently to have different production-cost structures. The cost variations are indicated by the different positions and slopes of the regional supply curves that are aggregated to form the national supply curve. Price is the same in each region but the production levels vary. The latter are indicated by the different sloping segments of the national supply curve. Separate regional demands are not considered and the national demand determines the prices P_0 and P_1.

Figure 1. Regionally disaggregated model for a production-increasing technology (after Davis 1994)



Assessing a new technology is applicable specifically to *region 3* in which technology adoption increases production in that region, but not in the other two regions. The main effect of supply shift in *region 3* is to reduce price to P_1 in each region because all regions face the same national demand. Producers in *regions 1* and *2* suffer welfare losses as production falls in response to P_1 because they are unable to adopt the technology and the lower price forces a shift down the supply functions to quantities QR_1 and QR_2 at higher average production costs. This effect differs from *region 3* where technology adoption lowers average costs and shifts production out to QR_3. The effect of the technology across all regions is the sum of the regional effects which, in this instance, is to increase production to *QA*. The national increase in economic surplus is less than that in *region 3* because of the losses to producers in the regions where the technology cannot be adopted.

The formulas for calculating these welfare changes for a three-region model are given in Alston et al. (1995, p. 407) in which the production technology that is adopted in *region 3* results in equal price changes (to P_1) and price spill-overs to *regions 1* and *2*.

Change in *region 1* consumers' surplus:

$$\Delta CS_1 = P_0 Q_1 Z(1 + 0.5Z\eta_1) \quad (1)$$

Change in *region 1* producers' surplus:

$$\Delta PS_1 = P_0 Q_1 Z(1 + 0.5Z\varepsilon_1) \quad (2)$$

Change in *region 2* consumers' surplus:

$$\Delta CS_2 = P_0 Q_2 Z(1 + 0.5Z\eta_2) \quad (3)$$

Change in *region 2* producers' surplus:

$$\Delta PS_2 = P_0 Q_2 Z(1 + 0.5Z\varepsilon_2) \quad (4)$$

Change in *region 3* consumers' surplus:

$$\Delta CS_3 = P_0 Q_3 Z(1 + 0.5Z\eta_3) \quad (5)$$

Change in *region 3* producers' surplus:

$$\Delta PS_3 = P_0 Q_3 Z(1 + 0.5Z\varepsilon_3) \quad (6)$$

The relative price change Z is defined as $-(P_1 - P_0)/P_0$, K is the supply shift parameter calculated as the unit cost of production change expressed as a proportion of the commodity price, P_0 is the equilibrium price, Q_i is the equilibrium levels of production and consumption in each region (i), and are the price elasticities of supply and demand for each region (i) (Table 4). These equations represent parallel displacements of linear supply and demand functions which are expressed relative to initial prices and quantities. The major issue that this model represents is that the economic welfare of other areas is likely to be affected by technology adoption in one area. It is intuitively reasonable that when some producers adopt a technology such as CT that increases production in a part of an industry, all consumers benefit while non-adopting producers lose.

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