An Assessment of the Economic Impacts of NSW Agriculture Research and Extension: Conservation Farming and Reduced Tillage in Northern NSW

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Abstract
This assessment of research and extension in conservation farming in northern NSW was done as part of a systematic process of evaluating the economic, social and environmental impacts of major research, extension and education programs. The conservation farming program was a key area of investment by NSW Agriculture and an evaluation process fulfils accountability and resource allocation requirements.
This analysis evaluates the investments by the former NSW Agriculture in conservation farming and reduced tillage programs from the late 1970s to 2002.
The benefit-cost ratios (BCR) for no till only and no till plus reduced tillage practices up to 2002 were 4.1:1 and 9:1, respectively. The net present values (NPV) of the benefits from these efforts up to 2002 were $78 and $205 million, respectively. When program activities are extended to 2020 the BCRs were 11.4:1 and 20.5:1 and the NPVs were $302 million and $568 million, respectively.
There are likely to be other benefits such as environmental benefits of reduced soil erosion (and reduced infrastructure remediation costs) and improved soil structure. Without the RD&E programs of NSW Agriculture and other agencies the slower growth in productivity is likely to have retarded farm and industry profitability, with associated effects on industry and community strength.

Keywords: benefit cost analysis, conservation farming

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Acronyms and Abbreviations Used in This Report

ABARE	Australian Bureau of Agricultural and Resource Economics
ABS	Australian Bureau of Statistics
BCR	Benefit-Cost Ratio
CSIRO	Commonwealth Scientific and Industrial Research Organisation
GRDC	Grains Research and Development Organisation
ha	hectare
IRR	Internal Rate of Return
kW	kilowatt
LGA	Local Government Area
NPV	Net Present Value

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Executive Summary

Description of the Conservation Farming and Reduced Tillage program

The dryland cropping industries in northern New South Wales have developed over the past 30 years based predominantly on wheat production from fertile soils in a summer rainfall-dominant climate. Issues of crop performance and natural resource use, particularly soil erosion, initiated a number of programs of research, development and extension (RD&E) by NSW Agriculture, other public agencies, private firms and farmers into improved methods of conservation farming and reduced tillage (CFRT).

Early in the CFRT investigative process it was realised that changing tillage for wheat production alone was insufficient to fully capture the potential benefits from such RD&E in a farming systems context. These programs have therefore included investigations into tillage, weeds, herbicides, crop diseases, soil water and soil nitrogen, grain legumes and farming system alternatives (including interactions between these various components), and the Department's advisory officers have extended the results to farmers.

Approach to evaluation

In the analysis reported here the investments by NSW Agriculture in those programs from the late 1970s to 2002 have been evaluated in an economic framework. An estimation of the increased profits from using CFRT practices, together with evidence of crop areas established with these methods, is the basis for the economic benefit analysis.

Two sets of results are presented in this report. The first is a comparison of industry benefits and public costs of these investments by New South Wales Agriculture up to 2002, and the second extends the project benefits and costs to 2020. Prior to 2002 the costs related to investments in both research and extension activities, whereas the costs to 2020 are projected to be for extension purposes only. In each case the with-program and without-program scenarios are specified and compared.

There are three main methods of preparation for crop establishment used in northern New South Wales – conventional cultivation, no till and reduced tillage. Conventional cultivation methods use mechanical means of weed control and seedbed preparation for sowing, whereas no till relies completely on herbicides for fallow weed control and uses adapted planters to sow into stubble. Reduced tillage methods incorporate one or two cultivations with herbicides for weed control. The without-program scenario was assumed to be represented by areas of conventional cultivation while the with-program was represented by the area of no till, and also by the areas of no till and reduced tillage crop establishment combined. Crop enterprise budgets and crop sequence budgets were established for each crop establishment method within each of seven sub-regions of northern NSW. These profit figures were used to estimate the difference between with-program and without-program net dollar benefits per ha, and aggregated, using survey data, to develop a total benefit estimate for comparison with RD&E costs.

Funding Sources

A considerable number of research projects and extension activities were undertaken for this cluster of projects. NSW Agriculture costs up to 2002 were estimated to have a present value of $25.6 million, and when extension activities were projected to 2020 the total was $28.3 million. Of the funds invested in research to 2002, 51% was in-kind (salaries, capital and other costs) and 49% was from industry. The main industry funding source was Grains Research and Development Corporation (GRDC) and its predecessors such as the Wheat Industry Council. The advisory activities were almost all in-kind contributions of NSW Agriculture District Agronomists who spent part of their time on this work. When extension/advisory services were included to 2002, the share of total costs was 39% funded by industry levies and 61% by state taxpayers via NSW Agriculture. When the extra extension costs to 2020 were accounted for, the share of investment was 32% industry and 68% NSW Agriculture.

In assessing the industry benefits from RD&E into CFRT, it is important to acknowledge the important work and influence of other agencies (State Departments of Agriculture and Natural Resources, the universities, CSIRO and farm consultants) and farmer groups in the whole process. Nevertheless New South Wales Agriculture has been a key source of farming systems research within northern New South Wales and a substantial provider of advisory/extension activities. Inspection and assessment of the share of papers and other publications presented at conferences and other forums was the basis for claiming 35% of the adoption of CFRT within northern New South Wales as being due to the efforts of New South Wales Agriculture officers and programs.

Economic, social and environmental effects

Based on these assumptions, the BCRs (benefit-cost ratios) relating to NSW Agriculture efforts for no-till only and no-till plus reduced-tillage CFRT practices up to 2002 were 4.1:1 and 9.0:1, respectively. The NPVs (net present values) of the benefits from these efforts up to 2002 were $78 and $205 million, respectively. Internal rates of return (IRR) were 45% for no-till only to 2002 and 91% to 2002 for both no-till and reduced tillage CFRT practices. When program activities were extended to 2020 the BCRs were 11.4:1 and 20.5:1 and the NPVs were $302 million and $568 million, respectively. Internal rates of return were 46% for no-till alone and 91% for the combined CFRT practices. These are very healthy returns on investment, with the projections to 2020 based on the assumption that extension activities will continue to encourage adoption.

There are likely to be other benefits from this RD&E program besides direct economic advantages in crop production and profit. These include environmental benefits from reduced soil erosion (and reduced remediation costs) plus reduced use of machinery and fuel. Using estimates of savings on erosion losses from other research, it is likely that up to 18 million tonnes of soil are saved annually from adoption of these technologies compared to conventional cultivation in northern New South Wales. Some of these savings are included in the on-farm profit estimates listed here, but other soil losses having off-farm effects have not been included. However, there may be some potential environmental detriments associated with persistence of herbicides in soil (and possible leaching into ground or surface water), a possible shift in the weed populations, and developing weed resistance to herbicides such as glyphosate.

The social consequences from maintained or improved farm profitability include maintenance of local communities, although other social and regional initiatives have also been implemented for this purpose. Without the RD&E programs of NSW Agriculture and other agencies the slower growth in productivity is likely to have retarded farm and industry profitability, with concomitant effects on industry and community strength. It is impossible with the methods used here to quantify what would have occurred without the RD&E investments since other strategies or policies may have ensued, however the impacts of industry profitability are direct and important for farms, farm families and local communities.

Funders and Beneficiaries

The NSW Agriculture programs evaluated in this report have been partly funded by the GRDC or its predecessors. That funding is derived from industry levies and matching Commonwealth Government funds. The benefits measured here flow to farmers and industries but there are also positive impacts on consumers, transport services, processors, local towns and communities, and the environment. The use of industry and public funds to generate industry and public benefits is appropriate. While we have not been able to quantify benefits in both categories, it would not seem to be appropriate for further major RD&E expenditure in this area without industry funding. The results presented in this report show that the CFRT investments by New South Wales Agriculture in conjunction with other funders and providers have been an appropriate use of funds over the last 30 years.

Issues for New South Wales Agriculture

Some issues have emerged from this study for NSW Agriculture in its role of promoting and evaluating new technologies. While there has been a substantial increase in the areas of crop established using conservation farming methods (totals of between 15% and 40% for sub-regions in 2002), there is still a long way to go in encouraging the adoption of what is considered to be a profitable technology for many farmers. Further, the statistical information available on technology uptake from external sources (ABS and ABARE) was patchy, which meant that some bold assumptions were necessary about adoption trends over time. Future research could include a survey of farmers to find out more accurately the extent of adoption of the technology and constraints to the adoption of the technology.

1. Introduction

There has been a long history within the former NSW Agriculture[1] of evaluating the returns from investment in specific RD&E projects. These evaluations were often used to support industry funding submissions and focused on the economic benefits from changes in farm productivity.

In 2003 NSW Agriculture began a more systematic process of evaluating the economic, social and environmental impacts of major programs of investment in research, extension and education. Five areas of investment were selected for evaluation of their economic, environmental and social impacts in 2003:

- an assessment of NSW Agriculture's wheat breeding program;
- an assessment of NSW Agriculture's advisory programs in water use efficiency;
- an assessment of net feed efficiency breeding research in beef cattle;
- an assessment of research and extension in conservation farming;
- an assessment of research and extension in annual weeds (*Vulpia*) in pastures.

This report presents the results of one of these initial evaluations conducted in 2003.

NSW Agriculture has been investing about $100m per year in research, extension and education activities making it the largest provider of research and development services within the NSW government sector. The opportunity cost of this investment is the benefit to the people of NSW if these resources were used in other areas such as health and education. Hence it is important that NSW Agriculture can demonstrate that it uses these resources in ways that enhance the welfare of the people of NSW.

This suite of evaluations is designed to assess the economic, social and environmental impacts of some key areas of investment by NSW Agriculture. It is anticipated that each year another set of investment areas will be evaluated, so that a significant proportion of the Department's portfolio will be evaluated on a regular basis. This evaluation process serves a number of purposes. The first is an external requirement for accountability in the way NSW Agriculture uses the scientific resources in its care. This evaluation process can also be used within NSW Agriculture to assist in allocating resources to areas likely to have high payoffs and to assist in designing research and extension projects that have clearly defined objectives consistent with the role of a public institution like NSW Agriculture. Working through this formal benefit cost framework gives those involved – economists, research and advisor officers and program managers - a greater appreciation of the paths by which, and the extent to which, research and extension activities are likely to have an impact at the farm level and hence lead to better projects. Part of this process is a greater understanding of other trends in the industry and of the extent to which "the market" is failing to deliver outcomes sought by the industry or by the community.

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[1] This work was done prior to the formation of the NSW Department of Primary Industries (on July1, 2004) through an amalgamation of NSW Agriculture, NSW Fisheries, State Forests of NSW and the NSW Department of Mineral Resources.

We would like to be able to value all economic, environmental and social impacts and relate these to the investments made, but generally we are only successful in valuing some of these impacts because of:

- uncertainty about the technology on farm production both now and in the future;
- uncertainty about environmental and social impacts both now and in the future;
- uncertainty about the value of environmental and social resources both now and in the future; and
- limited resources to undertake these evaluations.

Our approach has been to first describe qualitatively the economic, social and environmental impacts of the actual or proposed investment. We also describe the rationale for government investment from a market failure viewpoint which seeks to identify the characteristics of the investment resulting in farmers individually or collectively under-investing in the areas under consideration. We examine the share of public and private funding in the investment and compare this to a qualitative assessment of whether the benefits from the investment flow largely to farmers or largely to the community.

We then attempt to quantify as many impacts as practicable to arrive at the common measures of economic performance such as a benefit cost ratio. There are insights to be gained from persevering with an empirical benefit cost analysis even under uncertain scenarios. A key step is to identify not only the expected impact on an industry of the investment, the ‘with technology’ scenario, but just as importantly, how the industry would continue to develop without the investment by NSW Agriculture, the ‘without technology’ scenario. Rarely is the ‘without technology’ scenario a no-change scenario because there are usually other sources of similar technologies leading to ongoing productivity growth. This quantitative approach also gives an indication of the relative importance of key parameters such as the rate and extent of adoption of technology, the on-farm impacts, and the size of the investment and its time path.

In assessing the ‘with’ and ‘without’ technology scenarios, key outputs from research and extension activities and communication strategies used are described to give credence to claims about the contribution of NSW Agriculture and to assumptions about the rate and extent of adoption of the technology.

This evaluation report focuses on the returns to NSW Agriculture’s RD&E program on CFRT management practices for crop production in northern NSW. There was a major collaborative research component (with other government agencies, universities and industry) which began in the late 1970s. But there was also a significant extension component where NSW Agriculture staff had a considerable proportion of their time committed to extension of the research.

The farm problem involved soil degradation issues such as erosion, structural decline and declining fertility. In one sense these are separate issues from crop agronomy, but the processes leading to soil degradation stemmed from the farming methods and technologies that were initially used to produce wheat in north-western NSW. It was recognised that all these issues needed to be addressed, so a farming systems approach to RD&E was adopted by NSW Agriculture.

The tillage solution involved the maintenance of stubble cover during fallows, sowing into an undisturbed seedbed, and weed control via herbicides. This had the dual benefits of reduced erosion and increased moisture storage in the soil profile to allow crop sowing in the next planting window – a necessary condition for winter and summer cropping areas. However, tillage was only one problem in the northern farming region – wheat fertiliser strategies, crop disease and weed control, and machinery requirements were also addressed in a farming systems context with new crops (breeding, physiology and agronomy) being developed. Farmers needed to consider a range of management challenges to properly utilise the CFRT technology, but if they were able to do so the benefits were evident in an improved soil resource used with flexible and adaptive crop sequence decisions and improved long-term profits. There are many examples of successful adopters of the CFRT technology within improved farming systems programs on farms in northern NSW.

2. The Conservation Farming/Reduced Tillage program

2.1 Background

The broad problem that triggered research into conservation farming and reduced tillage in northern Australia was observed ‘widespread soil erosion, compaction, surface crusting and declining chemical fertility’, which can be referred to generally as ‘soil degradation’ (Cornish and Pratley, 1987). The rate of soil degradation accelerated in the 1960’s due to an expansion of area under crops, increased cropping intensity and the advent of larger machinery which allowed more frequent cultivation. Crop yield issues were also evident with declining wheat yields and protein levels becoming evident by the 1980s (sooner than in the older cropping regions) (Hamblin and Kyneur, 1993).

Holland *et al*. (1987) emphasised that stubble retention and the simple substitution of herbicides for cultivation were vital for the development of new farming systems. However, other aspects such as crop rotations, crop agronomy (eg nutrition, sowing rates and choice of cultivar), fallowing and other aspects of water management, pest, disease and weed management, and the place of structural works for erosion control were all important in development of conservation farming systems. Packer *et al*. (1988) defined conservation farming as ‘a system of farming which involves using the land in accordance with its capability and suitability and managing the land in accordance with the principles of conservation. Such a system would include contour farming, conservation tillage, crop and pasture rotation, judicious stocking management, pasture improvement, strip cropping and soil/water conservation works where appropriate’ (p. 4).

Research on this program in northern Australia has been conducted by several agencies over the last four decades, with NSW Agriculture making a major contribution along with other organisations such as the NSW Soil Conservation Service (now the Department of Infrastructure Planning and Natural Resources), the Queensland Departments of Primary Industries and Natural Resources, CSIRO, the Universities of Sydney and New England, and private industry such as chemical and fertiliser manufacturers. Farmers themselves also took leads from the research; and there was on-farm development of reduced and no till planting equipment in the 1980s and 1990s.

Winter crops in the region depend heavily on water stored in the soil from the previous fallow. Tilling the soil to control weeds during the summer fallow reduced soil moisture content and led to widespread erosion, particularly during the summer rainfall period. Therefore reduced tillage practices, which resulted in crop residues remaining on or near the surface to prevent erosion, subsequently became widespread (Holland *et al*. 1987).

A situation statement by the then Soil Conservation Service of NSW (Junor *et al* 1979) stated that ‘soil erosion is by far the most important environmental problem in the northwest of NSW.’ Soil erosion was caused by cultivation destroying the structural aggregation of soil particles, resulting in decreased water infiltration rates and increased erosion risk. Fallowing over the summer period also coincided with the period of highest erosion potential due to high intensity summer storms and the fact that on average 60% of rainfall occurs in the summer months.

2.2 History of tillage in the northern cropping region

Before the 1950s, cereal residues were commonly burned after harvest. Sixty-two percent of farmers burned stubble in the late 1940s (Martin *et al*. 1988). During the 1950s and early 1960s, tillage by shallow cultivation with disc ploughs and scarifiers drawn by low-powered tractors was the most common practice. 'Crop rotation' during this period usually meant continuous wheat with short fallow (i.e. between each wheat crop). Some farmers occasionally grew lucerne, oats, milo (sorghum) or used a long fallow (Marcellos and Felton 1992).

In the 1960s, cropping expanded rapidly as returns from grain increased relative to those of sheep. Large areas of native vegetation were cleared between 1962 and 1975 (Marcellos and Felton 1992). Strip cropping in the Liverpool Plains began, which involved growing crops in rotation in alternative strips across the slope of the land. This was due to the risk of damage caused by flood events. Fences were removed to avoid water channelling and runoff problems. The strips were between 20 to 100 metres wide and alternated between fallow, crop stubble and growing crop, using mostly wheat, sunflowers and sorghum.

During the 1970s, tyned trash working implements were introduced. The implications of this were that stubble retention and reduced tillage practices became more practical. Reduced tillage practices were recommended because they were more efficient at storing water in the profile during fallow periods and lessened erosion during rainfall events (Marcellos and Felton 1992).

A survey on crop rotation, tillage fertiliser use and weed control was carried out from 1983 to 1985 (Martin *et al*. 1988) covering the Shires of Moree, Narrabri, Yallaroi, Gunnedah, Inverell, Quirindi, Parry, Manilla, Bingara and Barraba. The survey found that eighty-one percent of farmers surveyed cultivated three to five times every year, implying a high cropping intensity. The survey indicated that on average, 74% of farmers in the north-eastern wheat belt practised conventional tillage, 14% practised reduced tillage and used herbicides, and 1% used no till (Martin *et al*, 1988). In the same survey, less than 30% of growers burned stubble.

A study in the mid-1990s re-visited 49 of the 50 farms surveyed by personal interview in the Martin *et al.* (1988) study (Hayman and Daniells 1997). The survey aimed to document then-current rotation practices and ascertain the main reasons behind crop rotation decisions in order to enable more effective research and technology transfer. Hayman and Daniells (1997) found that almost all farmers surveyed had decreased the number of tillage operations compared to five years previously. This indicates that there has been a recent change towards operations (such as reduced tillage) that are perceived as more sustainable practices.

The Martin survey could be seen as referring to longer term rotations, while the Hayman and Daniells survey may refer simply to the next crop. However the results of both were remarkably similar, particularly in the case of ranking weeds as the main reason for deciding a rotation or what crop to plant next.

2.3 Inputs to the CFRT program

A number of projects under the CFRT umbrella have been funded over the past 20 years, mostly from GRDC and previous incarnations such as the Wheat Council. Total inputs for NSW Agriculture projects to the CFRT program were valued at $25.6 million in 2002 dollar terms. The costs were converted to 2002 dollar terms (in order to enable valid comparison) by applying a GDP deflator to the nominal values to adjust for the effects of inflation, and by applying a compounding factor to alter the adjusted nominal figures to their 2002 equivalents. The projects included research and advisory personnel over a period from 1982 to 2002. The projects were generally funded from two sources – by cash from the grains industry (the GRDC and its predecessors) and in-kind by NSW Agriculture. The projects included both the conduct of research and the extension of results, including development of demonstration sites, field days and speaking at forums for scientific and farmer audiences. A breakdown of the inputs is shown in Table 2.1. The present (2002) value of inputs was $28.3 million when extended to 2020.

The total adjusted research input amounted to $20.4 million and advisory $5.1 million (Table 2.1). Forty percent of the adjusted research input was the in-kind contribution of NSW Agriculture staff and 60% was cash provided by industry (through GRDC) for operations. The majority of the value of advisory input was an estimated 20% of District Agronomist time for 11 officers in the northwest of NSW from 1980. There were also several no till groups run in particular districts. The Moree Conservation farmers Association was formed in 1993 to promote general conservation farming practices and systems, and this was supported by NSW Agriculture. There were a number of other advisory activities not included in this program. The ‘N in 96’ initiative and ‘Operation Quality Wheat’ were conducted to address issues of fertility and wheat quality, and although they addressed some aspect of the general problem, their focus was considered to be sufficiently different to be excluded from the inputs counted against the CFRT effort.

Table 2.1 Project details and funds invested for research and advisory inputs to the CFRT program by NSW Agriculture

Project	*Leader*	*Dates*	*Total funds $'000 (a)*	*NPV $'000 (b)*
Plant disease in reduced tillage	Moore	82-84	345.8	
Herbicide residues	Ferris	83-84	55	
No-till herbicide interactions	Ferris	83-85	714.7	
Dryland soybean production	Holland	85-86	162.4	
Weed control technology	Martin	85-87	374.8	
Weed detector - development	Felton	86-90	636.4	
Tillage and rotations - soil water and N	Martin/Marcellos	89-91	373.8	
Weed detector- commercial development	Felton	89-95	960	
Winter grain legumes - northern NSW	Marcellos	91	33.2	
Chickpea - wheat	Marcellos/Herridge	91-95	309.7	
Tillage and rotation for sustainable wheat production	Felton	92-00	4,125.9	
Management practices leading to chemical leaching	Ferris	95-96	65.9	
Cropping system analysis	Marcellos	95-98	284.4	
Integrated weed management	Medd	96-00	2,454.1	
Western Farming Systems	Martin	96-00	3,309.9	
Northern crown rot	Moore	98-00	141.1	
Eastern Farming Systems	Herridge	98-00	870	
Other			3,294	
Research Sub-Total			18,511	20,429
Advisory inputs				
20% of DA*(c)* time			3,268.6	
Moree CFA *(d)* – DA in-kind			169.8	
No-till groups – 30% DA in-kind			1,103.7	
GRDC study tours			30	
Advisory Sub-Total			4,572	5,124
NPV of research and advisory investment in 2002 terms				**25,554**

(a) Actual (nominal) year figures *(b)* AU$2002, 4% discount rate *(c)* District Agronomists in north-west NSW *(d)* Moree Conservation Farmers Association

2.3.1 Involvement of different agencies

In this section the involvement of different agencies is discussed for two purposes. First it indicates the type of work conducted within each agency. This information is then used to provide a basis for developing the attribution of grains industry effects to NSW Agriculture activities.

Although early commentators had noted the damaging effects of tillage on soil structure, the depletion of soil organic matter and the subsequent increased erosion risk (Callaghan and Millington 1956), as of the late 1970s full no till technology had 'not yet fully developed to enable this technique to be widely adopted' (Junor *et al.* 1979).

A northern NSW research project team was formed in December 1978 to 'evaluate the problems and potential of no-tillage systems' (Martin 1982). The project team included collaborators from NSW Agriculture, Soil Conservation Service of NSW, Queensland DPI, the Universities of Sydney and New England, wheat growers and commercial agribusiness (ICI, Monsanto, Ciba Geigy, Dupont, Bayer Australia, Hoechst Australia Ltd). Observation sites were established, and from observations a list of research needs were developed. These included:

- development of a planter to sow into an uneven soil surface with heavy stubble residue;
- devising effective and economic herbicide recommendations;
- determining how zero tillage influences weed populations;
- establishing which soil types are suited to zero tillage;
- increasing information available on the effect of cultivation practices on soil structure stability and assessing their effectiveness in soil conservation;
- overcoming nutritional problems associated with zero tillage by examining the efficiency of different methods of fertiliser application, the nutritional role of legume crops grown in rotation with wheat, and the redistribution of nutrients in the soil profile;
- studying the adaptation of crops (other than wheat) to zero tillage;
- evaluating the suitability of currently-recommended wheat varieties to zero tillage;
- determining how zero tillage influenced the incidence of plant diseases; and
- identifying insect and other biological problems (Martin 1982).

The project team therefore had a wide membership across the industry and the research brief was broad from the start, not only looking at no till but also at changes to the cropping systems that would be necessary for it to work (such as rotating other crops with wheat). Funding was contributed by numerous funding bodies of the time including the Wheat Industry Research Committee of NSW, the Wheat Industry Research Council, the Grain Sorghum Research Committee, Commonwealth Special Research Grant and the Oilseeds Research Committee (Martin and Felton 1984).

The Australia Society of Agronomy (ASA) held a conference in 1982 focussed on reduced tillage and as a result published a book (Cornish and Pratley 1987) which detailed a selection of research projects undertaken in the early-1980s by ASA members. Information included the history of tillage in Australian farming systems, current practices, the various effects of tillage on plants and soil and the adoption of 'conservation farming'. There were 31 contributors listed in the book, 11 were from NSW Agriculture, four each from CSIRO and the Queensland Department of Primary Industries, three from the Victorian Department of Agriculture and Rural Affairs, five from tertiary institutions, one each from WA Department of Agriculture, ICI (chemical manufacturer) and John Shearer (machinery manufacturer), and one private consultant.

By 1983, the reduced tillage technology was feasible under research, but high chemical costs and uncertainty about yields and crop diseases prevented widespread adoption. The costs of herbicide for fallow weed control were above that of conventional cultivation, and machinery capable of sowing into heavy crop residues was not commercially available (Anon., 1983). An experimental no till planter was developed at the Tamworth Agricultural Research Centre, and was the only one of four trialled in the early 1980s that achieved consistent seed placement at sowing. It had further modifications by the Agricultural Engineering Centre at Glenfield (Anon., 1983).

A review of conservation farming research in NSW was published in 1988 by the then Soil Conservation Service of NSW (Packer *et al*. 1988). The report listed a number of active research projects in northern and southern NSW. Projects listed for northern inland NSW included:

- No tillage wheat production in northern NSW; NSW Agriculture/ Soil Conservation Service (this refers to the work of the northern NSW research project team mentioned above that formed in 1978);
- Integration of weed control strategies for cropping systems; NSW Agriculture, Tamworth;
- Development of summer cropping systems using no tillage, NSW Agriculture, Tamworth;
- Fate and persistence of herbicides, NSW Agriculture, Tamworth;
- Stubble retention and soil pathogens, University of Sydney, Narrabri and Moree;
- Crop protection utilising plant-produced chemicals, University of New England;
- The influence of stubble conservation on wheat production and nitrogen economy of black earths; University of New England/Soil Conservation Service, Warialda;
- Modification of soil physical properties on improved plant performance and productivity; University of New England;
- Soil productivity modelling; University of New England;
- Analysis of flood flow and sediment movement through strip cropping; CSIRO, Gunnedah; and
- Straw breakdown to fuel nitrogen fixation in soils; CSIRO, Gunnedah (Packer *et al*. 1988).

The review report noted that ‘Department of Agriculture results are generally accessible through regular departmental publications, such as AgFacts, or special publication’ (Packer *et al*, 1988, Appendix I p.2). Proceedings of northern no tillage project team meetings were also noted. Field days were held to extend the research results to growers, eg a field tour on 13 October 1988 at Croppa Creek was entitled ‘No-till eventually, Why not now?’

In addition to publications, NSW Agriculture extension staff members (district agronomists) have had a component of their work programs focused on improving tillage practices since the early 1980s. For example, John Kneipp (Coonamble district agronomist 1981-1985 and Gunnedah district agronomist 1985-1992) produced annual reports detailing planned activities and activities undertaken. First mention of conservation tillage was in the early 1980s with an increased focus specifically on encouraging reduced tillage and particularly no tillage sorghum after he moved to Gunnedah. Field days and meetings were held and in 1989 he estimated that tillage had been reduced in the Gunnedah area by 30%, resulting in savings in labour and fuel costs. Also, from the early 1980s, chemical companies began working with NSW Agriculture district agronomists at field days in demonstrating to growers how to use fallow herbicides and how to calibrate and use application equipment such as boom sprays (J. Kneipp, pers. comm., 2003).

The Soil Conservation Service of NSW also employed a Soil Conservationist in 1982. This position was to co-ordinate the extension effort regarding conservation tillage in northern NSW. The Service regarded that it held the responsibility under the Soil Conservation Act 1938 to prevent or mitigate soil degradation, erosion, transport and deposition, and the conservation farming aspects included strip cropping, crop rotation, no tillage, and stubble retention (Packer *et al*, 1988).

Perceptions of the role of NSW Agriculture included ‘a primary source of research information’ (J. Esdaile, pers. comm.) with certain projects being seen as having a major contribution, such as the multi-disciplinary, multi-agency no till project formed in northern NSW in 1978 (G. Rummery, pers. comm.). In addition, private agribusiness also contributed to the adoption process. As research results from NSW Agriculture and other organisations came to light, various private agronomists also contributed to the adoption of the technology. These included Agroservices, based in Gunnedah in the 1980s (whose agronomists included Greg Giblet, Paul Findlay and Rob Evans), David Bailey with Agroservices at Moree, as well as John Hosking, Peter Birch and Rob Onus of Moree. Other agronomists worked for NSW Agriculture for a period before moving into private industry, including Greg Rummery (Walgett Sustainable Agriculture Group) and Rob Everleigh (Cotton Seed Distributors).

2.4 Outputs from CFRT Program

The key outputs of the CFRT program have included reduced tillage machinery, spray rigs as well as scientific journal articles, specialised publications, advisory materials and extension activities such as field days and the formation of advisory groups.

Appendix A contains a detailed listing of NSW Agriculture publications and activities and Appendix B a selection of publications published by other organisations.

Every NSW Agriculture district agronomist had (and continues to have) input into extending reduced tillage research results to the farming community (J. Kneipp, pers comm.). These include NSW Agriculture extension materials, meeting and field days as well as contributions to farmer groups. For example, a Gunnedah no till farming group was formed by John Kneipp in 1990 and is still operating currently. The Moree Conservation Farmers Advisory Group was initiated by Jeff Esdaile (University of Sydney-Livingston Farm) in the early 1980s and local NSW Agriculture agronomists had input into the group’s activities.

2.5 Outcomes from CFRT Program

The key outcome of the RD&E program is in the adoption of CFRT practices by farmers, leading to increased productivity of (and therefore improved farm incomes from) cropping systems in northern NSW.

2.5.1 Economic outcomes

The key economic outcome of adoption of CFRT practices in northern NSW is improved on-farm profitability. The evaluation approach is detailed in the next section, but it basically involves measuring improvements in profits from farming systems where these R&D recommendations have been adopted compared to those systems in which they have not. A series of crop sequence budgets were developed for key regions, to estimate the economic impact of the altered crop rotation system using full or partially adopted CFRT practices. The level of adoption in the regions was determined from survey information from ABARE and ABS.

Despite the efforts of the organisations involved in this program, there appear to be farmers who have not adopted the recommendations and continue to operate farming enterprises based on traditional methods. The observation of such farming enterprises allows a comparison of 'with' and 'without' scenarios which is the basis for the economic evaluation. There are also farming enterprises which have partially adopted the 'no till' technology and as a result have significantly reduced the number of tillage operations.

There are also flow-on industry benefits such as larger markets for herbicides and specialised reduced tillage machinery, but no attempt has been made to quantify these. There is likely to be continued influence on the cropping industry of the CFRT program into the future, with Departmental advisory officers having part of their work programs allocated to promoting CFRT practices.

2.5.2 Environmental outcomes

Some positive and potentially negative environmental outcomes have been observed in association with the adoption of CFRT practices. Soil erosion was a major problem under conventional tillage in the summer-dominant rainfall areas, but this has been substantially alleviated by new management, as discussed below. Two other affects are mentioned in this section. These are the persistence and fate of herbicides used to provide residual weed control beyond the current crop, and the effects of changed tillage and stubble management on weed control.

The problem of soil erosion in the northern summer-rainfall areas was recognised early. Junor *et al*. (1979) documented the soil erosion problem for the Shires of Liverpool Plains, Tamarang and Namoi. They compared figures for 1945 and 1975 and found that the proportion of areas experiencing moderate gully erosion and sheet erosion had risen from 22% and 9%, respectively, to 38% and 23% over the period. Similarly the area with no appreciable erosion had fallen from 61% to 31%.

Marschke and Thompson (1983) reported results of runoff and soil loss from a storm event on 2 January 1983. Three conservation tillage techniques (stubble incorporated, stubble mulched and no till) showed marked reductions in runoff and soil loss compared to stubble burning. The no till treatment was estimated to retain 99% of rainfall compared to 66% for the stubble burnt treatment.

Harte (1985) conducted field experiments to compare erosion susceptibility induced by conventional tillage and no till practices. Using simulated rainfall, the stubble retained plots showed significantly less runoff and soil loss than the conventionally tilled plots. Improvements in soil structure (bulk density, soil porosity, and water infiltration) were also associated with no till plots.

The Queensland Department of Natural Resources (DNR) (1995) investigated Brigalow scrub for runoff and erosion under alternative crop/pasture management systems. Using computer simulation studies based on detailed studies at key sites, the conclusion was that maintaining pasture or crop cover above 40% was necessary to protect soil against erosion losses.

Similar results have been reported in southern Australia. Malinda (1995) reported the results of a 10-year experiment at Tarlee, 70km north of Adelaide, using 3 levels of stubble retention and 4 types of tillage. This was for a red-brown earth. Using a rainfall simulator the experimental results indicated that increasing average stubble retention decreased runoff and soil loss linearly.

Lovett (2003) quoted Dr David Freebairn regarding substantial reductions in erosion and soil loss brought about by the widespread adoption of conservation farming. A paddock of 6% slope with no stubble cover over summer might experience soil losses through erosion of up to 30 t/ha. Under conservation farming with stubble cover of 60 to 70% the soil loss falls to 3 t/ha. Freebairn commented that ‘Australian farmers aren’t doing enough to tell the world about the positive and substantial things they are doing for the environment’.

If there is an average of 963, 000 ha total area cropped over the last 6 years in the 7 LGAs of Table 3.2.1.10, and if 71% of the cropping land in 2000-01 was prepared by no cultivation or minimum tillage (Figure 3), then there is about 683, 700 ha of crop land prepared annually using CFRT. If 27 t/ha of soil is saved from erosion (according to Freebairn’s figures), then 18.5 million tonnes of soil are saved each year by this technology in these areas of northern NSW. There is a major environmental soil benefit from the switch to CFRT management.

These new technologies have allowed crop production to be freer from potential problems or losses, hence leading to improved financial returns. There is less farm expenditure on fuel and oils associated with greater use of chemical herbicides. The 2003 Grains Industry Performance and Outlook Report by ABARE (Hooper *et al*. 2003) reported that crop and pasture chemicals costs were on average the second largest farm cost item across Australia (after fertiliser costs). The proportion of farm costs spent on fertilisers averaged at 17%, with expenditure on crop and pasture chemicals varying from 12% in WA to 8% of farm costs in NSW and Queensland. ‘Grains farms with relatively higher expenditures on crop chemicals have lower expenditure on fuels and oil because of reduced cultivation.’ (Hooper *et al*. 2003).

The main weed management challenges associated with new farming systems have been outlined by Adkins and Walker (2000). Environmental concerns include the fate of persistent herbicides used for weed control, a potential shift in the spectrum of weed species and the development of herbicide resistant weeds. The use of herbicides which provide weed control beyond the current crop or fallow is an integral part of CFRT systems. There is a danger that the residues from such chemicals (eg atrazine and chlorsulfuron) may be transported by erosion into streams or by deep drainage into groundwater. Ferris *et al*. (1989) studied atrazine used in grain sorghum in northern NSW. Walker and Robinson (1996) found that the likelihood of chlorsulfuron persistence was related to soil type and climate (temperature).

The development of herbicide resistance by weed species is also of concern. The increased importance of herbicides for weed control may be associated with an increased risk of resistance, especially to glyphosate which is relatively cheap, effective and widely used. Jennings (2003) has reported on a pre-emptive coordinated action to minimise development of weed resistance to glyphosate in Australia.

2.5.3 Social outcomes

Socially the populations in rural communities and country towns have been under pressure due to a variety of factors. Improved transport and economies of size for rural service providers have meant that some smaller centres may have declined in population and services provided. This depends on whether there are other major industries (eg mining, forestry) in the local area. The overall economic context in Australia (a small open economy with low levels of protection and trading into world markets with little market power) means that agricultural producers and industries are under pressure from price fluctuations. The ability of new farming technologies to offset these pressures and maintain profits has been a major means by which farmers can survive economically and therefore for social communities and infrastructure to be maintained.

3. Defining the 'With' and 'Without' Scenarios

Economic evaluations require the outcomes of RD&E to be represented in financial terms, and the net benefits to be calculated as a comparison of the 'with adoption' versus 'without adoption' scenarios. These net benefits are then compared to the RD&E costs allowing financial appraisal measures to be calculated.

The approach to calculation of net benefits required consideration within a farming system/crop sequence framework. As discussed in section 2.1 the initial soil degradation problems needed to be addressed by considering the whole farming system, because of the interdependencies between farm management decisions over the whole crop sequence, crop production outputs and natural resource outcomes.

3.1 Representative farm models in northern NSW

Scott and Farquharson (2004) described the northern cropping region of NSW and identified several crop-based farming systems within the region. They developed a number of whole-farm models based on sub-regional characteristics and the related farming systems. The models include agronomic and agricultural production characteristics as technical parameters in a transparent financial framework, and use a spreadsheet format to allow analysis of alternative scenarios.

The summer-dominant rainfall pattern in the region allows both winter and summer cropping. Soil types associated with successful cropping comprise the fertile clays and loams. Average precipitation levels from less than 500 mm to more than 700 mm rainfall per annum occur in the region, which comprises the cropping areas of the slopes and plains. Figure 3.1 shows the region with soil and rainfall characteristics. Soils were amalgamated into five broad soil groups (clays, loams, massive earths, sands and duplex soils) based on suitability for agricultural and cropping activities. The clay and loam soil amalgamations are most favoured for cropping.

Scott and Farquharson (2004) developed representative farms within the sub regions to test the impact of new technologies. Seven whole-farm budgets were constructed (one for each of the sub regions) which incorporated crop rotations, and included capital investment in land and machinery, as well as variable and fixed (overhead) costs allowing an estimation of rates of return to capital invested. The budgets show profit measures such as net farm income and rate of return on assets and operating labour. But they are not optimising models, being deterministic and static and not accounting for the transition period between one rotation system and another.

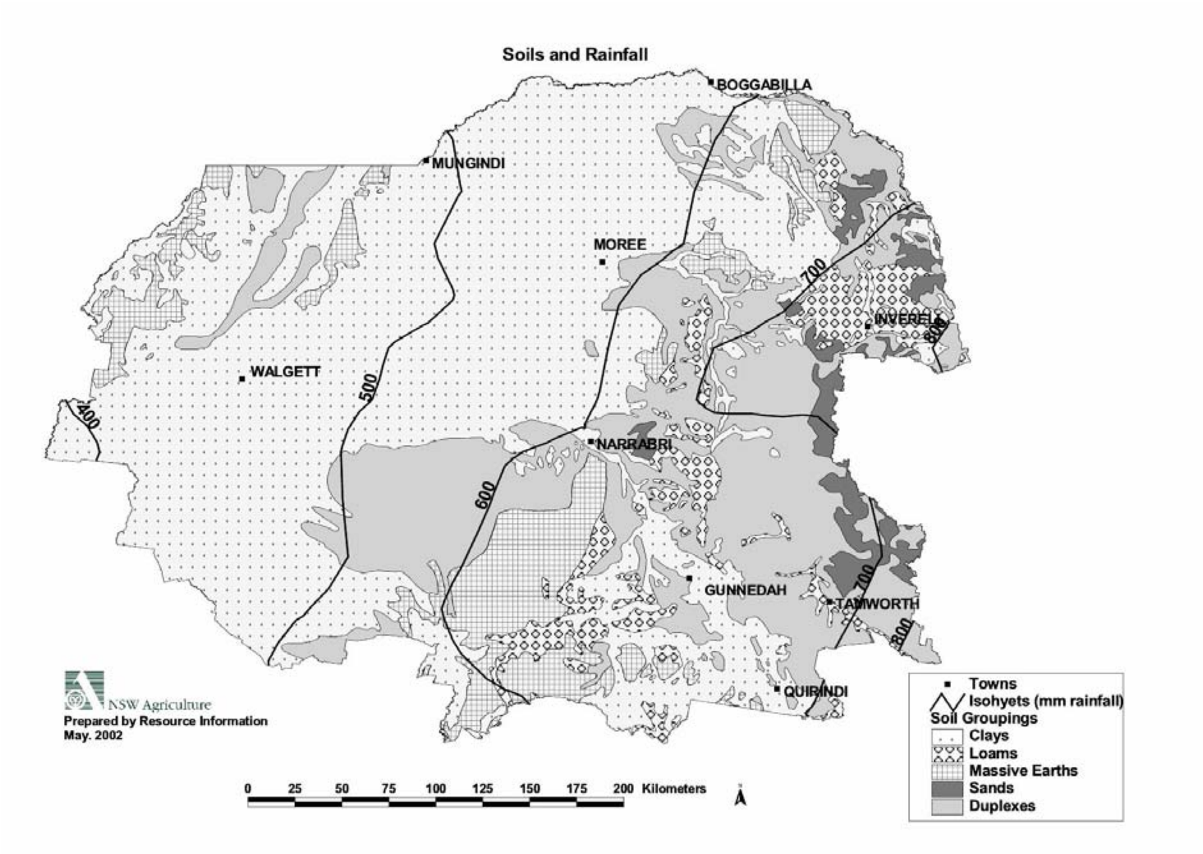

Figure 3.1. Soil and rainfall characteristics, the northern cropping region

The models were designed for comparing different rotations and this is the purpose to which they have been put in this analysis. The whole-farm models have been adapted to represent crop sequence budgets in seven LGAs to match ABS statistical information. These LGAs are also the basis for NSW Agriculture agronomy districts, see Figure 3.2. The districts are Walgett, Coonamble, Moree Plains, Yallaroi, Inverell, Narrabri and a combined district of Gunnedah and Quirindi.

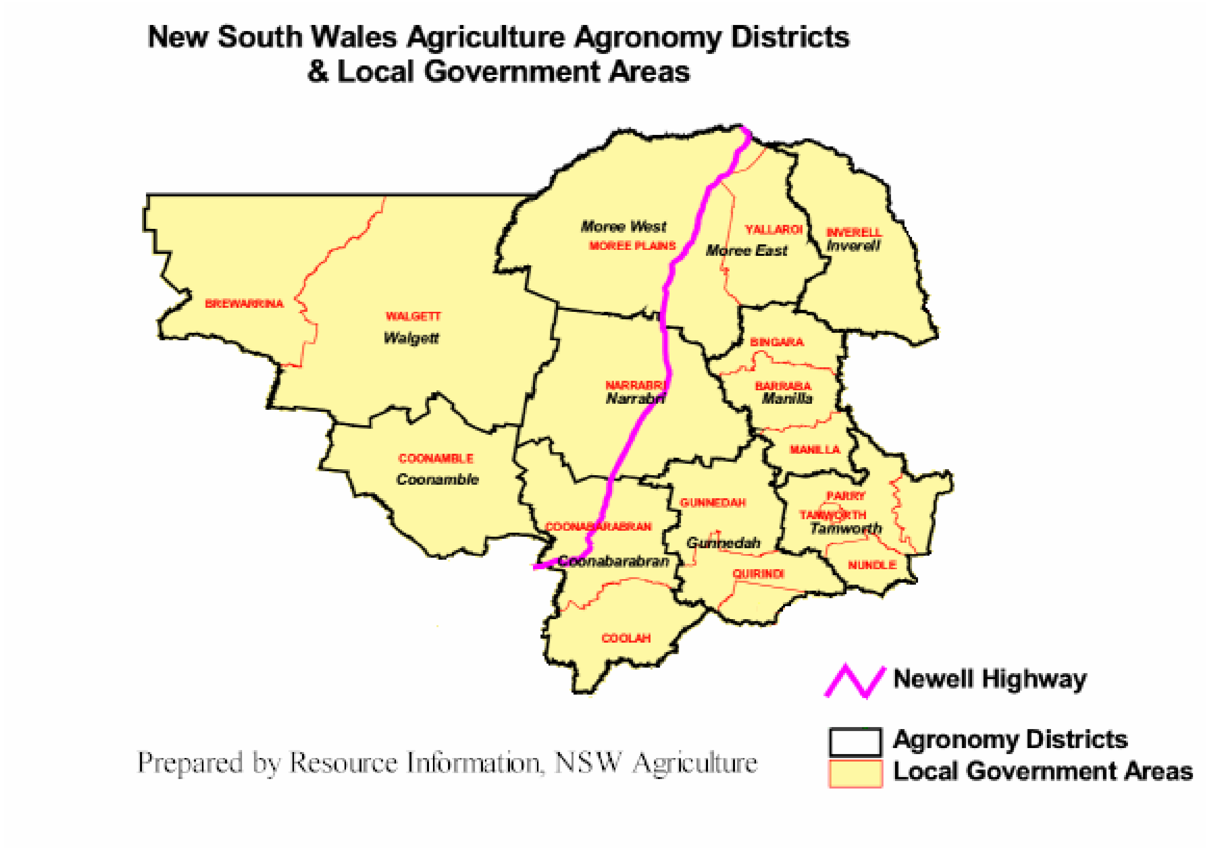

Figure 3.2. Cropping sub regions in northern NSW

The whole-farm models in each sub region developed by Scott and Farquharson (2004) were adapted to represent typical crop rotations for the 'with' case by incorporating no till and reduced or minimum tillage practices as well as crop rotations. The yields and costs associated with these practices documented by Scott and Farquharson (2004) were based on experimental results, on-farm trials and District Agronomist or agricultural consultant sources. Similarly the 'without' crop budgets were developed using assumptions of yields and input costs from typical conventional cultivation wheat-only rotations.

3.2 Farm level economic impacts

At the farm level, crop enterprise budgets were developed for crop sequences under different tillage methods within each sub region. The average budget figures were used in the whole-farm models to generate benefit estimates. The comparison of economic returns from a large number of alternative crop/tillage systems have been catalogued by Kaval (2004).

3.2.1 Developing alternative crop rotations

The 'with' (no till and reduced tillage) and 'without' (conventional cultivation) scenarios were defined in terms of crop rotations within each LGA. The differences in crop rotations can be seen in the types of crops used, the crop yields, and the enterprise variable costs. In each year two crops are possible (summer and winter), and fallows are important parts of the rotation. The typical rotations for each case in each LGA are shown in Table 3.1.

Table 3.1. Crop rotations for no till and conventional farms by LGA

	Year 1		*Year 2*		*Year 3*		*Year 4*		*Year 5*	
No/reduced-tillage	Sum	Win	Sum	Win	Sum	Win	Sum	Win	Sum	Win
Walgett	Fall	Wht	Fall	Ch	Fall	Wht	Fall	Fall	Sorg	Fall
Coonamble	Fall	Wht	Fall	Ch	Fall	Wht	Fall	Fall	Sorg	Fall
Moree Plains	Fall	Wht	Fall	Barl	Fall	Fall	Sorg	Cp		
Yallaroi	Fall	Wht	Fall	Barl	Fall	Fall	Sorg	Cp		
Inverell	Fall	Wht	Fall	Wht	Fall	Soyb	Fall	Fall	Sorg	Fall
Narrabri	Fall	Wht	Fall	Barl	Fall	Fall	Sorg	Cp		
Gunn/Quirindi	Sorg	Fall	Sorg	Wht	Fall	Fall	Sorg	Fall		
Conventional										
Walgett	Fall	Wht	Fall	Wht	Fall	Barl				
Coonamble	Fall	Wht	Fall	Wht	Fall	Barl				
Moree Plains	Fall	Wht	Fall	Barl	Fall	Fall	Sorg	Fall		
Yallaroi	Fall	Wht	Fall	Barl	Fall	Fall	Sorg	Fall		
Inverell	Fall	Wht	Fall	Wht	Fall	Barl				
Narrabri	Fall	Wht	Fall	Barl	Fall	Fall	Sorg	Fall		
Gunn/Quir Nth	Fall	Wht	Fall	Wht	Fall	Barl				
Gunn/Quir Sth	Fall	Wht	Fall	Wht	Fall	Barl				

Wht wheat, Fall fallow, Sorg sorghum, Cp chickpea, Soyb soybeans, Barl barley

Crop yield and wheat protein content assumptions used in each rotation are shown in Table 3.2. These figures are based on the best information available for typical outputs in these situations. There are substantial differences in these figures between the no till and conventional rotations. For reduced tillage, it was assumed the rotations would be the same as no till with the same wheat protein levels but with 10% lower yields.

Crop prices used are shown in Table 3.3. The associated figures for variable costs and gross margins (GM) are shown in Table 3.4. The variable costs associated with fallows have been estimated based on the type of management used. Conventional cultivation relies on soil tillage for weed control, but this has adverse effects on moisture storage in the soil profile and erosion risk.

In the no till case sprays are substituted for tillage with the soil moisture and erosion risks improved, however the fallow costs may be increased. For the reduced tillage budgets it was assumed the same costs would be used as for no till, but with a cultivation before sowing as well to prepare a seedbed, this added $8/ha to fallow costs.

Table 3.2 Crop yields and protein for no till and conventional farms by LGA (a)

	Year 1		*Year 2*		*Year 3*		*Year 4*		*Year 5*	
No till	Sum	Win	Su	Win	Su	Win	Sum	Wi	Sum	Win
Walgett Yld		2.7		1.1		2.2			1.8	
Protein		14%				14%				
Coonamble Yl		2.7		1.1		2.2			1.8	
Protein		14%				14%				
Moree Pla Yld		2.4		2.7			2.0	1.2		
Protein		13%								
Yallaroi Yld		3.0		3.5			4.5	1.5		
Protein		12%								
Inverell Yld		2.5		2.5		2.0			4.0	
Protein		10.5%		10.5%						
Narrabri Yld		2.75		3.25			4.25	1.3		
Protein		12%								
Gunn/Qu Yld	4.0		4.5	2.5			5.0			
Protein				10%						
Conventional										
Walgett Yld		2.4		1.5		1.7				
Protein		12%		12%						
Coonamble Yl		1.2		1.2		1.5				
Protein		12%		12%						
Moree Pla Yld		2.8		2.5			2.0			
Protein		12%								
Yallaroi Yld		4.0		3.0			3.0			
Protein		12%								
Inverell Yld		2.2		2.2		2.5				
Protein		12%		12%						
Narrabri Yld		3.8		2.8			2.8			
Protein		12%		12%						
G/Quir N Yld		2.7		2.7		3.0				
Protein		10%		10%						
G/Quir S Yld		3.0			4.5					
Protein		10%								

(a) Yields in t/ha, protein in percent

Table 3.3. On-farm crop prices

Prices	$/tonne
Wheat 14%	200
Wheat 13%	188
Wheat 12%	150
Wheat 10%	144
Feed Wheat	117
Barley	106
Chickpeas	385
Sorghum	130
Soybeans	350

Table 3.4. Crop variable costs and gross margin for no till and conventional farms by LGA (a)

	Year 1		*Year 2*		*Year 3*		*Year 4*		*Year 5*	
No till	Sum	Win	Su	Win	Su	Win	Sum	Wi	Sum	Win
Walgett VC	35	103	35	237	35	127	35	33	96	33
GM	-35	437	-35	186	-35	313	-35	-33	137	-33
Coonamble VC	35	150	35	240	35	150	35	33	100	33
GM	-35	390	-35	183	-35	290	-35	-33	133	-33
Moree Pla VC	52	100	52	115	52	40	122	320		
GM	-52	351	-52	171	-52	-40	138	142		
Yallaroi VC	37	149	37	211	37	33	182	321		
GM	-37	300	-37	159	-37	-33	401	257		
Inverell VC	22	128	22	128	22	211	22	37	246	37
GM	-22	246	-22	246	-22	48	-22	-37	272	-37
Narrabri VC	37	149	37	211	37	33	240	320		
GM	-37	263	-37	133	-37	-33	278	180		
Gdh/Quir VC	244	36	244	184	62	33	244	33		
GM	274	-36	339	190	-62	-33	404	-33		
Conventional										
Walgett VC	28	148	28	148	28	108	28	19		
GM	-28	211	-28	76	-28	72	-28	-19		
Coonamble VC	28	115	28	115	28	103				
GM	-28	65	-28	65	-28	56				
Moree Pla VC	28	106	28	116	28	24	123	24		
GM	-28	421	-28	148	-28	-24	136	-24		
Yallaroi VC	40	168	40	202	39	23	159	23		
GM	-40	431	-40	115	-39	-23	230	-23		
Inverell VC	40	166	40	166	40	195				
GM	-40	163	-40	163	-40	69				
Narrabri VC	40	168	40	202	40	24	159	24		
GM	-40	401	-40	95	-40	-24	204	-24		
G/Quir N VC	40	156	40	156	40	225				
GM	-40	234	-40	234	-40	92				
G/Quir S VC	40	156	40	24	236	24				
GM	-40	277	-40	-24	347	-24				

(a) All figures $/ha

The effects of these parameters on GM over the whole crop sequence and per year are shown in Table 3.5. The difference between average GM for no till and reduced tillage versus the conventional systems in each agronomy district is substantial. The size of these advantages has been verified by analysis of farm trial results conducted by NSW Agriculture at locations in Walgett and Warialda. These are potential benefits which should be representative of what happens on farms. However, the analysis is a normative analysis (what should be occurring generally), since detailed survey data of enterprise differences between types of crop production systems are not available.

Table 3.5. Mean improvement of no till and reduced tillage gross margins over conventional farms by LGA (a)

	Gross margin Total	Av/year	*Improvement on conventional*
Conventional			
Walgett	230	58	
Coonamble	102	34	
Moree Plains	575	144	
Yallaroi	613	153	
Inverell	276	92	
Narrabri	535	134	
Gunn/Quir Nth	440	147	
Gunn/Quir Sth	497	166	
No till			
Walgett	890	178	120
Coonamble	789	158	124
Moree Plains	894	223	80
Yallaroi	1089	272	90
Inverell	651	130	38
Narrabri	887	222	61
Gunn/Quirindi	1043	261	114
Reduced tillage			
Walgett	678	136	78
Coonamble	602	120	86
Moree Plains	756	189	45
Yallaroi	743	186	32
Inverell	444	89	-3
Narrabri	569	142	9
Gunn/Quirindi	852	206	59

(a) All figures $/ha/year

Results from past research projects have shown that returns of the magnitude shown in Table 3.5 are achievable. Table 3.6 shows one set of results from the Yallaroi LGA from a past project comparing tillage and crop rotation systems. Crop prices used were the same as in Table 3.3.

Whole farm budgeting exercises have also shown that once implemented, a no till system can significantly improve profitability. The budgets are deterministic and static, similar to a linear programming model, in that the selected rotation crops and fallow periods are distributed proportionally across the cropping area. Capital investment in land and machinery is incorporated, as well as variable and fixed (overhead) costs and an estimation of rates of return to capital invested (Scott and Farquharson 2004). Table 3.7 shows some results for the Walgett and Yallaroi local government areas using the rotations and prices indicated above, with a four-wheel drive 231 engine kW tractor used for conventional tillage and a 200 engine kW tractor used for no till. A substantial improvement in return to capital is apparent from using no till methods.

Table 3.6. Gross margins results from GRDC/NSW Agriculture DAN23 project

	Croppa Creek, 1993-1998		
No till ('with' scenario)	Mean Costs $/ha	Mean GM $/ha	Extra GM $/ha over SB wheat
Chickpea/Wheat	272	212	168
Chickpea/Wheat	319	182	139
Barley/Chickpea/Wheat	247	113	69
Barley/Chickpea/Wheat	351	104	61
Stubble Burnt ('Without' scenario)			
Continuous Wheat	203	44	
	Warialda 1993-1999		
No till ('with' scenario)	Mean Costs $/ha	Mean GM $/ha	Extra GM $/ha over SB wheat
Chickpea/Wheat	255	419	284
Chickpea/Wheat	304	390	255
Barley/Chickpea/Wheat	222	418	283
Barley/Chickpea/Wheat	359	355	220
Stubble Burnt ('Without' scenario)			
Continuous Wheat	190	135	

Table 3.7. Whole-farm budget results

Return on Assets	**Conventional**	**No till**
Walgett/Western Clay	1.7%	5.3%
Yallaroi/Inner East	2.3%	5.9%

Parameters for the Walgett budget included a farm area of 6,080 hectares with 20% under crop, an asset value of $3.8 million with 90% equity, farm overhead costs of $130,000 and operating costs (interest, loan repayments) of $164,000. Parameters for the Yallaroi budget included a farm area of 1,660 hectares with 53% under crop, an asset value of $2.5 million with 84% equity, farm overhead costs of $130,000 and operating costs (interest, loan repayments) of $172,000.

3.3 Industry level adoption

In this section evidence is presented for usage of CFRT practices within the northern cropping region and for LGAs within that region. Estimates of patterns of changed usage of these practices over time are then presented and justified.

3.3.1 Historical evidence and trends

ABS agricultural census figures for the late 1990s indicate a relatively large proportion of crop areas in northern NSW grown under zero till or reduced till systems. Table 3.8 shows a drop in the area under no till in 1996. This is likely to have been due to seasonal and crop disease conditions, since stubble burning remains a disease control option after a wet season for cereal diseases such as rusts and yellow spot (J. Kneipp, pers. comm. 2003).

The NSW Grains Report for 29 November 1996 (NSW Agriculture 2003) reported that the winter crop harvest was well above the long term average, with a mild, cool spring. It was also noted that disease outbreaks were common during that season, and that a wide range of wheat diseases had reduced potential yield to varying degrees. Losses due to leaf and root diseases such as crown rot and take-all were noted. Barley yield losses were also observed due to leaf and root disease infections. The NSW Grains Report for 16 May 1997 mentioned that stubble burning was carried out over a wide area after the 1996 harvest but did not state reasons. Additional to carry-over disease concerns, heavy stubble from the 1996 winter crop may have been a hindrance to sowing of the 1997 winter crop, given that based on the 1995 ABS stubble treatment figures, only a small proportion of growers would have had no till/direct drill equipment suitable for seeding into heavy crop stubble.

Table 3.8. Crop stubble treatment operations and land preparation in northern NSW

	1995	1996	2000
Stubble treatment			
No till	22%	10%	22%
Mulched	11%	17%	11%
Ploughed, burnt or other	67%	74%	58%
Baled or grazed	nc	nc	8%
Preparation treatment			
No cultivation (except sowing)		8%	24%
1 or 2 cultivations (before sowing)		48%	47%
Other cultivation		43%	29%

Source: ABS Agricultural census and surveys for Walgett, Coonamble, Moree Plains, Yallaroi, Narrabri, Inverell, Gunnedah and Quirindi local government areas; nc = not collected

Farm surveys conducted by ABARE also focused on crop establishment practices in the 1990s (ABARE 1998 and 2000). Crop areas sown by method of land preparation in 1995-96 and 1998-99 are shown in Tables 3.9 and 3.10. These tables also include information from central NSW and central Queensland, provided to show crop methods in a broader area. Average areas per farm were used to derive population estimates of areas sown by tillage method (1995-96) and tillage method x stubble treatment (1998-99). The averages per farm figures imply that all methods were used on any farm; this is an artefact of the averaging process and unlikely to be observed in practice. However, the method is valuable in the aggregation process which provides information for analyses such as this.

The ABARE 1995-96 figures for the area sown in northern NSW by direct drill were estimated to be 14% and 12% in the north-west and north-east areas respectively. This compares with the 8-10% ABS census estimates in Table 3.8. The ABARE minimum tillage survey estimates of 48% and 35% for north-west and north-east NSW and Queensland areas respectively are close to the ABS census estimate of 48% in Table 3.8. Traditional cultivation areas from Table 3.9 (37% and 50%) compare with 43% from the ABS census in Table 3.8. Overall there appears to be reasonable similarity in these 1995-96 estimates from the two sources.

For 1998-99 (Table 3.10) the population estimates of areas sown using direct drill were 35% and 36% in north-west NSW/south-west Queensland and north-east

NSW/south-east Queensland respectively. These proportions are much higher than in central NSW and central Queensland. In comparison, the Table 3.8 figures for 2000 are lower (24% used no cultivation). The total minimum tillage figures in Table 3.2.1.11 for 1998-99 (38 and 34%) compare with 47% in 2000 from Table 3.8. Traditional cultivation in 1998-99 (27 and 29%) was similar to the 2000 figure of 29% in Table 3.8. The general agreement on tillage trends from the ABS and ABARE sources provide confidence in the time series of figures that can be used for adoption of CFRT methods in this evaluation.

Table 3.9. Crop area sown, by method of land preparation: 1995-96

Item	Unit	Region			
		NW NSW SW QLD	NE NSW SE QLD	NSW CENTRAL	QLD CENTRAL
Population	no.	1215	4537	3523	447
Sample	no.	16	63	73	15
Average per farm					
Area sown to crops	ha	470	386	488	1233
Population estimate					
Area sown to crops	ha	571 191	1 752 489	1 719 078	550 401
Direct drill	ha	81 790	204 601	186 703	45 900
Minimum tillage	ha	276 116	620 153	539 325	134 843
Traditional	ha	213 285	872 842	993 049	369 657
Percentage area (a) using					
Direct drill	%	14	12	11	8
Minimum tillage	%	48	35	31	24
Traditional	%	37	50	58	67

Source: ABARE (2000), Table 3.25.
(a) Derived from the population estimate

Other information in Table 3.10 consists of stubble treatments in 1998-99. In aggregate it seems that stubble ploughed in or retained was 48% and 77% in north-west NSW/south-west Queensland and north-east NSW/south-east Queensland respectively. This is higher than the 33% of area estimated to have no till or stubble mulched in 2000 (Table 3.8). Similarly the estimated areas with stubble burnt, cut or grazed in 1998-99 (52% and 23% respectively) can be compared with the ABS estimate of 64% stubble ploughed, burnt, baled or grazed in 2000 (Table 3.8). There is less agreement between these figures from the different sources.

The figures in Tables 3.8 to 3.10 show that there are grain growers in the region who use no till or stubble mulch methods (in conjunction with alternative crop rotations and other management) and others who plough or burn stubble in fallows. The practices associated with CFRT involve stubble retention and reduced tillage, and so these farms were taken to represent the ‘with technology’ scenario. The farms which plough or burn stubble were used to represent the ‘without technology’ group.

The areas of dryland crop in each LGA are shown in Table 3.11. These include cereals, oilseeds and pulses. This information is the basis for the aggregation of benefits

Table 3.10. Crop area sown, by method of land preparation: 1998-99

Item	Unit	NW NSW SW QLD	NE NSW SE QLD	NSW CENTRAL	QLD CENTRAL
Population	no.	1131	3944	3620	464
Sample	no.	25	76	48	9
Average per farm					
Area sown to crops	ha	900	458	492	1022
Population estimate					
Area sown to crops	ha	1 017 674	1 804 940	1 781 188	474 524
Direct drill into stubble	ha	217 944	414 462	86 163	34 041
Direct drill, stubble burnt/cut/grazed	ha	136 964	235 033	125 986	5 433
Min Till, stubble ploughed	ha	84 599	472 826	234 595	177 726
Min Till, stubble burnt/cut/grazed	ha	299 263	151 825	334 878	35 991
Trad cult, stubble ploughed	ha	188 085	496 487	465 933	191 890
Traditional cultivation, stubble burnt/cut/grazed	ha	90 819	34 308	533 632	29 397
Percentage area (a) using					
Direct drill into stubble	%	21	23	5	7
Direct drill, stubble burnt/cut/grazed	%	14	13	7	1
Min Till, stubble ploughed	%	8	26	13	38
Min Till, stubble burnt/cut/grazed	%	29	8	19	8
Trad cult, stubble ploughed	%	19	28	26	40
Trad cult, stubble burn/cut/graze	%	9	2	30	6

Source: ABARE (2000), Table 3.23. (a) Derived from the population estimate.

Table 3.11. Historical crop areas by LGA

Crop Areas (ha)	Walgett	Coonamble	Moree Plains	Yallaroi	Inverell	Narrabri	Gunnedah + Quirindi	Total
1985	168,925	172,667	226,996	162,136	67,769	218,650	200,719	1,217,862
1986	161,045	145,348	378,388	169,574	74,401	242,730	227,690	1,399,176
1987	154,600	133,891	289,770	154,382	50,155	124,290	152,061	1,059,149
1988	149,144	133,160	410,546	181,201	61,436	229,408	238,020	1,402,915
1989	141,888	114,685	379,234	167,038	60,049	175,416	189,875	1,228,185
1990	136,117	110,334	398,899	173,313	49,669	201,201	194,126	1,263,659
1991	112,680	95,749	375,700	158,345	43,153	181,919	181,078	1,148,624
1992	98,960	95,516	330,401	149,832	36,626	151,995	171,492	1,034,822
1993	133,890	113,411	333,277	139,818	31,292	141,197	157,652	1,050,537
1994	84,160	69,268	338,317	138,968	34,310	129,001	140,877	934,901
1995	97,888	77,624	253,468	103,700	39,477	101,208	130,728	804,092
1996	247,477	145,980	511,948	155,566	56,234	202,835	187,453	1,507,492
1997	179,400	151,240	442,400	210,000	29,800	181,835	122,200	1,316,875
1998	148,540	131,720	266,830	176,400	24,370	108,780	107,080	963,720
1999	184,000	149,100	436,500	226,700	26,820	165,200	116,590	1,304,910
2000	145,000	128,700	257,040	93,040	20,800	83,400	114,500	842,480
2001	239,000	149,100	204,700	209,700	28,850	202,800	136,200	1,169,350
2002	9,500	8,600	21,650	71,800	5,920	35,000	25,700	178,170

Source: ABS, AIAST (1999a, b and c), NSW Grains Reports (NSW Agriculture 2003) calculated with the whole-farm budgets. The other piece of information required for the aggregation is the proportion of crop area using CFRT.

The information in Tables 2.1 and 3.8 is the basis for the adoption estimates. Information from Martin *et al*. (1988) indicated that adoption of these technologies began around 1985 in the eastern areas and a little later in the west of the region. This evidence of adoption for the whole region is shown in Figure 3.3. Estimates of adoption of no till and minimum till for the sub regions in 1985 (Inverell, Moree Plains, Yallaroi, Narrabri and Gunnedah) were obtained from the survey results. In the absence of any other information about adoption, linear interpolation was used to estimate the pattern of adoption from 1985 to 2002 for the sub regions (LGAs). This is shown in Figure 3.4. These figures were used in the benefit estimation process.

Two other comments can be made about the trends in Figure 3.4. First they have been discussed with some experienced industry observers (Jeff Esdaile, pers. comm.) who have verified the date of commencement. The second comment is that the levels of adoption in 2002 were still only of the order of 10 to 40% of the area cropped. Given the apparent advantages of these technologies and the efforts to promote them by many organisations, it seems surprising that the adoption figures are not higher.

The rationale for presenting different scenarios was that the research was aimed at development and adoption of no till, but in reality the adoption process involves reducing the number of tillage operations over time until a complete no till system is adopted. Some growers have partially adopted the system in terms of having reduced the number of fallow tillage operations from five or six to one or two. Figure 3.4 shows the data available on tillage practices from Martin *et al.* (1988) and ABS surveys. The 'preparation of cropping land' figures do show a trend towards reducing the number of tillage operations from 1996 to 2000-01 (the preparation of cropping land question was not asked in the 1995 survey).

3.3.2 Projected trends to 2020

An attempt at quantifying future benefits due to adoption of CFRT was also made by projecting the adoption trends to 2020. This was done by estimating the annual change in no till between 1985 and 2000, and applying that annual trend for each year until 2020. The results of this are shown in Figure 3.5 for the whole region. Data on tillage practices were available from Martin *et al.* (1988) and ABS Agricultural Census figures from 1995, 1996 and 2001. The average annual increase in no till per year was 1.4% of cropping area. The area under conventional till, baling or grazing has fallen fairly rapidly since the early 1980s. Reduced tillage area has also increased substantially since the early 1980s.

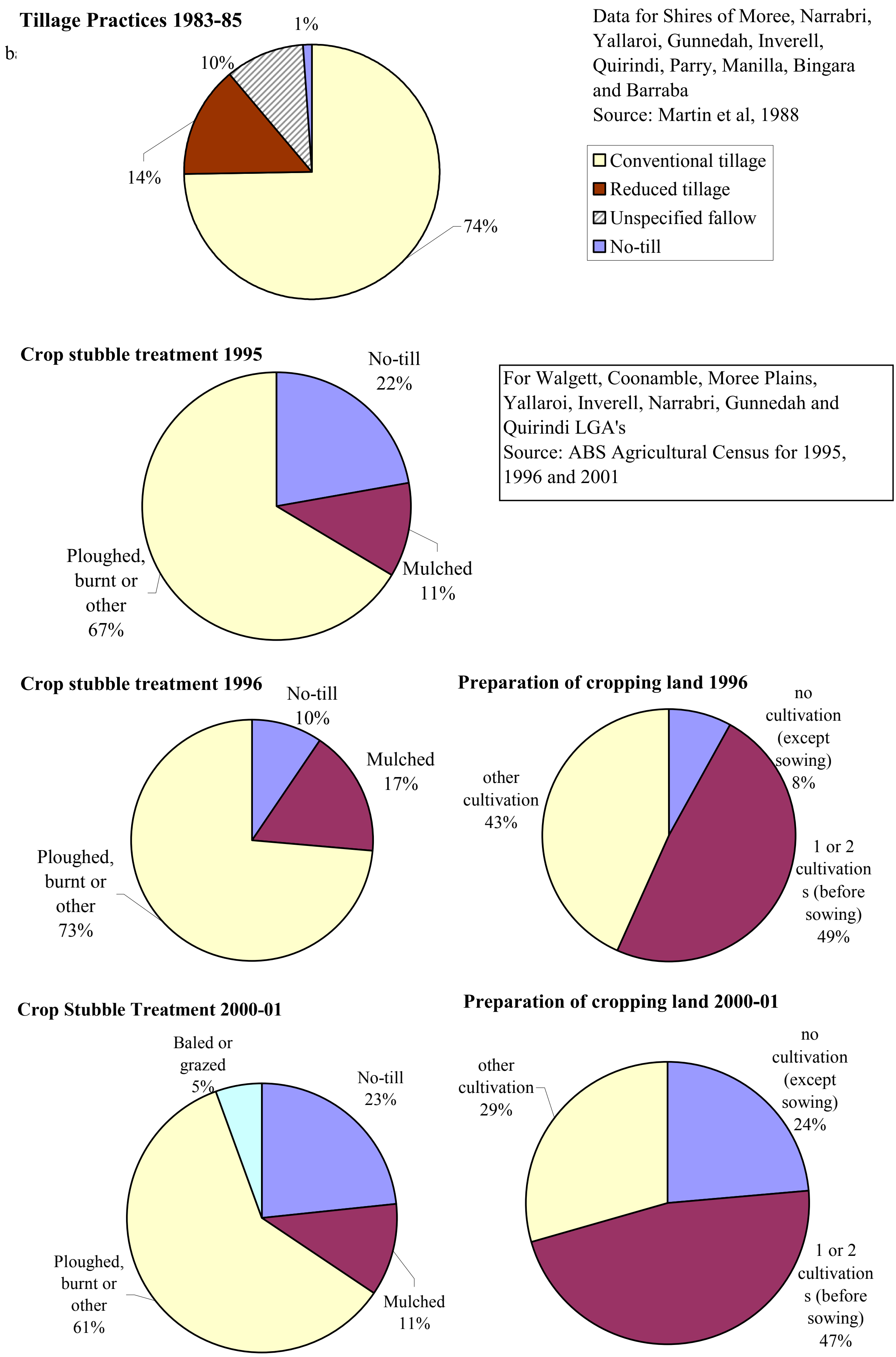

Figure 3.3 Adoption of no till in northern NSW

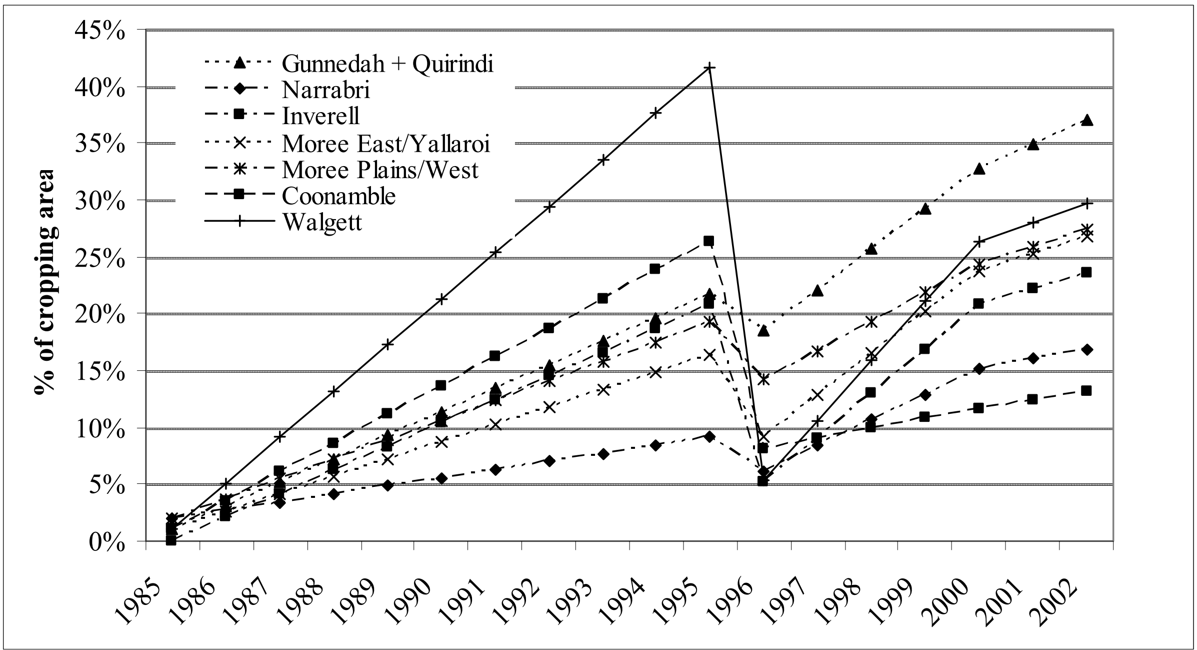

Figure 3.4 Adoption of no till technologies by LGA

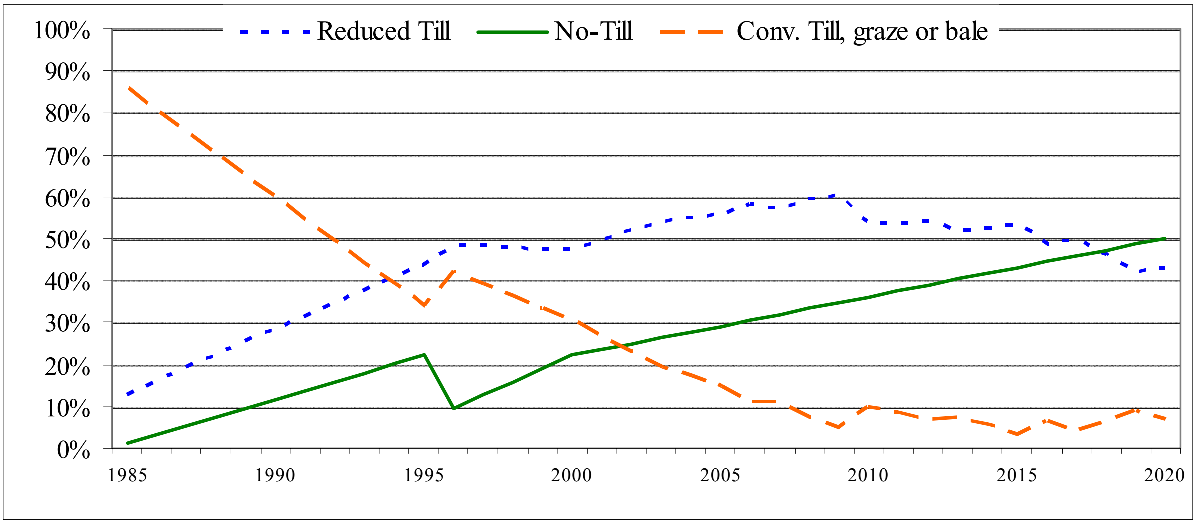

Figure 3.5 Actual and projected tillage adoption pattern for northern NSW

3.3.3 Apportioning benefits to NSW Agriculture

The last piece of information required is the share of total benefits which can be attributed to NSW Agriculture. As previously discussed, there are several organisations (both government and private) who have contributed to the CFRT program. Within NSW, NSW Agriculture has been the primary source of research input in a farming systems context and a substantial provider of advisory/extension activities. From shares of papers at proceedings and other conferences, and after discussions with industry observers (Jeff Esdaile, pers. comm.), a figure of 35% for benefits due to NSW Agriculture was used as the main determinant of benefit share. The estimates of returns to RD&E investments presented in section 5 are based on this figure. However, sensitivity analysis is also conducted to show the implications of varying the benefit share.

4. Benefit-Cost Analysis

4.1 Approach used in economic analysis

Annual benefits were estimated by first defining the 'with' (no-till or reduced till) and 'without' crop rotations for each of the seven districts. This process (described in detail in Chapter 3) gave a change in gross margin per hectare (from conventional tillage) for each district for both no-till and reduced till crop rotations. This figure for each district was then multiplied by the area under no-till (and reduced till) in each year (derived from the crop area in that year multiplied by the extent of adoption) and by the share of benefits attributable to NSW Agriculture. Adoption was assumed to start in 1985, when survey information first indicated a small proportion (1%) of the region had adopted the technology. Projected crop areas to 2020 were based on a long term average for each district. Similarly to the estimation of inputs (section 2.3), the benefits were adjusted for inflation using a GDP deflator and then compounded (using a rate of 4%) to bring the values to the 2002 equivalents. A discount rate of 4% was applied for values of benefits projected to 2020.

Our approach in effect estimates the annual benefits from research into conservation farming as the change in gross margin per hectare times the annual area under crop, times the extent of adoption, times the share of benefits attributable to NSW Agriculture. This simple approach provides a reasonable approximation to the gross benefits enjoyed by the industry. These industry benefits are shared between producers, processors and consumers of grain products according to demand and supply elasticities and the extent of competition in the processing and retailing sectors. If the grain handling and processing sector is competitive and if the demand for grain crops is highly elastic, meaning that there will be little change in price from the adoption of this technology, then most of the benefits will be captured by Australian grain growers.

This approach ignores any changes in area sown to crops because of the improvement in their profitability relative to other enterprises that are not part of the cropping rotation, such as livestock. Further, if the prices of grains do fall as a result of this technology then more of the benefits will be captured by consumers, some of whom are not residents of Australia; and growers who cannot or do not adopt the technology will lose as a result of the development of this technology.

The changes in crop sequences and mixes are not likely to have been at the expense of livestock enterprises, since the soil types in this northern region are not generally used for crop and livestock rotations. If sheep or cattle enterprises are conducted on northern farms they are generally situated on separate areas of the property and livestock infrastructure such as fences and watering points are removed from the cropped areas.

4.2 Time period for analysis

The analyses presented in this report for CFRT RD&E are for two time periods – first, from the beginning of the project funding up to 2002 and, second, extending the potential costs and benefits to 2020. There is likely to be continued influence on the cropping industry of this RD&E into the future, with Departmental advisory officers having part of their work programs allocated to promoting CFRT practices. However, the cut-off in 2020 was considered long enough for currently-planned activities to be considered.

The RD&E programs for CFRT within NSW Agriculture commenced in 1982 and have continued at least until 2002. Whether GRDC-funded research into farming systems projects is continued into the future is unknown and no assumptions about such funding are made. The financial analyses relate to the costs of NSW Agriculture program activities set against the industry benefits which can be claimed as due to these activities.

4.3 Valuing benefits to 2002

The initial evaluation was conducted in an *ex post* framework, i.e. no account of future benefits and costs beyond 2002 was attempted. This was due to the uncertainty of future adoption trends and crop areas. Given that most of the research in this program has been finished but the benefits will continue and possibly grow, the net benefits from NSW Agriculture's activities are likely to be underestimated in this scenario.

Against a total investment by NSW Agriculture of $25.6 million up to 2002, an adoption share of 35% gives a total benefit of $104.9 million, an NPV of $78.4 million, a BCR of 4.1:1 and an IRR of 45%. Due to the fluctuating nature of the benefit stream an internal rate of return calculation was not possible. The proportion of the contribution of NSW Agriculture to the benefits to the industry would have to be quite low at 8.5% for the investment in research and extension to break even and thus lower than 8.5% to show a loss. When the reduced tillage adoption is included a NPV of $205.4 million is achieved with a BCR of 9.0:1 and an IRR of 91%.

4.3.1 Sensitivity analysis

Step-by-step static sensitivity analyses were run on three key parameters - proportion of adoption attributed the NSW Agriculture, discount rate and variation in crop prices. Table 4.2 summarises the effects on BCR and NPV of varying each parameter in turn, for both no till adoption benefits only and also for no till plus reduced tillage adoption benefits.

The sensitivity analysis of the proportion of adoption due to NSW Agriculture's activities from 20% to 40% showed that the BCR varied between 2.3:1 and 4.6:1 for no till only, and between 5.2:1 and 10.3:1 for no till and reduced tillage. Similar analyses for discount rate and crop prices showed that the BCR was quite insensitive to the discount rate but was responsive to changes in crop prices to a similar extent as changes in the NSW Agriculture benefit proportion. In general the estimated financial results showed a healthy return to NSW taxpayers of funds invested in the CFRT program of activities.

The software package @RISK™ was used to simulate the effects of all three variations mentioned above (proportion of NSW Agriculture contribution, discount rate and crop prices). Simulations were run for 1000 iterations since this was adequate for the results to converge (less than 1.5% change in key statistics with each additional iteration). The results including the benefits from no till alone to 2002 are shown in Figure 4.1. Even with all three key parameters varying the BCR remained above one, with a mean of 3.8:1 with 90% of values falling between 2.7:1 and 4.8:1.

Table 4.1: Summary of Sensitivity Analysis

NSW Ag %	*BCR*	*NPV $m*	*Discount Rate*	*BCR*	*NPV $m*	*Crop prices*	*BCR*	*NPV $m*
			No till only to 2002					
20%	2.3:1	33.8	0%	4.3:1	61.9	-20%	2.9:1	49.8
35%	**4.1:1**	**78.4**	**4%**	**4.1:1**	**78.4**	**Base**	**4.1:1**	**78.4**
40%	4.6:1	93.2	7%	3.9:1	94.3	20%	5.2:1	106.9
			No till and reduced tillage to 2002					
20%	5.2:1	106.4	0%	9.4:1	157.6	-20%	5.9:1	125.2
35%	**9.0:1**	**205.4**	**4%**	**9.0:1**	**205.4**	**Base**	**9.0:1**	**205.4**
40%	10.3:1	238.4	7%	8.7:1	253.4	20%	12.2:1	285.6

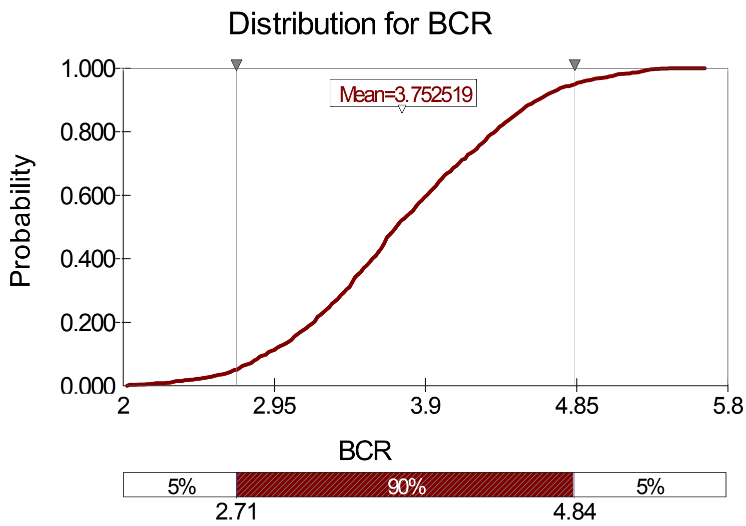

Figure 4.1. BCR distribution of no till benefits only to 2002

Figure 4.2 shows the BCR with all three variations, but includes the value of the reduced till areas as well. In this case the BCR has a mean of 8.3, with 90% of values between 5.8 and 10.9.

4.4 Valuing benefits to 2020

Projections of adoption of no till and reduced tillage to 2020 were used to estimate the benefits of continued adoption of these methods. Crop areas from 2004 to 2020 were estimated by eliciting the best fitting probability distribution from past crop area data for each of the seven districts using the software package @RISK™. These distributions were constrained so that the crop area for each district in each year

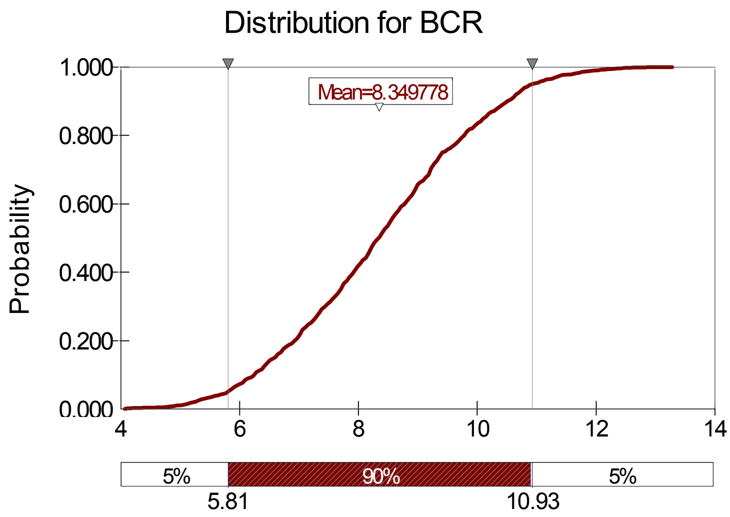

Figure 4.2. BCR distribution of no till and reduced tillage benefits to 2002

was between zero and the maximum crop area achieved since 1985. The crop area distributions, share of benefits attributed to NSW Agriculture (20%, 35% and 40%), discount rate (0%, 4% and 7%) and crop prices (80%, base and 120%) were used as inputs into a @RISK[TM] model (5000 iterations to ensure convergence of results) which reported the likely range of values of BCR and NPV.

Figure 4.3 shows the BCR results when the benefits of no till only are included in the analysis. The mean BCR was 11.4:1 with 90% of values falling between 8.0:1 and 15.0:1. The mean NPV was $302 million.

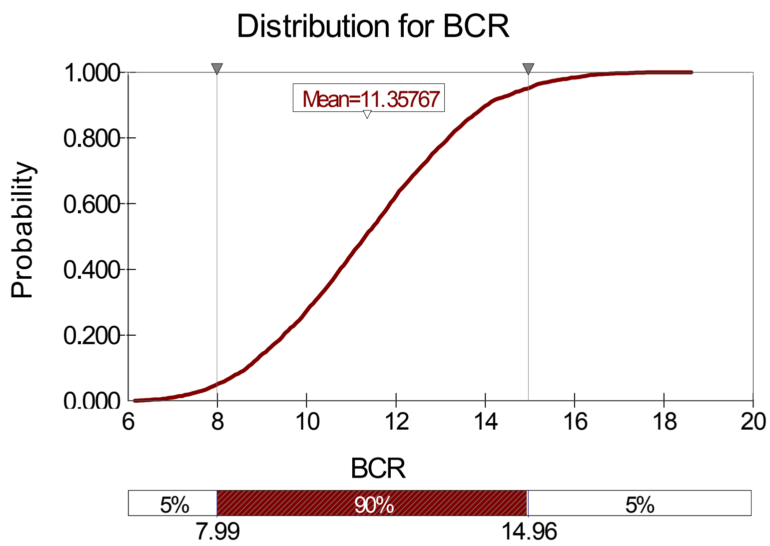

Figure 4.3. BCR distribution of no till benefits only to 2020

Figure 4.4 shows the BCR results when the benefits from reduced tillage are also included. The mean BCR was 20.5:1, with 90% of values falling between 14.0:1 and 27.3:1. The mean NPV was $568 million.

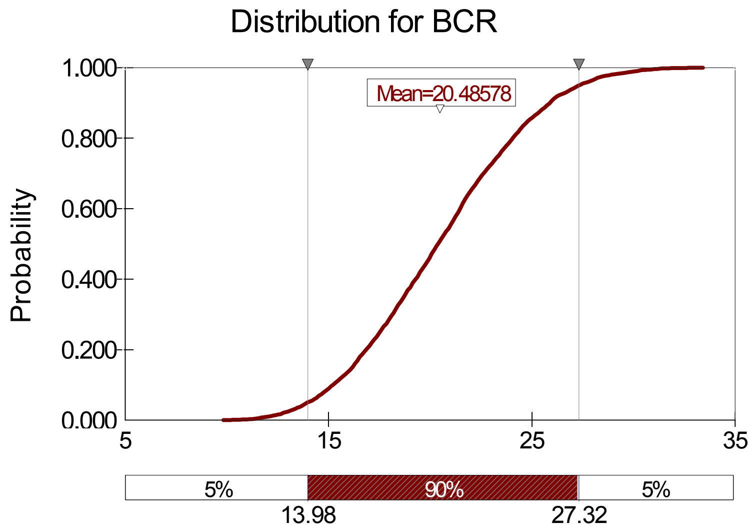

Figure 4.4. BCR distribution of no till and reduced tillage benefits to 2020

5. Conclusions

Dryland wheat production in northern NSW and southern Queensland is relatively young compared to some other agricultural industries (eg wool) in Australia. The RD&E programs that have developed in northern NSW have addressed specific issues that have arisen because of the interaction of climate, topography and soil types with crop production. Soil erosion was a particular initial concern that focused on tillage and stubble management, and which had a close link to soil moisture management and crop sowing rules. However, it became apparent that for industry to appropriate those benefits other management needed to be addressed, including the development and incorporation of new crops and cultivars into the crop rotations and addressing issues of weed, pest and disease control. The resulting CFRT RD&E programs have been conducted in a farming systems context.

When natural resources are used for an agricultural production purpose in an economic and social context, and problems or disturbances to the system occur, then these variations can have economic, environmental or social implications. The main focus of this analysis has been on the financial or economic effects of the new resource management technology. Possible environmental or social effects have not been quantified here due to the difficulties of undertaking those types of analyses and the restricted time frame.

This assessment of farm- and industry-level returns to these programs within NSW Agriculture has been undertaken with whole-farm models where the technology impacts have been evaluated with crop sequence budgets to capture farming system implications. The main conclusions (qualitative and quantitative) from this assessment are now presented.

5.1 Economic Impacts

In general the estimated financial results showed a healthy return to NSW taxpayers of funds invested in the CFRT program.

When benefits of no till only to 2002 were considered the results showed an estimated NPV of $78.4 million and a BCR of 4.1:1. When reduced tillage is included the NPV rises to $205.4 million with a BCR of 9.0:1. The results seem fairly robust, with a sensitivity analysis of the percent adoption due to NSW Agriculture's activities from 20% to 40% showed that the BCR varied from 2.3:1 to 4.6:1 and from 5.2:1 to 10.3:1 in each case. An analysis which varied share of adoption, discount rate and crop prices showed the BCR varying from 2.3:1 to 5.2:1 for no till and from 5.2:1 to 12.2:1 for no till plus reduced tillage.

Additional analysis with projected adoption figures to 2020 for no till only showed a mean BCR of 11.4:1 and an NPV of $302 million with 90% of BCR values falling between 7.9:1 and 14.9:1. Adding in the estimated benefits from reduced tillage to 2020 increased the estimated mean BCR to 20.5:1 with a mean NPV of $568 million.

5.2 Social and Environmental Impacts

There have been substantial economic benefits, but also more difficult to measure social and environmental benefits. The carryover social consequences from maintained or improved farm profitability include maintenance of vital local communities, although other social and regional initiatives have also been implemented for this purpose. Without the RD&E programs of NSW Agriculture and other agencies the slower growth in productivity is likely to have retarded farm and industry profitability, with concomitant effects on industry and community strength. It is impossible with the methods used here to quantify what would have occurred without the RD&E investments since other strategies or policies may have ensued, however the impacts of industry profitability are direct and important for farms, farm families and local communities.

It should be noted that the economic benefits are shared by growers, agribusiness and consumers in the form of increased income (and this increase in income has been measured in the estimated benefits) and have important social consequences for regional communities. In addition, the skills developed by grain growers have added to regional social capital (grower skills) resulting in greater capacity to respond to future challenges. The potential benefits of increased social capital were not fully quantified in this report. The carryover social impacts of adoption of CFRT practices (eg growth in local retail businesses) were considered to be outside the scope of this evaluation, but the value has been partially accounted for in the estimated financial value of the introduced CFRT systems.

Environmental benefits such as reduced soil erosion and resultant reduction in infrastructure and waterway siltation are likely to have been substantial. Using estimates of savings on erosion losses from other research, it is likely that up to 18 million tonnes of soil are saved annually from adoption of these technologies compared to conventional cultivation in northern NSW. The resultant reductions in infrastructure and waterway siltation costs are also likely to have been substantial, thus saving state and local government funds that would have been spent on damage remediation, for other purposes.

However, there may be some potential environmental detriments associated with persistence of herbicides in soil (and possible leaching into ground or surface water), a possible shift in the weed populations, and development of weed resistance to glyphosate.

5.3 Future Directions

The benefits of the CFRT program will continue to flow into the future, with growers still adopting the technology at the current time. The technology will continue to be refined, with controlled traffic cropping systems currently increasing in popularity. The issues of residual herbicides, changing weed distributions and potential weed resistance to herbicides are being addressed by current research projects.

The success of a multi-player co-ordinated research and extension effort such as this has lessons for future programs. In this case, there is a perception that adoption was successful due to all of the players delivering a consistent message regarding the benefits of reduced tillage and working on collaborative projects. There is substantial scope for further uptake of best management conservation farming techniques by farmers in northern NSW.

5.3.1 Issues in measuring and promoting the uptake of technology

When conducting evaluations of this sort, information on the uptake of the technology by farmers is a pre-requisite for benefit estimation. As is nearly always the case, such information was incomplete for this evaluation, so that some bold assumptions were required for the analysis. One recommendation from this report is that consideration be given to conducting more frequent surveys or data-gathering activities to enable assessments of how successful our RD&E activities have been and what are the constraints to ongoing adoption of conservation farming practices. Past examples have included Martin *et al*. (1988) and Hayman and Daniells (1997).

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