Review of the role and practices of stubble burning in New Zealand, including alternative options and possible improvements

A report prepared for the Canterbury Regional Council

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Executive summary

This technical report on stubble burning has been prepared for Environment Canterbury by an expert panel, led by the Foundation for Arable Research. The panel included research scientists, arable farmers, a policy advisor and a rural fire officer. The terms of reference for the panel were to assemble and review available information regarding the current role of stubble burning in the New Zealand arable industry and the feasibility of alternative crop residue management options. Additionally, the panel was tasked to identify any possible improvements to current stubble burning practice and recommend further work to fill any knowledge gaps related to stubble burning.

Arable farming in New Zealand, and especially in Canterbury, is unique in its production of diverse arable crops. These are grown in complex sequences (rotations), which are aimed at managing soil fertility, reducing weed, pest and disease problems, and spreading economic risk. Integration with livestock production is a traditional feature of Canterbury cropping farms.

Arable rotations include a wide range of seed crops (including grasses, clover, vegetables and pulses), cereal grains (including wheat, barley, oats and maize), and silage (from cereals and maize). Through these the sector contributes around $1bn per annum to gross domestic product. Half of the grass and clover seed produced is used within New Zealand for renewing pastures, thereby supporting the $24bn per annum pastoral sector. Exports of high value seed crops are increasing and currently exceed $170m per annum. A recent ‘Situation and Outlook for Primary Industries’ report by the Ministry for Primary Industries highlighted the importance of adjusting the mix of crops in New Zealand towards high value seed production to enable the sector to take advantage of these markets and remain a competitive land use (Anon 2012).

Stubble burning is the removal of crop residue after harvest via combustion in the field. It is regarded by many in the arable industry as an important tool for clearing away straw, chaff and other plant material prior to drilling the next crop. Although stubble burning may be practised at various points in the arable rotation, it is particularly valued for removal of cereal crop residue prior to drilling small-seeded, high value crops such as ryegrass and clover grown for seed. This is because it is a rapid, economic, and relatively environmentally benign way of dealing with crop residues without the need for removal of straw by baling or for stubble chopping followed by relatively intensive cultivation. It is conducive to preparation of a good seedbed. It is also an effective non-chemical means of weed management, which is especially important in the production of seed crops, and it can contribute to pest and disease control.

However, it is recognised that crop residues have a value, e.g. by returning nutrients to the soil following their decomposition or by providing feed for livestock, and as such, selection of the optimum management practice for this material in any given situation requires careful consideration of a wide range of factors. The principle alternatives to stubble burning for crop residue management are:

- Incorporating the residue via chopping and non-inversion cultivation (surface/top work);
- Incorporating the residue via chopping and ploughing (full-inversion cultivation);
- Baling and removing cut straw (may be followed by direct drilling or various cultivation methods);
- Retaining the crop residue on the soil surface and direct drilling through it.
Whilst each of these alternatives can match some of the advantages of stubble burning, none meets all of the prerequisites for sustainable rotations in New Zealand that include production of small-seeded crops as summarised below.

<table>
<thead>
<tr>
<th>Crop residue management options</th>
<th>Maximising soil and seedbed quality</th>
<th>Supporting sustainable weed management</th>
<th>Minimising cultivation intensity and fuel use</th>
<th>Enhancing farm system productivity</th>
<th>Reducing pest and disease problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burning residue</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>Incorporating residue via non-inversion cultivation</td>
<td>✔ ✔</td>
<td>✔</td>
<td>✔</td>
<td>✔ ✔ ✔</td>
<td>✔</td>
</tr>
<tr>
<td>Incorporating residue via ploughing</td>
<td>✔</td>
<td>✔ ✔ ✔</td>
<td>✔</td>
<td>✔ ✔ ✔</td>
<td>✔ ✔ ✔</td>
</tr>
<tr>
<td>Baling and removing cut straw</td>
<td>✔ ✔</td>
<td>✔</td>
<td>✔ ✔ ✔</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Retaining residue and direct drilling</td>
<td>✔ ✔ ✔</td>
<td>✔</td>
<td>✔ ✔ ✔</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

A detailed paired analysis of the multiple factors evaluated in preparation of this summary table is given in Appendix 5.

Stubble burning has been banned in some other countries and, as a consequence, alternative management options have been widely adopted. However, two important factors specific to the New Zealand situation would hinder a similar change in practice here.

- Firstly, the quantity of crop residue per hectare produced in New Zealand is large compared to many other countries, mainly due to the high yields achieved. This is particularly significant in cereal crops (wheat and barley), which frequently precede small-seeded crops in the rotation. The greater the quantity of crop residue, the bigger the challenge of establishing the following crop in its presence. Hence the strategic use of stubble burning in New Zealand to deal with the large amounts of residue produced in the cereal crops that generally precede small-seeded crops in the rotation.
- Secondly, production of these small seeded, high value crops makes a much more significant contribution to the economic sustainability of arable farming in New Zealand than in countries where stubble burning is not practised.

In addition, there has been a concerted effort by the arable industry to improve soil quality through adoption of reduced cultivation. This confers a wide range of benefits including improved soil structure, healthier soil ecosystems and reduced erosion risk. This movement has been aided by the strategic use of stubble burning to avoid the need for intense cultivation such as ploughing after cereal crops. The loss of stubble burning as a rotational management tool would put these soil quality gains at risk through the need for greater reliance on the plough.
Notwithstanding the importance of stubble burning as a rotational tool in New Zealand arable farming, the area of stubble being burned each year is falling for two main reasons. Firstly, the land area under production has decreased by around one fifth over the past 20 years (Appendix 3). Secondly, based on the sparse historic survey data available, there appears to be a trend amongst farmers to adopt other residue management practices in place of burning in some phases of the rotation (Section 1.3).

Regardless of the compelling evidence supporting the use of stubble burning as a rotational residue management tool in arable cropping, it is recognised that there are potential adverse effects. These are primarily smoke nuisance and the risk of fire escape, both of which can already be managed through a combination of legislation and regulation, and good management practice. Unfortunately, while these two potential adverse effects can be managed and minimised, the nature of stubble burning is such that the level of risk cannot be reduced to zero.

While in most cases, good management practice and the consistent enforcement of existing regulations seems to be sufficient to manage the risk of wild fire, there may be scope for farmers, and regional authorities to work together on further development of codes of good practice to reduce nuisance created by smoke discharge. Using the joint Federated Farmers and Ashburton District Council Crop Residues Burning Code of Practice (Appendix 6) as a template, this arrangement could be broadened to include further measures to reduce the instances of smoke nuisance and then expanded to other areas where arable production is significant.

During the course of this technical review, some important gaps in our knowledge of the impacts of different crop residue management options have become apparent. These include:

- Developing novel slug management approaches for situations where crop residues are partially or full retained.
- Investigating the long term impacts of different residue management techniques on:
  - Soil quality and processes;
  - Dynamics of weed grass populations;
  - Beneficial insects.
- Improving our knowledge of the variation in nutrient content of different crop residues i.e. the fertiliser replacement value.
- Modelling the potential impacts of changes in residue management on land use change.
- Measuring the amount of crop residue removed by baling in New Zealand.
### Glossary of terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adsorb</td>
<td>Where molecules or particles bind to a surface.</td>
</tr>
<tr>
<td>Agrichemical</td>
<td>A generic term for the various chemical products used in agriculture, including pesticides, herbicides and fungicides.</td>
</tr>
<tr>
<td>Agronomic</td>
<td>Farming practices relating to crop production and soil management.</td>
</tr>
<tr>
<td>Arable crops</td>
<td>In the context of this report, crops that are harvested using a combine harvester.</td>
</tr>
<tr>
<td>Back burning</td>
<td>A safe method of stubble burning where a fire break is created downwind (by burning) thereby depriving the main fire of fuel when it reaches this buffer zone.</td>
</tr>
<tr>
<td>Chaff</td>
<td>The protective casings of the seeds of cereal grain, or similar fine, dry, scaly plant material such as scaly parts of flowers, or finely chopped straw.</td>
</tr>
<tr>
<td>Crop residue</td>
<td>Plant material left on the soil surface after harvest including standing plant stems (usually cut by the combine harvester to within a few centimetres of the soil surface) and the straw and chaff.</td>
</tr>
<tr>
<td>Decomposition</td>
<td>A natural process carried out by invertebrates, fungi and bacteria of dead plant (or animal) tissue being rotted or broken down.</td>
</tr>
<tr>
<td>Discing</td>
<td>A form of non-inversion cultivation.</td>
</tr>
<tr>
<td>Fire break</td>
<td>A gap in vegetation or other combustible material that acts as a barrier to slow or stop the progress of a fire.</td>
</tr>
<tr>
<td>Full inversion</td>
<td>Where cultivation involves use of a plough to fully invert the soil at the surface.</td>
</tr>
<tr>
<td>incorporation</td>
<td></td>
</tr>
<tr>
<td>Grain crops</td>
<td>Grain crops are grown to produce grains for human/animal/industrial use.</td>
</tr>
<tr>
<td>Harvest index</td>
<td>The amount of grain yield divided by the amount of grain yield plus straw yield.</td>
</tr>
<tr>
<td>Hybrid seeds</td>
<td>Consistent, high quality, high value seeds produced by crossing specific parent seed-lines.</td>
</tr>
<tr>
<td>Land clearance</td>
<td>Removal of all unwanted plant material from the soil surface.</td>
</tr>
<tr>
<td>Non-inversion</td>
<td>Where soil cultivation is conducted using without full inversion of the soil e.g. using tines to mix the soil.</td>
</tr>
<tr>
<td>incorporation</td>
<td></td>
</tr>
<tr>
<td>Rotation</td>
<td>The practice of growing a series of different types of crops on the same area of land in sequential seasons.</td>
</tr>
<tr>
<td>Rotational ploughing</td>
<td>The practice of ploughing for cultivation between specific phases of a crop rotation.</td>
</tr>
<tr>
<td>Seed crops</td>
<td>Seed crops are grown to produce seed for multiplication and have high quality standards e.g. very low tolerance of weed seed contamination.</td>
</tr>
<tr>
<td>Silage</td>
<td>A form of preserved crop or pasture which can be fed to stock either as well as, or in lieu of, fresh pasture.</td>
</tr>
<tr>
<td>Stale seedbed</td>
<td>Where a seedbed is prepared and left fallow for a short period to allow weed seed germination prior to drilling the crop.</td>
</tr>
<tr>
<td>Straw chopper</td>
<td>The facility on a combine harvester for chopping straw into short sections.</td>
</tr>
<tr>
<td>Stubble</td>
<td>Usually only refers to the remaining cut stalks in the ground after grain or hay has been harvested and gathered, but in the context of this report also includes the crop residue component that is thershed through the combine harvester and returned to the paddock.</td>
</tr>
<tr>
<td>Stubble burning</td>
<td>Removal of crop residue left on the soil surface after harvest via combustion in the field.</td>
</tr>
<tr>
<td>Surface/top work</td>
<td>Cultivation by non-inversion mixing of soil close to the soil surface.</td>
</tr>
<tr>
<td>Swath</td>
<td>The row of cut plant material left after a combine harvester or mower has passed.</td>
</tr>
<tr>
<td>Tilth</td>
<td>The state of aggregation of a soil especially in relation to its suitability for crop growth.</td>
</tr>
<tr>
<td>Volunteers</td>
<td>Self-sown plants from previous crops which have become weeds in the current crop.</td>
</tr>
<tr>
<td>Wild fire</td>
<td>An uncontrolled fire in an area of combustible vegetation that occurs in the countryside.</td>
</tr>
</tbody>
</table>
Introduction

Arable cropping
Arable cropping in New Zealand is a $1bn per annum industry producing seeds, grains, peas, beans and forage for domestic and export markets. The sector covers around 125,000 hectares, including around 90,000 of arable crops in Canterbury, where seed and grain production is concentrated (based on Statistics New Zealand data). According to the results of a 2007 Statistics New Zealand survey of national arable production, by area, 88% of the wheat, 71% of barley, 51% of oats and 93% of herbage seed produced in New Zealand is grown in Canterbury. Maize dominates crop rotations in the North Island.

Arable cropping in Canterbury is characterised by complex sequences (rotations) of a wide range of different crops. Some of these crops, such as wheat and barley, are annual i.e. sown and harvested within a year. Others, such as herbage seed crops, may last for several years and be grazed as well as harvested for seed. Thus, arable crops can be part of a mixed farming system i.e. integrated with livestock production.

There are strong interdependencies between different crops on mixed cropping farms and each part of the rotation plays an important role in creating a resilient and economically sustainable production system. For example, high value, low volume herbage and hybrid vegetable seed production is only made possible because it fits well agronomically and economically within arable cropping rotations including lower value, higher volume cereal grain production.

Stubble burning, i.e. removal of crop residue after harvest via combustion in the field, can ease establishment of following crops and is highly valued as a non-chemical means of reducing weed, pest and disease pressure. It is frequently used as a rotational tool to manage crop residues prior to drilling small-seeded crops such as ryegrass and clover grown for seed. It can be especially useful following cereal crops, where high yields of grain are associated with substantial volumes of crop residue.

Significant regional differences exist in the extent to which stubble burning is practised across New Zealand. A 2011 survey indicated that around a third of South Island respondents burnt almost all their wheat stubble whereas less than 10% of North Island respondents did so (Fraser & Lawrence-Smith 2011). Removal of wheat stubble through burning is most prevalent in South Canterbury, where more than 80% of respondents reported burning at least half of their wheat stubble. Similar trends were reported for barley residue disposal.

Chapter 3 (Air Quality) of the Canterbury Natural Resources Regional Plan
Chapter 3 of the Canterbury Natural Resources Regional Plan (NRRP) notes that Canterbury generally has good air quality but that localised air quality issues exist (Anon 2011). Amongst these, the NRRP mentions that ‘Stubble burning in arable rural areas and vegetation clearance in the hill and high country by burning can also have adverse effects on amenity values and cause adverse health effects.’
Stubble burning in Canterbury is currently managed in the Air Plan through Policy AQL4: Restrictions on outdoor burning outside residential and living zoned areas. Rule AQL28 (Outdoor burning of standing crop residue or vegetative stubble) classifies outdoor burning of crop residue or vegetative stubble as a permitted activity subject to conditions. The rules states:

‘Burning of crop residue (stubble) is significant in Canterbury because approximately 60% of New Zealand’s arable crops are grown in the region. In terms of quantity of material burned, outdoor burning of residual crops in Canterbury is the dominant emission source. Approximately 1,000,000 tonnes¹ per year of crop “stubble” is burned, compared to only approximately 10,000 tonnes per year of vegetation from horticultural and “lifestyle farming” properties.

‘Despite the large mass of material burned, the adverse effects of stubble burning may often be less than those caused by other vegetation fires. This is because stubble burns generally occur during late summer and autumn when the material is dry, resulting in good combustion conditions and effective dispersal of contaminants. Further, because of the short term nature of stubble burning, it is considered that it can be undertaken in weather conditions that avoid significant adverse effects.

‘Adverse effects of stubble burning have never been quantified, although Environment Canterbury receives complaints about the adverse effects of stubble burning. Localised effects are highly likely and there is a potential for contribution to ambient air quality problems for Ashburton and some small rural towns of Canterbury. It is plausible that the use of good practice techniques will result in adverse health effects and nuisance effects being minimised. In the future, research may identify that tighter controls are necessary, especially if good practice does not occur. These regulatory controls may include distance limits as contained in Rule AQL29 and signage posted on public roads to ensure adverse effects of the discharge are avoided.

‘The alternatives to stubble burning are limited and have not gained widespread favour as yet. Alternatives to crop residue burning near sensitive activities are being advocated by Environment Canterbury.’

**Review of stubble burning**

As part of the NRRP review process, Environment Canterbury (ECan) initiated a review of current approaches to managing stubble burning. To inform this process, it was decided that the current role of stubble burning in land management in New Zealand, and the feasibility of future alternative agronomic interventions for achieving the same management goals, should be assessed.

ECan approached the Foundation for Arable Research (FAR) to undertake this technical review and, in consultation with ECan staff, a methodology was adopted based on peer review of available data by an expert panel. Details of the approach taken are given below.

**Objectives of the review**

1. To review the current role of stubble burning in land management across New Zealand, i.e. purpose and efficacy, with particular emphasis on Canterbury where the practice is most widespread.

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¹ This figure within Chapter 3 of the NRRP is not consistent with the findings of this report. Whilst around 1,000,000 tonnes of crop residue are produced each year, significantly less than half of this is burned.
2. To evaluate the feasibility of alternative land management practices that could deliver the same (or better) desirable agronomic outcomes associated with stubble burning.
3. To identify areas where current management of stubble burning could be altered to reduce any adverse impacts whilst maintaining efficacy.
4. To recommend any further work that is required to address any knowledge gaps identified in objectives (1), (2) and (3).

**Review panel members**

- Nick Poole (project chairman; FAR)
- Trish Fraser (research scientist, Plant and Food Research)
- Dave Grant (farmer and FAR Board member)
- Nick Hanson (policy advisor, Federated Farmers)
- Jim Orson (research scientist, NIAB, UK)
- Phil Rolston (research scientist, AgResearch)
- Jim Sim (United Wheat Growers Subsection Chairperson, Federated Farmers)
- Roger Williams (project facilitator; FAR)

In addition, Don Geddes, Principal Rural Fire Officer, Ashburton District Council was consulted for objective 3 in particular.

**Terms of reference for panel members**

- To assemble and review available data, related to their expertise and experience, prior to the first project workshop.
- To contribute to the first project workshop which addressed the key questions regarding:
  - Extent of stubble burning in New Zealand;
  - Rationale for use of this management option;
  - Alternative management options;
  - Possible improvements to stubble burning practice;
  - Gaps in knowledge.
- Following the first workshop to:
  - Gather and analyse further data as required;
  - Begin drafting report chapters as agreed at the workshop.
- To contribute to the second project workshop to integrate the draft report chapters and agree key findings and any recommendations.
- Following the second workshop, by email, to review and comment on drafts of the report.
- To hold a final workshop to collectively refine and finalise the report for submission to ECan.

**Industry consultation**
The panel also drew on the practical, grass roots experience represented in FAR’s six regional ‘Arable Research Groups’, which each consist of 10-15 leading arable farmers. This was achieved through face to face discussion with a selection of ARGs about the issues surrounding stubble burning. These discussions took place between the first and second workshops (4 April and 10 May, respectively) and were undertaken by Nick Pyke (FAR CEO), Nick Poole and Roger Williams.
1 Stubble burning in New Zealand

Key points

- Wheat, barley and oat residues are most commonly considered for burning.
- Across New Zealand, since 2008, c.124,000 ha of these crops have been grown annually, and c.40% of straw residues burned.
- The area of land growing arable crops has decreased by c.20% since 1990.
- Around 1m tonnes of cereal crop residue are produced each year but only around 40% of this is burned.
- Canterbury is home to c.70% of New Zealand’s arable crops, thus stubble burning is more commonly practised in Canterbury than other regions of New Zealand.
- New Zealand cereal crops produce more than double the residue as the same crops in Australia.
- Small seeded crops such as ryegrass and clover play a much more significant role in New Zealand crop rotations than in the UK, and are reliant on following burned cereal crop residues.

1.1 Quantity and distribution of crop residue produced in New Zealand

The main arable crops grown in New Zealand are wheat, barley, oats, maize, and seed crops including vegetables and herbage (e.g. ryegrass and clover). Residues of wheat, barley and oats are most commonly considered for burning by growers. Maize and seed crop residues are rarely burned (Fraser & Lawrence-Smith 2011) and are not therefore considered further in this report.

Significant quantities of crop residue are produced each year from wheat, barley and oats: using Statistics New Zealand data, it is estimated that nearly 1 million tonnes of crop residue were produced in New Zealand in 2012 (Table 1).

Table 1. Area of arable crops grown and quantity and percentage of residue produced in New Zealand in year ending 30th June 2012.

<table>
<thead>
<tr>
<th></th>
<th>Area grown (hectares)*</th>
<th>Quantity of straw produced (tonnes)**</th>
<th>Percentage of total straw produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>54,900</td>
<td>362,500</td>
<td>38</td>
</tr>
<tr>
<td>Barley</td>
<td>66,300</td>
<td>563,500</td>
<td>59</td>
</tr>
<tr>
<td>Oats</td>
<td>3,900</td>
<td>26,000</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>125,100</td>
<td>952,000</td>
<td>100</td>
</tr>
</tbody>
</table>

*Based on Statistics New Zealand data.

**Based on median harvest indices and median yields (where a range is given) from Appendix 1.

Over the past 20 years, total national production of grain from arable crops has increased by 36% (from 850,446 tonnes in 1990 to 1,155,400 tonnes in 2012; Appendix 2). This is despite a decrease in the area under production of around 20% (Appendix 3). Improvements in varieties and agronomy have enabled this increase in grain yield (tonnes per hectare). As a consequence, the crop residue produced is now
1.2 Management of crop residues in New Zealand

The options available to New Zealand growers for managing crop residues are:

- Incorporating the residue via chopping and non-inversion cultivation (surface/top work);
- Incorporating the residue via chopping and ploughing (full inversion cultivation);
- Baling and removing the cut straw;
- Retaining the crop residue on the soil surface and direct drilling through it.

A 1996 review of crop residue management in New Zealand (Fraser & Francis 1996) revealed that at that time there was very little information available on the extent to which these different options were adopted in practice. Nevertheless, based on a number of personal communications, the authors concluded that most of the wheat, barley and oat farmers in New Zealand burned their residues, some baled and sold the residues, with only a small number chopping and/or incorporating them back into the soil.

More recently, FAR conducted two grower surveys: one in 2006 (380 growers responded; (Lawrence et al. 2007)) and another in 2011 (398 growers responded; (Fraser & Lawrence-Smith 2011)). The 2006 survey revealed that there were some differences between the proportion of cereal stubbles burned by growers in the North and South Islands. Overall, growers in the South Island were more likely to burn their stubbles than those in the North Island, but this result was most likely skewed by North Island cropping systems typically involving a large amount of maize, for which the stubble is not commonly burned (about 10% of survey respondents reported burning maize residues). The survey also revealed that individual growers tended to opt to burn either all or none of the residues of a given crop.

The 2011 FAR survey (Fraser & Lawrence-Smith 2011) explored crop management practices in more detail and showed that of all crops grown, the types most frequently considered by growers for burning were wheat, barley or oats. A small number of other crops (e.g. grass seed and maize) were also identified as occasionally being burned.

By contrast a survey in South Australia (Smith et al. 2007) identified a different array of crops as being burned: most respondents (90%) burned wheat crop residues, but smaller numbers of growers identified canola, barley, lupins, oats and grass as crop residues that they might also burn. Meanwhile in England, stubble burning was banned in autumn 1992 although burning is still currently allowed in Scotland.
1.3 Quantity of crop residue burned in New Zealand

Data relating to the area of land under cereal production that is burned annually has only been collected by Statistics New Zealand since 2005. Initially, information relating to the burning of all vegetation was aggregated but since 2008 differentiation on a geographical basis (North versus South Island) for cereal burning per se as well as ‘other crop’ burning has also been provided. A summary of the data collected to date by Statistics New Zealand on burning of crop residues is given in Appendix 4.

From 2008 to 2012 inclusive, the average area of cereals burned each year was 50,172 hectares across all of New Zealand (Table 2). For the same five years the total average area sown to wheat, barley and oats (the cereal crops most commonly identified as considered for burning by growers) was 123,720 hectares (Table 2). These values can be used to calculate the percentage of cereal crop residues burned, albeit based on the assumption that respondents to the Statistics New Zealand survey of area of cereals burned included only wheat, barley and oats in their returns. However, given that other surveys show that these are overwhelmingly the most commonly burned crop residues, this is a reasonable assumption. This calculation shows that over the five years from 2008 to 2012, 41% of the straw residues from these crops were burned (Table 2).

Table 2. Total area of cereal crop residues burned in New Zealand, total area of production of cereals (wheat, barley and oats), and percentage of cereal production area burned each year between 2008 and 2012.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total area of cereals burned (hectares)*</th>
<th>Total area of wheat, barley and oats grown (hectares)**</th>
<th>% of cereal production area burned</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>47,442</td>
<td>114,900</td>
<td>41</td>
</tr>
<tr>
<td>2009</td>
<td>53,782</td>
<td>139,000</td>
<td>39</td>
</tr>
<tr>
<td>2010</td>
<td>53,207</td>
<td>116,000</td>
<td>46</td>
</tr>
<tr>
<td>2011</td>
<td>41,863</td>
<td>123,600</td>
<td>33</td>
</tr>
<tr>
<td>2012</td>
<td>54,567</td>
<td>125,100</td>
<td>44</td>
</tr>
<tr>
<td>Average</td>
<td>50,172</td>
<td>123,720</td>
<td>41</td>
</tr>
</tbody>
</table>

*Appendix 4; **Appendix 3. Note: it is not possible to infer the relative proportions of wheat and barley stubble burned but anecdotal evidence suggests a greater proportion wheat residue is burned than barley.

Similar findings have been reported for some areas of Australia where a survey of growers in 2008 revealed that approximately 33% and 47% of growers burned some stubble in central and southern New South Wales respectively, while the median area burned was 40% and 50% respectively (Llewellyn & D’Emden 2009). However, in the western central region of Western Australia the proportion of burning was higher at 55%, whilst in southern Queensland the figure was only 1% of the entire stubble area (Scott et al. 2010).

Although there is variation in the percentage of cereal production area in New Zealand burned each year over the period 2008 to 2012, there is no evidence of an upward or downward trend. However, given that anecdotal evidence from the mid 1990’s (Fraser & Francis 1996) suggested that the majority of cereal growers tended to burn their cereal crop residues back then, it is possible that there may have been a substantial overall reduction in the proportion of cereal crop residues burned in New Zealand over the last 15-20 years that cannot be explained simply by the 20% reduction in total area of wheat, barley and oats grown (Appendix 3).
This reduction in burning would be consistent with a number of developments within the farming industry. For instance, the advent of new machinery that is better able to deal with the increasing volumes of straw being produced, alongside a general movement in New Zealand towards reduced tillage practices (Fraser & Lawrence-Smith 2011), may be in part responsible for the reduction in the area of cereal residues burned. In addition, arable farmers have tried increasingly hard not to burn under conditions which will cause a nuisance to neighbouring property owners. Furthermore over the last 15-20 years a large increase in dairy farming in New Zealand has opened up a new market for straw residues. Dairy farmers commonly use straw as a source of roughage to add to their cows’ diet. This has most likely increased the amount of straw that is marketable compared to 20 years ago although the exact amount is difficult to quantify.

1.4 Quantity of crop residue burned in Canterbury

Of the total national production of cereals in 2012, 87% of wheat (47,800 ha), 66% of barley (43,600 ha), and 51% of oats (1,989 hectares) were grown in Canterbury. It follows that stubble burning is more commonly practised in Canterbury than other regions of New Zealand.

Based on area of cereal crops grown, area burned, and yields (tonnes per hectare) of crop residue produced (which can be derived from harvest indices) it is possible to estimate the total tonnage of crop residue burned in Canterbury. Estimates for 2012 are given in Table 3.

Table 3. Area of cereals grown in Canterbury as a proportion of the New Zealand total, area of crop residue burned, and estimated tonnage of crop residue burned for the year ending June 2012.

<table>
<thead>
<tr>
<th>Wheat</th>
<th>Area grown (hectares)</th>
<th>Area burned (hectares)**</th>
<th>Amount burned (tonnes)***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canterbury</td>
<td>47,800</td>
<td>21,032</td>
<td>138,811</td>
</tr>
<tr>
<td>New Zealand</td>
<td>54,900*</td>
<td>24,156</td>
<td>159,430</td>
</tr>
<tr>
<td>% in Canterbury</td>
<td>87</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Barley</th>
<th>Area grown (hectares)</th>
<th>Area burned (tonnes)**</th>
<th>Amount burned (tonnes)***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canterbury</td>
<td>43,600</td>
<td>19,184</td>
<td>163,064</td>
</tr>
<tr>
<td>New Zealand</td>
<td>66,300*</td>
<td>29,172</td>
<td>253,796</td>
</tr>
<tr>
<td>% in Canterbury</td>
<td>66</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Oats</th>
<th>Area grown (hectares)</th>
<th>Area burned (tonnes)**</th>
<th>Amount burned (tonnes)***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canterbury</td>
<td>1,989*</td>
<td>875</td>
<td>5863</td>
</tr>
<tr>
<td>New Zealand</td>
<td>3,900*</td>
<td>1716&quot;</td>
<td>11,497</td>
</tr>
<tr>
<td>% in Canterbury</td>
<td>51&quot;</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Appendix 3.
**Calculated using provisional 2012 Statistics New Zealand data that showed 44% of stubbles were burned in 2012.
***Based on wheat producing 6.6 tonnes of residue per hectare, barley producing 8.7 tonnes of residue per hectare, and oats producing 6.7 tonnes of residue per hectare (see Table 4) and assuming 100% combustion of residues was achieved at burning.
#Figures calculated assuming proportion of oats grown in Canterbury is still similar to that of 2007 (51%) since the regional figures for Oats production for 2012 will not be released by StatsNZ until 17 June 2013.
1.5 Yields of crop residue produced and implications for management options

Management of crop residues in New Zealand presents some unique challenges compared to other countries. The first of these is related to the yield (tonnes per hectare) of crop residue produced. As shown in Table 4, yields of residues of cereal crops grown in New Zealand are generally more than double the yields for the same crops grown in Australia. Hence, due to the quantity of material present, chopping and incorporation of these residues into the soil surface presents greater challenges in New Zealand than in Australia. Secondly, production of small seeded crops such as ryegrass and clover grown for seed is a much more significant element of crop rotations in New Zealand than, for example, the UK. Consequently, although the yields of crop residue from cereal crops are similar in the two countries, the UK does not face the same agronomic challenges of establishing small seeded crops in these cereal residues.

Table 4. Quantity of crop residue per hectare produced for arable crops grown in New Zealand, Australia, and the UK.

<table>
<thead>
<tr>
<th>Crop residues produced (tonnes per hectare)*</th>
<th>New Zealand</th>
<th>Australia</th>
<th>UK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>6.6</td>
<td>2.6</td>
<td>7.5</td>
</tr>
<tr>
<td>Barley</td>
<td>8.7</td>
<td>3.7</td>
<td>5.6</td>
</tr>
<tr>
<td>Oats</td>
<td>6.7</td>
<td>3.9</td>
<td>6.3</td>
</tr>
<tr>
<td>Maize grain</td>
<td>11.5</td>
<td>5.7</td>
<td>-</td>
</tr>
</tbody>
</table>

*Based on median harvest indices and median yields (where a range is given) from Appendix 1.
2 Value of crop residues

Key points

- Over a 12 month period, losses of carbon to the atmosphere from crop residues as CO₂ and CO are broadly similar whether the residues are incorporated or burned.
- Crop residues contain potentially useful but variable amounts of plant nutrients including nitrogen, sulphur, phosphorus, potassium, calcium and magnesium.
- When burned, the majority of the nitrogen, carbon and sulphur in crop residues will be lost to the atmosphere.
- Other nutrients present in the residues, such as phosphorus, potassium, calcium and magnesium will mostly be returned to the soil as ash.
- Nitrogen content of cereal crop residues is relatively low compared to e.g. grass or pea straw.
- In New Zealand, contrasting residue management systems are unlikely to have major effects on soil organic matter during the arable phase of the rotation.
- When incorporated, barley straw decomposes more rapidly than oat straw which in turn decomposes more rapidly than wheat straw.

Crop residues mainly consist of cellulose, hemicellulose and lignin, together with smaller amounts of protein, waxes, amino sugars, amino acids, organic acids and insoluble ash. Examples of the approximate chemical constituents of wheat, barley and oat straw and pasture herbage under New Zealand conditions are given in Table 5.

Table 5. Chemical constituents of three cereal straws and pasture herbage in New Zealand (Fraser et al. unpublished - cited in Fraser and Francis 1996).

<table>
<thead>
<tr>
<th>Chemical constituent</th>
<th>Approximate content (percentage of total dry matter)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wheat straw</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.59</td>
</tr>
<tr>
<td>Carbon</td>
<td>40.64</td>
</tr>
<tr>
<td>Phosphorous</td>
<td>0.07</td>
</tr>
<tr>
<td>Potassium</td>
<td>1.28</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0.12</td>
</tr>
<tr>
<td>Calcium</td>
<td>0.15</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.07</td>
</tr>
<tr>
<td>Lignin</td>
<td>14.60</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>26.49</td>
</tr>
<tr>
<td>Cellulose</td>
<td>30.26</td>
</tr>
<tr>
<td>Carbon: Nitrogen ratio</td>
<td>69</td>
</tr>
<tr>
<td>Lignin: Nitrogen ratio</td>
<td>25</td>
</tr>
</tbody>
</table>
As well as the chemical composition of residues varying considerably between crops, it can vary between cultivars of the same crop and can be affected by the soil type on which the crop is grown and the amount of fertiliser it receives. Table 6 shows examples of variation in composition of wheat residues from different locations.

Table 6. Concentration of nutrients in wheat straw after harvest in Australia, Canada and New Zealand.

<table>
<thead>
<tr>
<th>Location</th>
<th>Crop</th>
<th>Nutrient content (% of total dry matter)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>A</td>
<td>South Australia</td>
<td>0.51</td>
</tr>
<tr>
<td>B</td>
<td>Victoria, Australia</td>
<td>0.42</td>
</tr>
<tr>
<td>C</td>
<td>Manitoba, Canada</td>
<td>0.97</td>
</tr>
<tr>
<td>D</td>
<td>Canterbury, New Zealand</td>
<td>0.59</td>
</tr>
</tbody>
</table>

(A = (Schultz and French, 1976); B = (Pearce et al., 1979); C = (Heard et al., 2006); D = Fraser et al., unpub.)

Notwithstanding the variability in chemical composition of crop residues, they all contain potentially useful amounts of plant nutrients. Based on the values in Tables 5 and 6, the removal of 1 tonne of wheat residues per hectare would remove 4-10 kg nitrogen, 0.5-1.4 kg phosphorous, 6-14 kg potassium and 1.1-1.3 kg sulphur per hectare.

The fate of these nutrients depends on residue management practice:
- When stubbles are burned, some of the nutrients are returned to the soil;
- When incorporated or left on the soil surface, the nutrients are retained in the paddock and eventually become available to subsequent crops depending on the rate of decomposition;
- When baled and removed, the nutrients are exported off the paddock.

The implications of these scenarios for the agronomy and the cycling of nutrients is explored in more detail below.

### 2.1 Fate of nutrients when crop residue is burned

During burning, 50-70% of the residue carbon is commonly volatilized to CO₂ and CO (Rasmussen & Collins 1991), although losses of up to 90% have been measured when combustion of the residue is almost complete (Raison & McGarity 1979). The remainder of the carbon is returned to the soil surface as charred residue, which is not biologically active. Consequently, burning can change both the quantity and the quality of organic matter in the soil (Rasmussen & Collins 1991).

The ash from burning stubble is alkaline, which can give a rapid increase to the pH at the soil surface. In general, losses of nutrients due to burning decrease in the order N > Ca > S > K > Mg > P > Na. These losses depend on the temperatures reached during burning. Volatile losses of P and K occur at temperatures exceeding 500°C, whereas the vaporization of Na is reported to be 880°C (Raison & McGarity 1979). However, these temperatures may not be achieved during the burning of cereal crop residues or grass/legume pastures and most of these elements are left in the ash (Kumar & Goh 2000).
Cereal crop residues contains approximately 15% of the N and P, 36% of the S and 80% of the K present in wheat at maturity (Whitbread et al. 2000). Burning cereal residues results in an immediate increase in the content of extractable phosphorus and potassium in the surface 0-2.5 cm soil layer, although no long-term build-up of these nutrients is observed (Biederbeck et al. 1980; Prasad & Power 1991).

The majority of the nitrogen, carbon and sulphur in burned residues will be lost to the atmosphere as gases, but the other nutrients present in the residues, such as phosphorous, potassium, calcium and magnesium will mostly be returned to the soil as ash residues. Estimates of losses of N to the atmosphere during burning are in the order of 30-90%, depending on the extent of combustion (Raison & McGarity 1979; Biederbeck et al. 1980). This represents a loss of 10-25 kg N ha⁻¹ for a straw crop of 5 tonnes per hectare.

Scott et al. (2010) compared the results of 3 experiments in Australia which sought to assess the nutrients lost from residues during burning (Table 7). The losses of N (82%-88%; mean 85%) and S (65-81%; mean 74%) were reasonably consistent. However the loss of solid oxides varied widely which was probably due to variation in the vigour of the fire and the resultant convection producing losses of the solid ash component.

Table 7. Estimates of nutrients loss (%) from straw due to burning - nutrients present in the straw which were not recovered in the ash after burning.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>100</td>
<td>nr²</td>
<td>92</td>
<td>nr</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>100</td>
<td>88</td>
<td>85</td>
<td>82</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0</td>
<td>0.4</td>
<td>10</td>
<td>44</td>
</tr>
<tr>
<td>Potassium</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>40</td>
</tr>
<tr>
<td>Sulphur</td>
<td>100</td>
<td>75</td>
<td>65</td>
<td>81</td>
</tr>
<tr>
<td>Calcium</td>
<td>0</td>
<td>8</td>
<td>Nr</td>
<td>52</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0</td>
<td>2</td>
<td>Nr</td>
<td>47</td>
</tr>
<tr>
<td>Suggested loss³</td>
<td>0</td>
<td>2.6%</td>
<td>10.5%</td>
<td>46%</td>
</tr>
</tbody>
</table>

¹Assumed from oxides of N, S and C being gases, and other oxides being solids.
²nr = not reported.
³Suggested loss due to ash loss by convection (mean of solid oxides).

Further losses may occur due to subsequent wind and water wash removing ash from a paddock. While airborne ash, containing the solid oxides may be lost from the burnt paddock, it may deposit on neighbouring paddocks.

2.2 Decomposition of crop residues
If crop residues are not removed from the paddock through burning or baling they will, over time, decompose. Their decomposition has important agronomic implications, which are explored in this section.
In general terms, crop residue decomposition is influenced by:

- Method of incorporation of the crop residue;
- Composition of the crop residues;
- Factors related to the soil to which the residues are added;
- Climate.

Each of these factors affecting decomposition of residues has been comprehensively reviewed in a paper by New Zealand based authors Kumar and Goh (2000). These authors concluded that no one residue management system is superior under all conditions. The influence of both incorporation method and residue composition on decomposition rates are discussed below.

2.2.1 Influence of method of incorporation on crop residue decomposition

Residue breakdown rates will be affected by the distribution of the residue within the soil profile (Buchanan & King 1993; Curtin et al. 2008). Where residues are incorporated by ploughing, there can be limited contact between the soil and the thick layer of residue at the bottom of the plough layer. However, where residues are thoroughly mixed through the soil (e.g. as in discing) decomposition rates are enhanced through greater contact between the soil and residue (Curtin et al. 2008).

Depending on the method and depth of cultivation used, the residues may be partially or fully incorporated into the soil resulting in various degrees of ground cover by the residues. This can have important implications for water and wind erosion control. Indeed in certain States of America where erosion is particularly prevalent, legislation has been passed that requires farmers to carry out ‘conservation tillage’ to maintain a minimum ground cover by residues of 30% (Griffith & Wollenhaupt 1994).

Working in New Zealand, Curtin et al. (2008) simulated incorporation of crop residues by ploughing or by discing and compared these practices with leaving straw on the top of the ground. They were able to show that following straw mixed through the soil (i.e. disced into the soil) residues decomposed more rapidly than straw ploughed-in, which in turn decomposed more quickly than residues left lying on the surface. They attributed this in part to the degree of direct contact of the residues with the surrounding soil.

The method of incorporation can affect rates of residue decomposition and, given that residues from individual crops differ markedly in their quality (both physically and chemically), residues will not all behave similarly following incorporation. Residues with a higher N content (i.e. a low C:N ratio) decompose more rapidly than those with a lower N content (i.e. a high C:N ratio).

Following incorporation of residues, immobilisation of soil nitrogen can occur during the decomposition process in the soil and can be especially noticeable when residues with a low N content or high C:N ratio are incorporated. Where the soil has a high background level of mineral nitrogen this is of lesser importance, but where nitrogen is low in the soil, this may in some situations affect the growth and subsequent yields of the next crop unless additional nitrogen is added to assist with residue breakdown. However, studies in New Zealand have found that it was not usually necessary to add nitrogen to assist with residue breakdown in New Zealand soils as sufficient background nitrogen was usually available (Francis et al. 1999; Curtin et al. 2001).
2.2.2 Influence of properties and quality of the crop residues on decomposition

The constituent components in crop residues decompose at different rates (Table 8). Generally residues containing large amounts of sugars will break down rapidly, whereas residues containing large amounts of lignin will decompose slowly. The size of the lignin component can vary quite considerably between plant species. Lignin provides straw with its strength and rigidity. For example, barley straw contains around 10% lignin whereas wheat straw contains about 15% and as a result barley straw is less rigid and more difficult to chop, but easier to burn than wheat straw. Lignin also influences the palatability of the residues. Residues with increasing proportions of lignin also tend to be less palatable to animals.

Table 8. The primary chemical compositions for a range of straws and their respective rates of breakdown under New Zealand conditions.

<table>
<thead>
<tr>
<th>Component</th>
<th>Approximate content (% of dry weight)</th>
<th>Breakdown rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water soluble materials (e.g. sugars)</td>
<td>~10</td>
<td>Days</td>
</tr>
<tr>
<td>Cellulose (a polymer of glucose)</td>
<td>15-60</td>
<td>weeks – months</td>
</tr>
<tr>
<td>Hemicellulose (a polymer of glucose and other sugars)</td>
<td>10-30</td>
<td>weeks – months</td>
</tr>
<tr>
<td>Lignin (a polymer of phenols)</td>
<td>5-30</td>
<td>Years</td>
</tr>
</tbody>
</table>

Adapted for NZ from Butterworth (1985) and Kumar and Goh (1999)

Residues decompose more quickly when they are incorporated into soil than when they are left on the soil surface due to more favourable conditions for microbial activity (Parr & Pappendick 1978; Curtin et al. 1998). In addition, soil placement is an important consideration as straw well distributed through the soil (e.g. when residues are disced into soil) will decompose more rapidly than straw placed in a thick layer – as may happen during ploughing (Curtin et al. 2008).

When incorporated, barley straw decomposes more rapidly than oat straw which in turn decomposes more rapidly than wheat straw (Summerell & Burgess 1989; Fraser et al. unpublished; Cookson et al. 1998; Curtin et al. 2008). This can be in part attributed to the increasing proportion of the more recalcitrant lignin component in these respective straw residues (Table 8). The rate of residue decomposition tends to decline as the lignin: nitrogen ratio increases (Buchanan and King, 1993) and the nitrogen content of residues can have a major influence the rate of their decomposition (Janzen and Kucey 1988). By contrast, grasses have a much higher proportion of water soluble materials and a relatively low proportion of hemicellulose and cellulose. Consequently, grass residues decompose much more rapidly following incorporation than do cereal residues (Fraser et al. unpublished).

Although Herman et al. (1977) and Tian et al. (1995) found that the decomposition rates of plant residues could not be predicted from an individual characteristic of the organic material such as the C:N ratio, lignin content or carbohydrate content, they found that when combined, these properties could accurately predict the relative rates of decomposition for a broad range of plant residues.

The rate of the organic matter breakdown is thus highly dependent on the relative proportions of the main components such as soluble sugars, cellulose, hemicelluloses and lignin (Stout et al. 1981). Hagin and Amberger (1974) reported that the half-life of sugars, cellulose, hemicelluloses and lignin were 0.6, 6.7, 14.0 and 364.5 days respectively.
2.3 Influence of residue management practice on soil organic matter

Long-term experiments under continuous arable production often show organic matter content declines less when crop residues are incorporated rather than burned. However, these differences are small, and often only about 0.2 - 0.4% C even after a period of up to 58 years e.g. Powlson et al. 1987; Heenan et al. 1995; Johnson and Chambers 1996. Indeed, even when straw is incorporated, organic C levels in long-term arable soils often decline with time, although the rate of decline may be slower than if the residues were burned (Rasmussen et al. 1980). However, in some long-term experiments, residue management had no significant effect on soil organic C content e.g. (Undersander & Reiger 1985; Curtin & Fraser 2003; Dalal et al. 2011). Such conflicting results are possibly due to the degree of residue burning achieved, the depth of sampling and the type of tillage used (Prasad & Power 1991). From a review of 25 long term trials, Powlson et al. (2011) conclude that, although changes in soil organic content resulting from addition or removal of straw are small, continuous removal is likely to lead to deterioration in soil physical properties.

Arable soils in New Zealand usually have organic carbon content in the range of 2.0-3.0% (Haynes et al. 1991; Lawrence et al. 2006), although content in peat based soils can be much higher. Assuming a bulk density of 1.2, 2% soil organic carbon corresponds to about 36 t/ha to 15 cm and similarly 3% corresponds to about 55 t/ha to a depth of 15cm. In situations where the arable phase dominates the cropping rotation or in continuous mono-culture situations, however, organic matter content can decline in the long-term (Collins et al. 1992; Fraser et al. 1996). It has been suggested that this decline in organic matter content could be reversed or at least reduced by returning crop residues to the soil (Ladd et al. 1994; Campbell & Zentner 1993), but in a six year field trial in New Zealand, returning crop residues had no significant effect on the soil organic matter (Curtin & Fraser 2003). Despite around 25t/ha of straw (11t/ha of C) being returned over the six year trial (suggesting that the organic matter may have increased by about 1 t/ha), no significant changes in organic matter were able to be detected against the relatively high background level of 55 t/ha in the upper 15cm depth.

Overall, in New Zealand, contrasting residue management systems are unlikely to have major effects on soil organic matter during the arable phase of the rotation (Haynes & Francis 1990). This is because organic matter returns to the soil are much greater under pastoral than the arable production. Large amounts of organic matter are returned to the soil under pasture from root exudates and from the turnover of roots in the dense, adventitious root system. Furthermore, 60-90% of the pasture dry matter consumed during grazing is returned to the soil as dung and urine which returns more organic material to the soil (Haynes & Williams 1993). In contrast, under arable cropping, less organic matter is returned from the sparse root systems of row crops and large amounts of carbon are removed from the soil in harvested products.

Hence, in the mixed farming rotations common in Canterbury, any changes in soil organic matter due to residue management in the arable phase are likely to be small compared with the large differences present under the arable and pastoral phases.

Whilst the living component of the soil organic matter, the microbial biomass, comprises only a small proportion (1-4%) of the total organic C it has rapid turnover and responds rapidly to changes in C availability. Up to 50% greater microbial biomass C has been measured in soil where residue has been incorporated rather than burned (Powlson et al. 1987; Dalal et al. 1991).
Over a 12 month period, losses of carbon to the atmosphere from crop residues as CO$_2$ and CO are broadly similar whether the residues are incorporated or burned, although the pattern of production is markedly different.

2.4 Baling and removing cut straw from the paddock
Knowledge of the nutrient concentration in crop residues, alongside the quantity present, can enable estimation of the amount of nutrients contained in the residues. To raise awareness of the economic value of the nutrients in crop residues, FAR released an *Arable Update* in 2001 detailing the amounts of nutrients contained in various types of residues and later developed a simple, online calculator for estimating the economic value of baled residues: [http://www.far.org.nz/index.php/economic-cost-of-straw-nutrient-losses](http://www.far.org.nz/index.php/economic-cost-of-straw-nutrient-losses)

As a result, New Zealand arable farmers have become increasingly aware of the amounts of nutrients contained in the straw and the need to achieve a price for baled straw that exceeds the fertiliser replacement cost. However, as straw bales have a low bulk density their transport costs are high and markets for them may not be readily available$^2$. The value of baled straw is highly variable and in some seasons is exceedingly difficult to sell.

The impact of baling and removing cut straw on soil organic matter is likely to be intermediate between residue burning and incorporation as some plant material is left in the form of plant stems.

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$^2$ As of 2013, it presently costs around $2.50 to $3 to make small (12-15kg) cereal straw bales or around $30 to produce a medium square bale (equivalent of about 12 small bales). Small bales currently sell for around $3.00 to $3.50 each, and medium square wheat bales can be worth around $40 each, or as much as $60 for barley straw, where markets can be found.
3 The rationale for burning as a crop residue management technique

Key points

- Burning is a key cultural tool which removes large quantities of cereal residue and enables timely and successful establishment of high value small seeded crops with minimal cultivation in a more weed, pest and disease free environment.
- Some high value seed crops cannot be grown in paddocks with large quantities of cereal residues.
- Residue burning reduces risk of untimely operations and subsequent crop failure.
- Trials in Canterbury showed large reductions in the yield of wheat following wheat when straw was incorporated.
- Burning cereal residues means fewer cultivation passes resulting in increased soil moisture retention, finer soil tilth and better soil structure.
- Stubble burning can also improve weed control.
- Large quantities of crop residue on or close to the soil surface can restrict the choice of herbicide and lead to an increased risk of herbicide resistance.
- Stubble burning lowers the cost of production on cropping farms by reducing agrichemical usage, machinery costs and the number of cultivation passes.

3.1 Importance of retaining small seeded crops within sustainable rotations

New Zealand cropping rotations are amongst the most diverse in the world, primarily as a result of the country’s climatic advantages and its importance as a small seed producer and exporter of grass seed, clover seed and, in more recent years, vegetable seeds. This export industry is currently worth $173 million per annum (Ministry for Primary Industry, personal communication, 2013) and is primarily based on the Canterbury Plains. The grass seed component also underpins the domestic pastoral sector with approximately 50% of production dedicated to re-seeding in New Zealand.

The majority of these crops are grown in rotation with more traditional broad acre crops such as cereals (primarily wheat and barley), pulses and oilseeds. Small seed production and its rotation with high yielding broad acre crops is not a feature of European or Australian cropping rotations (for example, 2011 New Zealand area of grass seed & clover production was 23,688 ha with an estimated 93% production centred in Canterbury, compared to UK grass seed & clover acreage of less than 6000ha; source: NIAB).

The principal crop residues burnt in New Zealand cropping rotations are from cereal crops and the practice is primarily carried out on the Canterbury Plains, the same region in which small seed production is centred (2011 MPI/FAR/PFR Cropping Survey). New Zealand cereal crops are amongst the highest yielding in the world, with wheat yields regularly exceeding 12 t/ha (current world record wheat yield is held by a Southland grower 15.63t/ha). As a consequence of these high cereal yields, New Zealand growers are frequently faced with crop residue quantities of between 10-15 t/ha (levels of residue far higher than their Australian counterparts, 2-6 t/ha).
Since small seeded crops, such as grass seed and clover, frequently follow these high yielding cereal crops, burning is a key cultural tool that allows the removal of large quantities of residue (with a high C:N ratio of approximately 100:1 see Table 5) and successful establishment of these crops with minimal cultivation in a more pest free environment.

Other crop residues are burnt by a minority of growers under certain circumstances (Fraser & Lawrence-Smith 2011), these are typically grass seed residues where grass stands have been laid down for several years. With one-year ryegrass crops the straw has good market value and is rarely burnt. However it is burning large volumes of cereal residue (which has reduced value as a by-product due to the high C:N ratio) prior to the small seeded crops that follow that is the regarded as the key rotation position for this important cultural tool.

3.2 Maximising soil and seedbed quality
Currently the primary method of cultivation following cereal crops in New Zealand is minimal tillage (surface/top working of the soil with 1-2 passes of a tine or disc harrow cultivator) or direct drilling\(^3\) (Figure 1).

![Figure 1. Forms of tillage used to establish arable crops following cereals by proportion of survey respondents in the North and South Islands (Fraser and Lawrence-Smith, 2011).](image)

These minimal methods of cultivation are associated with sustainable indicators of soil quality compared to more intensive cultivation techniques such as ploughing (Beare et al. 2003). The ability to burn cereal residues allows growers to adopt fewer cultivation passes thus increasing soil moisture retention (provided burning is conducted in the autumn as opposed to the summer), finer soil tilth (soil particle size) and better soil structure.
The quality of soil near the surface and preserved soil moisture post burning provides an excellent seedbed for establishing small seeded crops (such as grasses, clover and vegetable seed) without the need for intensive cultivation. Fewer cultivation passes help preserve soil quality, reduce production costs (labour and fuel costs) and allow the operation of a wider range of New Zealand cultivation equipment, such as the popular New Zealand cultivator, the Maxitil. Where residues from the previous crop are less are not generally burned, for example following grass, there is a tendency for more cultivation to be necessary prior to the establishment of the next crop (Figure 2).

![Bar chart showingForms of tillage used to establish arable crops following grass by proportion of survey respondents in the North and South Islands (Fraser and Lawrence-Smith, 2011).](image)

**Figure 2.** Forms of tillage used to establish arable crops following grass by proportion of survey respondents in the North and South Islands (Fraser and Lawrence-Smith, 2011).

### 3.3 Enabling sustainable weed management

Soil quality has improved as reduced tillage practices have replaced ploughing. However higher weed numbers, especially of annual grasses like sterile brome, occur where reduced tillage is practised. This is because in traditional plough cultivation weed seeds are buried and often decay.

Where straw burning is not practised before reduced tillage, the presence of significant levels of crop residues on or close to the soil surface can reduce the control achieved by the commonly used soil and soil/foliage acting herbicides. In contrast, straw burning can bring several benefits to weed control, particularly where reduced tillage is adopted. It can destroy freshly shed viable weed seeds (particularly of annual grasses) and, in some grass species, reduce the dormancy of the freshly shed seed that survive the straw burning operation.

The Western Australia Department of Agriculture notes the following benefits of stubble (residue) burning (Anon 2013a):
1. Burning windrows of wheat, canola or lupin trash has been found to destroy 75% of wild radish seed and a high proportion of annual ryegrass seeds.
2. Burning can stimulate weed germination, often by breaking seed dormancy (Moss, 1981), of some weed species which provides for a greater opportunity for subsequent control by either cultivation or with herbicides prior to the next crop being sown;
3. Seeds close to the soil surface are more likely to be killed by burning than seeds that have been buried;
4. Burning removes crop residues and allows more effective incorporation of pre-emergent herbicides.

In Oregon, weed levels in creeping red fescue seed at harvest increased from 0.1% from open burning compared with 1.7 and 5.8% when the grass seed straw was either flail chopped or crew-cut after the previous harvest (Table 9). Burning of straw also increased the seed yields compared to the non-burn stubble removal treatments (Table 9; Gingrich et al. 1993).

**Table 9. Effect of stubble residue management on seed yield in ‘Cindy’ creeping red fescue (Gingrich et al. 1993).**

<table>
<thead>
<tr>
<th>Residue Treatment</th>
<th>Weed seed (%)</th>
<th>Seed Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open burn</td>
<td>0.1</td>
<td>1010</td>
</tr>
<tr>
<td>Crew-cut</td>
<td>5.8</td>
<td>550</td>
</tr>
<tr>
<td>Flail-Chop</td>
<td>1.7</td>
<td>375</td>
</tr>
<tr>
<td>LSD 5%</td>
<td>2.3</td>
<td>89</td>
</tr>
</tbody>
</table>

In Canterbury, stubble burning reduced the incidence of ripgut brome in wheat and volunteer wheat in ryegrass seed crops (Table 10). If ripgut brome is established in a wheat field it is noticeably denser in the non-burn fire-break headland areas of fields. This effect is encouraged because many annual weed infestations start from fence lines and invade into the field. In a field experiment in the UK, straw-burning destroyed 97% of the un-germinated sterile brome (Anisantha sterilis) seeds on the soil surface and reduced seedling numbers by 94% (Froud-Williams 1983).

**Table 10. Impact of stubble burning and cultivation on populations of Ripgut brome (brome grass heads/m²) in wheat and volunteer wheat plants (plants/m²) in a ryegrass seed crop.**

<table>
<thead>
<tr>
<th>Crop residue treatment</th>
<th>Cultivation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direct drilling</td>
</tr>
<tr>
<td><strong>Ripgut brome</strong></td>
<td></td>
</tr>
<tr>
<td>Burn</td>
<td>0.05</td>
</tr>
<tr>
<td>Chopped</td>
<td>0.25</td>
</tr>
<tr>
<td>Chopped + raked</td>
<td>0.33</td>
</tr>
<tr>
<td><strong>Wheat</strong></td>
<td></td>
</tr>
<tr>
<td>Burn</td>
<td>1.0</td>
</tr>
<tr>
<td>Chopped</td>
<td>21.7</td>
</tr>
</tbody>
</table>

*Anon 2009*

Population models in the UK suggest that the annual level of control of wild-oat (Avena fatua) seeds required from herbicides to contain populations in continuous winter wheat is 81% where ploughing
and no straw burning is adopted. This falls to 72% where the straw is burnt. 82% control is required where shallow tillage and no straw burning is adopted and this falls to 73% where the straw is burnt (Cousens et al. 1986). The small difference between the chemical control required under the different cultivation systems is because, unlike other annual grass weeds, wild-oats can typically emerge when buried to plough depth. The impact of cultivation system and straw burning on the annual control required from herbicides to contain populations is higher for the small seeded black-grass (Alopecurus myosuroides).

Vulpia hair grass is an annual grass that is an emerging problem in grass seed crops that follow cereals in the rotation in Canterbury. In Western Australia burning residues provides 50% control (range 30-80% control) of Vulpia when a hot fire back-burning into the wind is used (Anon 2013b). In New Zealand the herbicide Firebird (flufenacet + diflufenican) is providing good control of Vulpia in cereal crops, provided the seed bed is moist, of good tilth, free of clods and trash (Young 2012). Burning of stubble is one option to ensure the trash free environment is achieved to maximise herbicide efficacy.

### 3.3.1 Crop residue impacts on herbicide efficacy

Herbicides can be classified as soil- and/or foliage-acting, depending on their mode of action. Chopped straw on or close to the soil surface is generally expected to reduce the efficacy of soil acting herbicides. Research in Denmark (Kudsk & Mathiessen 2006) and the USA (Banks & Robinson 1986) clearly shows that increasing amounts of straw on or close to the soil surface can impede herbicide efficacy. For instance, Danish pot trials indicated that chopped straw residues equivalent to just one tonne/hectare, lying on the soil surface or incorporated in the top few cms of soil, increased the dose of soil-acting herbicides required to control loose silky bent (*Apera spica-venti*) by between 40-70% (Kudsk & Mathiessen 2006). This increased to an extra dose of 90% being required where the equivalent of three tonnes of straw per hectare was on the soil surface.

However, there are occasional exceptions to surface straw inhibiting the control achieved by soil-acting herbicides. The soil-acting herbicide propyzamide (used to control grasses in white clover seed crops) is very effective in controlling annual grasses when applied post-emergence to a crop where there is a matt of straw lying over a soil surface that has not been disturbed by cultivations. The likely explanation is that in this situation the weed roots are very close to the soil surface and this herbicide is particularly effective in controlling shallow rooting weeds. Similarly, a study at Rothamsted Research (UK) indicated that up to 20% of coverage of the soil surface with straw did not inhibit the activity of the soil-acting herbicide isoproturon on black-grass.

There may be foliage acting herbicides available whose activity will not be reduced by surface straw. However, with continuous use there is a high risk of resistance developing to the dominating group of foliage acting herbicides used to control most annual grass weeds, the ‘fops’, ‘dims, and ‘dens’³ (Anon 2010). Hence, it is good practise to adopt a range of modes of action to control annual grass weeds which realistically requires that the straw is burnt where reduced tillage is adopted.

It should also be noted that straw ash, when left near or on the soil surface can adsorb soil-acting herbicides thereby reducing their efficacy (Cussans & Moss 1982). However, significant reductions in herbicide efficacy are only likely to occur where crop residues are burnt every year for four of five years and very shallow tillage is adopted (Cussans & Moss 1982).

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³ A group of herbicides (ACCase and ALS inhibitors e.g. sulfonylureas) whose regular use is associated with a high risk of herbicide resistance and consequently poor weed control.
Although there have been no published studies of the effect of crop residues on herbicide efficacy in New Zealand, the international scientific literature clearly indicates that reductions in efficacy of soil-acting herbicides would be expected in New Zealand where crops are either directly drilled through cereal crop residues or where non-inversion cultivation is used in the absence of burning. This is due to the large volumes of cereal crop residue produced in New Zealand. Conversely, where crops residues are burnt every year there is likely to be a gradual increase over time in the adsorptive capacity of the soil surface layers that could eventually lead to severe reductions in the performance of soil-acting herbicides. However, annual burning of cereal crop residues in the same paddock is not likely to occur in New Zealand and, in any case, the data suggest that ploughing every 5 or 6 years will keep in check any build-up in adsorptive capacity due to ash accumulation.

3.4 Enhancing productivity
For some crops e.g. high value white clover for seed, it is exceedingly difficult to establish them into the quantity of residue left by a preceding cereal crop in New Zealand. Full inversion cultivation or baling cut straw and non-inversion cultivation are the only alternatives to stubble burning. For other crops, e.g. perennial ryegrass for seed, New Zealand research shows that for productivity, stubble burning is slightly preferable to chopping the residues and incorporation via minimum tillage but that both these approaches are far superior to direct drilling (Figure 3).

![Residue management (wheat straw & stubble) - LSD 410kg/ha](image)

**Figure 3. Influence of wheat residue management on following perennial ryegrass seed yields in Methven, Canterbury 2007 (Anon 2009).**

In trials on the Canterbury Plains from 2004-2006 large reductions in the yield of wheat following wheat were recorded when straw was incorporated (Figure 4). In some cases yield reductions have been associated with increased levels of the root disease take-all (*Gaeumannomyces graminis var tritici*), though this increase in root disease is not a consistent feature of burning versus incorporating straw residues.
Apart from a single, six-year long trial, there are no long term trials comparing the cumulative yield effects of stubble burning versus crop residue incorporation in New Zealand. However, results from a series of long term trials in the UK showed consistent yield increases in crops established following stubble burning compared to crops established following residue incorporation with tine cultivation (Table 11). The extent of the yield reduction (3-18%) associated with residue incorporation was influenced by soil type with yield reductions being greater on the lighter soils (e.g. High Mowthorpe and Bridgets).

The conclusions of a southern Australian review also supported this finding that productivity tends to be greater where crop residues are burned (Scott et al. 2010).
Table 11. Influence of long term residue management on yields of wheat at locations across the UK with clay and silty clay loam soils.

<table>
<thead>
<tr>
<th>Soil type &amp; location</th>
<th>Burn/tine</th>
<th>Chop/plough</th>
<th>Chop/tine</th>
<th>Std error</th>
<th>P</th>
<th>LSD₀.₀₅</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay soils</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boxtworth</td>
<td>7.84</td>
<td>7.70</td>
<td>7.43</td>
<td>0.080</td>
<td>&lt;0.01</td>
<td>0.230</td>
</tr>
<tr>
<td>Drayton</td>
<td>7.37</td>
<td>7.35</td>
<td>6.80</td>
<td>0.072</td>
<td>&lt;0.001</td>
<td>0.207</td>
</tr>
<tr>
<td>Rochford</td>
<td>6.15</td>
<td>6.10</td>
<td>6.12</td>
<td>0.117</td>
<td>ns</td>
<td>-</td>
</tr>
<tr>
<td>Silty clay loams</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bridgets</td>
<td>6.13</td>
<td>6.36</td>
<td>5.03</td>
<td>0.118</td>
<td>&lt;0.001</td>
<td>0.337</td>
</tr>
<tr>
<td>High Mowthorpe</td>
<td>7.90</td>
<td>7.55</td>
<td>6.86</td>
<td>0.086</td>
<td>&lt;0.001</td>
<td>0.247</td>
</tr>
<tr>
<td>Terrington</td>
<td>9.32</td>
<td>9.30</td>
<td>9.05</td>
<td>0.069</td>
<td>&lt;0.05</td>
<td>0.197</td>
</tr>
</tbody>
</table>

Summary mean data presented here; source: Turley et al., 2003. Figures in bold = highest mean yields for a given site.

3.5 Reducing cost of production

The use of stubble burning as a rotational management tool on New Zealand cropping farms has a large effect on the cost of production. This link is apparent at a number of different levels.

- **Number of cultivation passes.** Burning residues on farm reduces the number and intensity of cultivation passes carried out by the grower. This reduces production costs in terms of fuel usage (and associated CO₂ emissions), labour costs and machinery replacement and depreciation costs. Typically costs could be reduced by $50-70/ha depending on the intensity of the cultivation pass omitted, this would include fuel savings of approximately 8 - 13L/ha (Askin & Askin 2012). If the paddock was ploughed in order to incorporate residues, costs would be increased by approximately $100/ha in comparison to burning, this would include fuel of 21L/ha. N.B. Costing assumptions are based on farmer costs being 70% of contractor costs specified in Lincoln University’s Financial budgets manual 2012/13 (Askin & Askin 2012). Timeliness of establishment is difficult to accurately cost in the system, but after heavy rain, soils become workable far quicker where residues have been removed (burned or baled) than where they are retained.

- **Agrichemical usage.** Burning residues reduces costs through less use of agrichemicals, for example herbicide (weed killer; section 3.4) and molluscicide (slug pellet) applications (see section 3.7). The need for herbicide applications is reduced (both pre-sowing glyphosate and in-crop herbicides), since burning destroys a percentage of the weed seed population, the exact figure depending on weed species and degree of heat generated by the burn. A conservative cost saving based on one less herbicide application is $30-40per hectare. Without stubble burning there would be an increased emphasis on the use of herbicides on New Zealand cropping farms, particularly use of glyphosate pre-sowing, which could increase herbicide resistance pressures as more herbicide is used to keep weed populations in check. The need for molluscicide applications is reduced by stubble burning as a function of reduced slug numbers (see below).
• **Machinery requirements.** Burning crop residues reduces the amount of capital that needs to be invested in machinery required for straw incorporation. Many New Zealand-made cultivators and seed drills can work in paddocks where straw has been baled or burnt but would not be able to handle chopped straw residues (the machine would block up with straw, due to presence of tines and cultivation legs with insufficient clearance in the stagger spacing between them). Removing the ability to rotationally burn crop residues would increase the need for new machinery capable of dealing with chopped straw residues and as a consequence increase production costs.

### 3.6 Reducing pest pressure

There is surprisingly little published data worldwide regarding the impacts of stubble burning on pest numbers and damage in subsequent crops, and almost none from work in New Zealand. This section highlights key available information that is relevant to cropping in New Zealand.

#### 3.6.1 Nematodes

In Oregon, the incidence of Seed gall nematode (*Anguina agrostis*) was reduced by between 98 and 99% when seed fields of browntop were either open burned or propane flamed compared to the unburned control (Alderman & Young 1990).

#### 3.6.2 Slugs

Where residues are incorporated into the top surface of the soil, the incidence of pest attack, particularly slugs, is usually expected to increase. For example, in Canterbury the percentage of wheat with slug damage was five times higher in chopped straw compared to burned residue (Table 12). The risk is greatest where crops are established using direct drilling into chopped cereal straw. Ploughing will reduce slug pressure provided the resultant seedbed is not cloddy (a cultivated soil condition that also increases slug activity in following crops). Slug pressure and use of slug pellets has increased in UK crops in recent years and it is likely that the ban on stubble burning is a contributory factor. This increased use of slug pellets, combined with wet weather over winter, has resulted in some instances of contamination of freshwater with the mollusicide, metaldehyde, in the UK.

Table 12. Influence of residue management and establishment system on percentage of plants showing slug damage at 2 leaf stage (GS 12), cultivar Consort (Makikihi, South Canterbury 2005; Anon 2009).

<table>
<thead>
<tr>
<th>Establishment method</th>
<th>Residue Management / Drill used</th>
<th>Mean (all treatments)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Burned</td>
<td>Chopped</td>
</tr>
<tr>
<td></td>
<td>JD 750 A Simba C04 Broadcast</td>
<td>JD 750 A Simba C04 Broadcast</td>
</tr>
<tr>
<td>Direct</td>
<td>11 10 3 42 49 36 25</td>
<td></td>
</tr>
<tr>
<td>Min till (1 pass)</td>
<td>1 1 3 20 21 23 12</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>6 6 3 31 35 30 12</td>
<td></td>
</tr>
<tr>
<td>LSD</td>
<td>19</td>
<td></td>
</tr>
</tbody>
</table>

*JD 750 A is a disc based direct drill; Simba C04 is based on a duet tine band coulter.*
The density of slugs was slightly higher in burned versus non-burned ryegrass seed crops in Oregon (Table 13) (Fischer et al. 1996). The authors also noted a similar trend in Chewings fescue (Table 13). They note that “these results are contrary to the popular belief that a burnt field is ‘cleaner’ (has less straw residue) and thus, is a less desirable habitat for slugs.” There are now reports from Oregon that burning is helping to reduce slug damage and mollusicide applications where slugs have become a serious problem (Pat Boren – Crop Protection Service, personal communication, 2013).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>10 Nov</th>
<th>16 Nov</th>
<th>21 Dec</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burn</td>
<td>14</td>
<td>81</td>
<td>151</td>
<td>82</td>
</tr>
<tr>
<td>No Burn</td>
<td>7</td>
<td>42</td>
<td>131</td>
<td>60</td>
</tr>
<tr>
<td>LSD 5%</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 13. Slug numbers per plot for perennial ryegrass (PRG) areas and Chewings fescue field for burn and no burn (stubble chopped) (Fischer et al. 1996).

3.6.3 Hessian fly

Hessian fly (*Mayetiola destructor*) damage is a sporadic problem in NEW ZEALAND generally affecting cereal to cereal plantings. In the US, hessian fly problems increase as growers adopt minimum tillage or no-till practices. Stubble burning is recommended as one control tool to destroy surface pupae after harvest (Royer et al. 2009). In New Zealand, the observation has been that with Hessian fly stubble control is crucial. No-tillage or strip-tillage that leaves wheat stubble on the soil surface greatly enhances Hessian fly problems. Burning destroys pupae that are present in the straw, but does not kill pupae that have fallen out of the crop debris onto the ground. Therefore burning must be combined with discing to bury the pupae (Abie Horrocks – Plant and Food Research, personal communication, 2013).

3.6.4 Beneficial Insects

A study on burning of lucerne (alfalfa; *Medicago sativa* (L.)) stubble from the previous autumn seed harvest in the spring found that it reduced some pest insect populations in the year of the burn including alfalfa plant bug (*Adelphocoris lineolatus* (Goeze)) and Lygus bug (*Lygus* spp). Other pest specie populations, e.g. alfalfa weevil (*Hypera postica* (Gyllenhal)) and pea aphid (*Acyrthosiphon pisum* (Harris)), were reduced for the first year only when alfalfa was burned at 20-25 cm of growth. Burning had no effect on beneficial insect species in either year when alfalfa was burned before growth. However, burning at 20-25 cm of growth reduced populations of ladybird beetles for the first year and spiders for both years (Schaber & Entz 1988).
3.7 Reducing disease pressure
The implications for disease if straw residues are incorporated rather than burned, are in the main, neutral, unless growers are sequencing the same cereal crops in their rotations, for example barley after barley or wheat after wheat. In these cases, stubble-borne diseases, such as tan spot in wheat are likely to increase.

3.7.1 Soil borne disease
In a review on stubble management to control soil borne disease, Bailey and Lazarovitz (2003) noted that it has limited utility for plant disease control as elevated soil temperatures are seldom uniformly intense enough at the surface and throughout the upper soil profile where pathogen survival structures reside (Felton et al. 1987).

3.7.2 Leaf diseases
In a five year trial at two sites comparing tillage systems with stubble burning it was concluded that use of fire to manage diseases of barley (Hordeum vulgare L.) and canola (Brassica napus L.) diseases was ineffective (Kutcher & Malhi 2010). They noted that the severity of leaf spotting diseases of barley, mainly net blotch (Pyrenophora teres Drechsler), and incidence of sclerotinia stem rot [Sclerotinia sclerotiorum (Lib.) de Bary] of canola were sometimes greater in the burned treatment than the non-burned treatment.

3.7.3 Ergot
The germination of ergot (Claviceps purpurea) sclerotia was reduced by 64% in open burned browntop compared to the unburned control (Alderman & Young 1990). Ergot causes severe illness in humans and livestock if consumed and some markets, e.g. malting barley, have a zero tolerance of ergot sclerotia in harvested grain. Fungicidal control of ergot is ineffective and cultural control methods such as stubble burning are therefore particularly important for reducing carry-over of the disease.

3.7.4 Other diseases
Take-all, Eyespot and Tan spot are all cereal diseases that become problems in continuous cereals systems where stubble burning is not the primary method of residue management. The presence of previous crop residues is also an important consideration for the control of Fusarium, as the disease can use the residues as a place to harbour over winter. There is increasing potential for carry-over of Fusarium to the next crop where increasing amounts of Fusarium inoculums are present in the previous crop residues at harvest (Fraser et al. 2000).
4 Other residue management options

Key points

- Choice of residue management approach is influenced by a wide range of interacting agronomic and environmental factors, which vary across seasons, so cropping farmers do not commit themselves to the exclusive use of one residue management technique.
- Rotational burning is viewed by cropping farmers as a management tool that is used in conjunction with many of the alternatives presented in this section, none of which represent complete stand-alone alternatives.
- Compared to stubble burning, incorporation of residues into the soil surface by non-inversion cultivation (surface/top work) tends to be associated with increased weed problems.
- Ploughing to bury crop residue has adverse impacts on soil quality and erosion and is relatively costly in fossil fuel usage.
- Either method of residue incorporation requires stubble chopping and spreading but the machinery required to do this is not commonplace on New Zealand cropping farms.
- Baling and removing cut straw is hampered by unreliable markets for the baled material, by potentially costly delays to crop establishment that can result from baling operations, and by soil damage arising from increased vehicle movements in the paddock.
- Reliable establishment of economically important small seed crops is not possible by direct drilling into cereal residues left on the soil surface. Adoption of direct drilling into retained surface residues would therefore require substantial changes to many crop rotations and dramatically reduce New Zealand’s capacity for producing high value, small seeded crops.

4.1 Introduction
Theoretically, farmers have a tool box of residue management options as shown below.

1. Chopping and incorporating residues into the soil through:
   a. Non-inversion incorporation (surface/top work) or
   b. Ploughing (full inversion cultivation).
2. Removing residues from the paddock through:
   a. Burning (see chapter 3) or
   b. Baling and removing cut straw.
3. Retaining crop residue on the soil surface and direct drilling through it.

In a small number of scenarios there may also be options for using livestock to graze stubbles, or forage crops established in stubbles from the previous crop, and partially incorporate them into the soil surface although modern cropping practices mean that this is rarely done any more (see section 4.7).

As set out in Chapter 3, stubble burning is a valued cultural tool because it delivers the following key agronomic and environmental outcomes:

1. Retains small seed crops within sustainable and economically optimised rotations;
2. Maximises soil and seedbed quality by minimising the intensity of cultivation;
3. Enables sustainable weed management;
4. Enhances productivity;
5. Reduces cost of production;
6. Reduces pest pressure and;
7. Reduces disease pressure.
This chapter now explores the extent to which each of the other available residue management options can deliver this suite of outcomes. Appendix 5 summarises the information presented in chapters 3 and 4 using paired analysis to enable ranking of the different residue management techniques.

4.2 Incorporating crop residues via non-inversion cultivation (surface/top work)
Incorporation of crop residues into the soil by ‘non-inversion incorporation’ involves chopping and mixing the residues in the top few centimetres of soil. This contrasts with ‘full-inversion incorporation’ where the residues are fully buried by ploughing. In practice, in countries where burning of crop residues is not permitted, such as England and Wales, across substantial areas crop residues are managed by non-inversion incorporation and this has led to the development of new cultivation equipment capable of mixing the crop residues with the top soil.

Incorporating cereal straw residues into the soil surface by non-inversion incorporation has a number of agronomic implications for the following crop and these are discussed below.

4.2.1 Retaining small seeded crops within sustainable rotations
Incorporation of crop residues within topsoil limits crop choices following cereal crops compared to stubble burning. In particular, this rotation position would be rendered unsuitable for high value, small seeded crops such as grass seed, clover seed and vegetable seed production. In the case of crops such as white clover it is unlikely that the crop could be established successfully in a paddock where chopping and non-inversion cultivation was used.

4.2.2 Maximising soil and seedbed quality
As discussed earlier, non-inversion tillage tends to be associated with indicators of sustainable indicators of soil quality.

4.2.3 Enabling sustainable weed management
Incorporation of cereal straw residues using non-inversion techniques is likely to increase grass weed populations in the rotation, particularly where cereal crops predominate. There are three primary reasons for this:
1. More viable seeds are incorporated into a soil horizon where germination is likely to occur in the following crop;
2. Incorporating straw residues tends to reduce seed to soil contact, leading to poorer crop establishment and poorer competition with any germinating weeds;
3. Heavy stubble loads, even when incorporated with cultivation, increase % residue ground cover reducing the effectiveness of soil acting herbicides.

With non-inversion incorporation, growers would be more dependent on stale seedbed weed control using glyphosate (a technique where land is cultivated and rolled shortly after harvest in order to encourage germination of weed seeds, which are then sprayed off using herbicide before the next crop is sown). In addition growers would need to be prepared to use more in-crop herbicide in order to combat higher grass weed populations. A move from stubble burning to non-inversion cultivation would also be expected to increase the levels of contaminating cereal volunteers in grass seed crops.

4.2.4 Enhancing productivity
Data on the effects of short term straw incorporation, and long term studies conducted in the UK and Australia, indicate that when cereal straw residues exceed 4-5 tonnes per hectare, incorporation of these residues in the top soil reduces yields compared to burning. In many cases the yield reductions are
associated with inferior establishment in the presence of incorporated cereal straw. Increased weed competition and in some cases increased root disease, such as take-all, were other factors responsible for the yield depression when crops were grown in the presence of chopped straw incorporated by non-inversion cultivation. New Zealand cereal crop residues would typically well-exceed this 4-5 tonnes per hectare threshold.

4.2.5 Reducing cost of production
Compared to stubble burning, incorporating cereal straw residues using non-inversion cultivation would increase the number of cultivation passes or the cultivation intensity carried out in a single pass. It is estimated that 1-2 more cultivation passes would be needed assuming equipment was able to handle chopped straw on the surface. If that was not the case, non-inversion incorporation would require investment in new equipment or the use of full-inversion cultivation (ploughing) instead, with increased production costs of an estimated $50-150 per hectare and increased carbon dioxide emissions.

4.3 Incorporating crop residues via ploughing (full-inversion cultivation) Incorporation of crop residues into the soil by ‘full-inversion incorporation’ involves burying crop residues into the soil with a plough. This contrasts with ‘non-inversion incorporation’ where the residues are chopped and mixed in the top few centimetres of soil. The agronomic implications of full-inversion incorporation differ in important respects to non-inversion incorporation.

4.3.1 Retaining small seeded crops within sustainable rotations
Full-inversion incorporation would enable the continued production of high value, small seeded crops in the key rotation position following cereals. This is primarily because the crop residues are buried deeply enough within the soil to prevent them influencing establishment.

4.3.2 Maximising soil and seedbed quality
Compared to non-inversion cultivation, ploughing is widely regarded as deleterious to soil quality hence moves worldwide to encourage adoption of reduced tillage practices. Moves towards ploughing in place of non-inversion cultivation would lead to increased wind and water erosion risk, degraded soil aggregate characteristics, and would erode soil quality advances due to reduced tillage that have been achieved over the last decade. In addition, ploughing requires further cultivation to prepare a suitable seedbed. This, in turn, reduces seedbed moisture which hampers the establishment of small seeded crops.

4.3.3 Enabling sustainable weed management
One way in which cultivation can be used to reduce grass weed populations (where burning residues is restricted) is to plough prior to the next crop. This full inversion of the soil is very effective at reducing grass weed populations, such as brome species. This advantage of ploughing over non-inversion or surface/top work tillage was shown in recent research done in Mid Canterbury on the weed ripgut brome (Figure 5).
4.3.4 Enhancing productivity
In comparison to non-inversion incorporation, ploughing has not been associated with yield reductions in the following crop unless soil moisture loss is high and the seedbed is particularly cloddy or poorly consolidated (a problem associated with ploughing heavier, clayey soils).

4.3.5 Reducing cost of production
Ploughing is more costly than non-inversion cultivation (typically at least $100 per hectare) because:
- It requires greater operator skill levels.
- It necessitates subsequent additional cultivation passes to produce a seedbed. The number of additional passes is dependent on whether the seed drill itself can cultivate when sowing (a feature of many newer seed drills used in crop residue retention scenarios in Europe). These further follow up cultivations and consolidation of the seedbed alone potentially mean that establishment costs could be $100-150/ha greater than where growers currently burn crop residues, the exact cost depending on the number of cultivation passes employed after the ploughing operation.
- It is slower (0.8 -1.5 ha/hour ploughing compared to 4-6 ha/hr with non-inversion cultivation depending on implement width). In addition to the higher cost of cultivation per se, delays associated with the time taken to plough can reduce the timeliness of subsequent establishment operations with knock-on deleterious agronomic implications including reduced yield.

4.4 Machinery Implications of crop residue incorporation
Incorporating straw residues would require a number of capital investments to be made in order to ensure even distribution and thorough mixing of straw residues into the soil. Blockages of sowing equipment were cited as the primary reason for non-adoptions of direct drilling in a 2006 review carried out in southern Australia (Davies 2006). The review found that crop residues of 2-3 t/ha could be retained without posing many problems for machinery.
However, stubble loads of 4-5t/ha required extra processing (harrowing or slashing) before drilling could be considered. With New Zealand typically well in excess of this threshold, it is clear that a whole suite of new machinery would be necessary in order to provide growers with the ability to incorporate cereal crop residues. This new machinery would either be cultivators with greater capability to handle chopped straw (usually based on both discs and tines) or seed drills able to sow in the presence of chopped cereal straw. The principal investments required to incorporate cereal straw residues, if the grower has not already made these investments, are outlined below but it should be noted that many New Zealand cropping are unable to afford new harvesting and cultivation equipment and frequently buy second hand. As a consequence, technical innovation in this equipment can take considerable time to arrive on significant numbers of New Zealand farms.

- **Straw choppers fitted to the combine harvester.** These give the grower the ability to chop cereal residues straight off the combine harvester at the time of harvest, assuming that the straw is not to be baled. Straw choppers cut the straw into a range of smaller fragments and require extra horsepower from the combine harvester. For farmers with combine harvesters lacking a straw chopper this would mean investment in harvesting equipment or being dependent on a contractor. All new combine harvesters have straw choppers fitted as standard, so machinery replacement policies would ultimately make this equipment available on farm albeit after a number of years.

- **Chaff spreaders fitted to the combine harvester.** Chaff spreaders ensure that chaff from the harvesting process is distributed across a greater width of the cutter bar giving rise to more even distribution of harvest residue. Again all new combine harvesters come with chaff spreaders fitted as standard so machinery replacement policies would again, in time, rectify any short comings of existing equipment.

- **Cultivators.** Many New Zealand farms depend on simple tined cultivators such as the Maxitill, Sunflower etc. for seedbed preparation (Table 14). However, with retained chopped straw residues, cultivation equipment would need to be more suited to incorporation than is currently the case. Many examples of European cultivation equipment, developed as a result of generally heavier soils and stubble burning restrictions in that region, would be suitable for crop residue incorporation in New Zealand. A feature of these machines is often the combination of discs, tines and consolidating press wheels or rollers. In order to prevent residues accumulating under the machine, tines are staggered to allow flow of residues through the machine, a feature that increases the overall length of the cultivator. For cost comparisons with simple tine cultivators see examples in Table 14 below.

- **Seed drills.** Typical hoe coulter seeding drills would need to be replaced by drills with stronger sprung coulters capable of working in mixes of soil and chopped straw. These more robust cultivation drills are now common place on UK farms but are not the norm in New Zealand at present. In the direct drill market it is possible to purchase direct drills reasonably cheaply that can sow into stubble where the straw has been removed or burnt, however in many cases these drills would not be suitable for direct drilling into chopped cereal straw. This would require a more major investment such as a Cross Slot or Simba CO4 which has been successfully used in full stubble retention scenarios. For cost comparisons see examples in Table 15 below.
Table 14. Typical cultivation machinery costing (Implement cost ($), Running cost ($/ha), Fuel Usage (l/ha) and Tractor Horsepower range.

<table>
<thead>
<tr>
<th>Cultivators</th>
<th>Implement Cost ($)</th>
<th>Running Cost ($/ha)*</th>
<th>Fuel usage (l/ha)*</th>
<th>Tractor Horsepower (hp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machinery geared to straw incorporation and seedbed preparation - cultivator</td>
<td>150-165,000</td>
<td>70-80</td>
<td>11-15</td>
<td>280-320</td>
</tr>
<tr>
<td>Machinery geared to cultivation following burning - cultivator</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vaderstad Top Down (5-6 m model)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maxitill (various models)</td>
<td>25-60,000</td>
<td>40-50</td>
<td>7-9</td>
<td></td>
</tr>
<tr>
<td>Simba SL (4-7 m model) machine directly attached to tractor unit (followed but another cultivator and roller)</td>
<td>135-182,000</td>
<td>70-80</td>
<td>11-15</td>
<td>280-320</td>
</tr>
<tr>
<td>Sunflower (model 5 – 6.7m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horsch mt Terranno (4.6 m model)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implement Cost ($)</td>
<td>130,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------</td>
<td>---------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Running Cost ($/ha)*</td>
<td>60-70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel usage (l/ha)*</td>
<td>11-13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tractor Horsepower *(hp)</td>
<td>280-320</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Delivered unassembled

Note that machinery costings are strongly influenced by the area of crop over which the equipment is used. Figures are presented here for broad comparison of machinery type.

Fuel consumption figures and running costs are based on figures derived from the nearest machinery comparison (Askin & Askin 2012) and from personal communication with machinery dealers.
Table 15. Typical drilling machinery costing (Implement cost ($), Running cost ($/ha), Fuel Usage (l/ha) and Tractor Horsepower range.

<table>
<thead>
<tr>
<th>Seed drills</th>
<th>Machinery geared to straw incorporation and seedbed preparation – cultivator drills</th>
<th>Machinery geared to cultivation following burning – seed drills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simba Pronto (6 m model)</td>
<td><img src="image" alt="Simba Pronto" /></td>
<td>A large range of products is manufactured in New Zealand of varying operating widths (3m-6m). These machines are typically used following intensive cultivation or burning</td>
</tr>
<tr>
<td>Implement Cost ($)</td>
<td>160,000</td>
<td>40-100,000</td>
</tr>
<tr>
<td>Running Cost ($/ha)*</td>
<td>100-120</td>
<td>70-80</td>
</tr>
<tr>
<td>Fuel usage (l/ha)*</td>
<td>8-10</td>
<td>4</td>
</tr>
<tr>
<td>Tractor Horsepower (hp)</td>
<td>200-220</td>
<td>80-140</td>
</tr>
</tbody>
</table>

| Vaderstad Rapide (5-6 m model)                    | ![Vaderstad Rapide](image)                                                        |                                                                  |
| Implement Cost ($)                               | 175-180,000                                                                       |                                                                  |
| Running Cost ($/ha)*                             | 100-120                                                                           |                                                                  |
| Fuel usage (l/ha)*                               | 8-10                                                                              |                                                                  |
| Tractor Horsepower *(hp)                         | 280-320                                                                           |                                                                  |

* Delivered unassembled. Note that machinery costings are strongly influenced by the area of crop over which the equipment is used. Figures are presented here for broad comparison of machinery type.

Fuel consumption figures and running costs are based on figures derived from the nearest machinery comparison (Askin & Askin 2012) and from personal communication with machinery dealers.
4.5 Baling and removing cut straw

Baling and removing cut straw is one alternative to burning or incorporating it. In New Zealand, baling is typically assumed to remove around 80% of the total above ground crop residue. However Lafond et al. (2009) showed that in Canada, the amount of wheat straw removed by baling is considerably lower at 22 – 40%.

Baling is already practised with a number of crops using a wide range of equipment and contracting services. The popularity of this practice varies with crop, straw price and nutrient replacement cost. The livestock sector primarily drives demand for straw, though locally important markets for mushroom composting also feature. Baling is commonly practised with barley, grass seed residue and pea straw, but there is less demand for wheat straw which is less palatable and may be burned instead as a consequence.

Surplus straw may be used for a number of useful purposes such as: stock feed; fuel; source of chemicals; building material; livestock bedding (cows, pigs, poultry); composting for mushrooms; bedding for strawberries, cucumbers, avocados etc; mulches for orchards, vineyards etc. Currently, however, each of these outlets utilises a relatively small proportion of the total amount of residue that is produced each year.

Although straw has been fed as roughage ever since grain was first grown, the use of straw residues as animal feed is generally limited by its low nutritive value and also by the amounts that animals are capable of eating (Alderman & Mason 1984). Straw varies considerably in its value as a feed, both physically and chemically, with variation between species and also between varieties. Overall, however, cereal straws are not capable of sustaining production diets at high levels of inclusion, as the animals could not eat or digest enough in a day to meet their energy requirements.

4.5.1 Retaining small seeded crops within sustainable rotations

Baling cut cereal straw (the principal residues that are currently burnt) would remove much of the dry matter residue that could impede the establishment of the following crop. The proportion of dry matter removed by baling is commonly quoted at 80%, remembering that stubble length is minimised when baling is considered. Removing this surface dry matter also removes residue that harbours pests, such as slugs, as well as ensuring better seed soil contact for sowing the following crop. Baling therefore increases the rotational crop options following cereals relative to incorporating residues and allows the operation of equipment that is currently used on New Zealand farms following burning.

Baling is generally cost-neutral as the costs involved plus the value of the nutrients should normally be covered by the sale of the baled straw. However, markets for baled straw are unreliable and baling can result in costly delays (see below).

4.5.2 Maximising soil and seedbed quality

Removing cut straw from the paddock by baling can result in less need to cultivate the soil and may increase the opportunities for direct drilling, by allowing the use of a wider range of New Zealand made seed drills that would not be suitable for sowing if all residues were retained. As a consequence, it is compatible with cultivation practices that tend to lead to improvements in soil quality. However, during a wet harvest, increased wheeling damage is likely to occur through the baling and carting operations and this will require more, not less, cultivation to remove the resultant compaction.
4.5.3 Enabling sustainable weed management
Baling cut straw can remove weed seeds from paddocks, but the extent of this benefit will depend on the maturity of weed seeds in relation to the time of harvest. Unlike burning, baling will not destroy or remove weed seeds which have matured and been shed by the plant. To fully take advantage of baling as a means of weed control, most crops would need to be harvested earlier for forage rather than grain, since weed seeds would be less mature and less likely to shed. Therefore, when harvesting for grain, burning allows opportunities for much later weed control than baling.

In comparison to incorporating cereal crop residues, baling cut straw will reduce weed pressure in the rotation which is likely to equate to reduced herbicide application. However overall, baling is unlikely to be as effective as burning in terms of reducing weed populations, particularly with grass weeds (Cussans et al. 1987).

4.5.4 Enhancing productivity
Removal of cereal crop residues can enhance the productivity of the following crop, especially where there is a large volume of residues present. Current cereal crop varieties are producing up to 15 tonnes of residue per hectare and although crop sowing machinery has been developed to try and cope with handling this volume of residues, the establishment of the following crop may still be impaired by the physical presence on the soil surface (assuming they are not incorporated) of such large volumes of residues. In addition, although benefits of soil moisture retention have been found through having residues remain on the surface, slug and disease pressure also commonly increase where residues remain, which can also impact on the productivity of the following crop.

An arable farmer may choose to use a contractor to bale and remove the straw for a royalty that will be slightly above the value of the nutrients removed. This can help to manage workload during a busy period. Where the farmer has their own baler or pays a baling contractor on a per bale basis, they have the option of holding this feed material and realising a more profitable sale in the winter. However, stacking bales is time consuming and occurs during a busy period. Also, covering the bales with tarps will be potentially dangerous and expensive and the straw quickly deteriorates once it is one year old if it does not sell, even when covered. Currently the spot price for straw is very weak and many farmers have stacks that are unusable except for mulch which is commercially worthless.

4.5.5 Reducing cost of production
The costs of baling are primarily composed of the operation cost itself ($200-300/ha4, partly depending on bale size) and the nutrient removal (dependent on straw type and weight). As a counterbalance, in the absence of being able to burn, baling could provide savings in establishment costs of the next crop in comparison to straw incorporation. Baling, whilst not always as effective as burning at removing residue from the surface, should allow the reduction of at least one cultivation pass (costed at $25-45/ha for conventional cultivation equipment). Alternatively with straw baled, as opposed to incorporated, conditions might allow the successful use of direct drilling (cost savings $50-90/ha based on conventional cultivation passes).

Additionally, baling cut straw enables growers to continue using existing cultivation equipment without making significant capital investments in harvesting, cultivation and sowing equipment necessary for seedbed preparation if straw residues were retained.

4 Based on a 10t/ha grain yield.
However, the baling operation slows down the establishment of the following crop by increasing paddock turn round times. This is particularly important during wet harvest periods, where in addition, baling leads to increased wheeling damage that requires more, not less, cultivation to remove the compaction. Additionally, there are risks associated with baling including:

- Growers failing to replace nutrient off-take in baled products (due to the high cost of nutrient replacement or ignorance of straw nutrient content);
- Absence of a market for the baled product, such as wheat, which is the primary residue burnt at present. NB Some fungicides that are used tactically to manage fungicide resistance in certain cereal diseases can render the straw unfit for feed and it must be disposed of within the paddock by burning or incorporation.

### 4.6 Retaining crop residue on the soil surface and direct drilling through it

An alternative to using burning, cultivation or baling cut straw to remove crop residues from the soil surface is leave them in place and directly drill the next crop through the material, which may or may not be chopped depending upon the farmer’s preference.

In 1989, it was reported that less than 10% of crops were established by direct drilling in New Zealand (McGuigan 1989), apparently mainly due to the practical difficulties encountered with the method at that time. The large volume of residues remaining on the soil surface often leads to machinery blockages, particularly where non-specifically designed equipment is used, or where the residues have not been chopped to short lengths (Staniforth 1982). Significant advances in machinery technology have enabled farmers to cope better with the simultaneous increase in straw volumes that have resulted from plant improvements over the same timeframe.

In 2005, a survey conducted by Crop & Food Research found that direct drilling had increased to being used by about 18% of growers, that 50% still ploughed and the remainder carried out minimum tillage. Then by 2011 in a survey conducted by FAR the figures had changed to 21% direct drilling, 21% ploughing and 58% carrying out minimum or non-inversion tillage practices (Fraser & Lawrence-Smith 2011). These figures suggest that there has been a movement by growers away from more intensive tillage practices in New Zealand over the last 20 years.

### 4.6.1 Retaining small seeded crops within sustainable rotations

Establishment of small seeded crops by direct drilling through cereal crop residues on the surface is exceedingly difficult. Amongst other problems, surface crop residues in direct drilling systems can potentially decrease soil temperatures and cause a delay in the emergence of the next crop (Gupta et al. 1988).

### 4.6.2 Maximising soil and seedbed quality

Overall benefits from having crop residues present on the soil surface can include: enhancement of soil structure; protection from erosion; promotion of nutrient cycling; control of some weeds and some diseases; and improvement of soil water and temperature conditions (Hoffman 1991). In addition, under direct drilling regimes, soil biological activities (particularly earthworm populations) are enhanced. The residue cover in direct drilling systems provides a favourable environment for the survival of various other soil invertebrates as well as earthworms (Edwards et al. 1992). However, less direct contact of the residues with the soil is also likely to reduce the microbial activity contributing to slower rates of decomposition.
4.6.3 Enabling sustainable weed management
Residues may harbour weeds and their presence is associated with increased herbicide use in direct drilling systems compared with conventional (inversion or non-inversion) cultivation (Griffith & Wollenhaupt 1994; Forcella et al. 1994).

4.6.4 Enhancing productivity and reducing cost of production
Speed and timeliness of drilling can be improved through adoption of direct drilling and the associated costs of production reduced. However, rotational options are limited and herbicide costs are likely to be higher than with non-inversion or full-inversion cultivation. There can also be an increased incidence of slugs (Butterworth 1985) and brown stem rot under direct drilling. Where straw on the soil surface leads to wetter soil conditions the likelihood of root pathogen survival is also increased (Cook & Haglund 1991).

4.7 Other crop residue management options
Some New Zealand farmers use grazing livestock to assist with crop residue management but this can only be adopted in certain farming systems and specific parts of the rotation. One approach, which was more prevalent in the 1990s than now, involves under-sowing a spring cereal crop, typically spring barley, with clover for grazing. Another approach involves direct drilling a green feed crop (grass seed, forage brassicas or oats) into cereal stubble. Grazing animals are important in these systems as they are used to graze off and/or trample the cereal stubble after its harvest. The animals thus also assisted with nutrient cycling through their dung and urine returns.

4.7.1 Under-sowing clover
Where the crop is under-sown with clover, the intention is to take the clover for a seed crop in the following year. The residues from the cereal crop remain on the soil surface after harvesting and the previously-suppressed under-storey clover crop was then able to grow through the residues. The clover supplies the crop with some additional nitrogen through the process of nitrogen fixation, thereby possibly enhancing the decomposition rate of the cereal residues as well as increasing the soil biota and earthworms in particular (Fraser & Piercy 1998).

However, under-sowing cereal crops is now rarely practiced following the move towards higher-yielding, autumn sown cereals that has occurred over the past 15-20 years. Establishing under-sown crops in autumn cereals is more difficult than in spring cereals due to competition and complications with weed control. It is also now widely recognised that planting cereal crops after fertility-building clover crops delivers greater benefits in terms of nitrogen supply than under-sowing with clover. Thus, the practice has little relevance today as a mainstream alternative stubble management technique.

4.7.2 Establishing green feed crops
Green feed establishment following cereal stubbles is still commonly practiced on the Canterbury Plains but requires a profitable livestock enterprise to graze these forage crops (commonly oats & brassicas). At present, the most profitable livestock enterprise is dairying. Lamb finishing (where lambs are brought onto cropping farms to be gain weight over winter) tends to be variable in terms of profitability and therefore not a fixed component of the farming enterprise. All of these livestock enterprises involve an over-winter grazing period which has to be carefully managed if it is not to result in nutrient losses to ground water. Forage crops can be established in the presence of chopped straw but most growers reduce the intensity of cultivation needed for forage crop establishment by baling or burning the cereal
residues first. Irrespective of method of establishment, grazing green feed crops obviously precludes the drilling of autumn sown small seed crops, such as grass seed, clover and vegetable seeds, since the commitment to a grazing period in the autumn/winter results in the following crops being spring sown.
5 Management of stubble burning

### Key points

- Both wild fire and smoke discharge risks are managed effectively through a combination of legislation and regulation and good management practice by the majority of growers who burn crop residues.
- Stubble fire escapes requiring emergency responses are rare.
- Stubble burning potentially reduces the risk and the intensity of wild fire events in cropping areas.
- Adverse impacts could be reduced further by improvements to, and wider adoption of the Ashburton District Council/Federated Farmers *Crop Residues Burning Code of Practice*.
- Effective communication and engagement between stakeholders is important.

#### 5.1 Introduction

This report has noted that land use change away from cropping, alongside increased marketing opportunities for cut straw and changing arable practices, have resulted over time in a reduction in stubble burning (Section 1.4). Nevertheless, it remains an important rotational tool in certain situations.

It is recognised that there are some associated potential adverse impacts on the community from the practice of stubble burning. As a result, the management of the practice require careful attention. This chapter explores the potential adverse impacts and how these can be managed effectively.

#### 5.2 Potential adverse effects of stubble burning

The potential adverse effects of stubble burning fall into two broad categories. Firstly, there is a potential for a stubble fire to break containment and threaten property and lives. Secondly there is the potential nuisance and, in some cases, danger, presented by the resultant smoke discharge.

##### 5.2.1 Stubble fire escapes

The risks of stubble fire escape appear well managed. Available data are scarce, as no organization or authority is required to record the frequency of stubble burns in an open fire season. This makes it difficult to estimate the proportion of stubble burns that result in escaped fires, although Rural Fire Authorities are required to investigate the causes of any escaped fires. The Ashburton District Council (ADC) administers rural fire control for the key area of arable production in New Zealand and anecdotal evidence from that area suggests that escapes occur from only a very small proportion of stubble burns, perhaps less than 1% in most years (Don Geddes, personal communication, 11 June 2013). ADC does, however, report that the number of escaped stubble fires that resulted in an emergency response has averaged just fewer than nine per year over the past ten years, although significant variation occurs between seasons (ADC data).
Figures from the National Rural Fire Authority (NRFA) show that fewer than 20%\(^5\) of the total number of escaped fires in New Zealand were the result of ignition for land clearance (NRFA data). The data are not broken down into land clearance type and this figure will include vegetation clearance other than stubble burning such as scrub, stumps or woody vegetation clearance.

So, while a small number of stubble do escape containment, significant damage to property or danger to people is relatively rare with crop residue fires undertaken by farmers in Canterbury. The NRFA supports the use of fire as an effective land management tool for the farming sector if its use is undertaken with care (Don Geddes and Murray Dudfield – National Rural Fire Officer, personal communication, 11 June 2013).

5.2.2 Smoke nuisance
Smoke nuisance is a potential adverse impact of stubble burning but is rarely a problem in rural areas. However, when it is blown through urban areas or where wind speed is not sufficient for effective dispersal it can create nuisance. In rare situations, for instance where it compromises the visibility for road traffic, it can present a potential danger.

Stubble burning takes place in a compressed period of time where the conditions are often such that the fuel is dry and produces a hot, rapid burn with minimal smoke discharge. However, if cool, wet conditions prevail following harvest then a good, fast burn may not be achieved, as the residues may be too damp. While a dry, rapid burn is preferable for growers, in the case of a delayed harvest, when the window between harvest and sowing the following crop is narrow, some paddocks may need to be burnt in damp, cool conditions.

Where residues are burned, the direction of the prevailing wind can be of particular importance especially in terms of its nuisance value to others. In inland Canterbury, for example, hot nor’west winds predominate in the summer, with easterly sea breezes along the coast. This wind pattern provides the key to stubble smoke disposal, keeping it away from the more populated areas.

5.3 Current management of adverse effects
Both smoke discharge and wild fire risks are managed through a combination of legislation and regulation, and good management practice by the growers who burn.

5.3.1 Reducing wild fire risk
Regulation to manage the risk of wildfire from stubble burning is well developed in New Zealand. Under the Forest and Rural Fires Act 1977 (http://www.legislation.govt.nz) Rural Fire Authorities (RFAs) have the mandate to regulate fire activities and to take any action deemed necessary to manage the risk of wild fire. An RFA can be a Territorial Authority, the Department of Conservation or an enlarged Rural Fire District which is comprised of a number of previously independent RFAs\(^6\). All discharge their responsibility for public safety through a Principal Rural Fire Officer (PRFO). The most important tool at the disposal of the PRFO is the ability to set Fire Seasons which apply an escalating level of control based on risk. As part of their assessment there is a set of objective data criteria co-ordinated by the NRFA

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\(^5\) There is not sufficient consistency of data collection method to give a suitable average however at no point does it exceed 20%

\(^6\) They can also be the Ministry of Defense or Private Forestry Companies.
called the Fire Weather Index which collects weather data from 150 remote weather stations nationwide (http://nrlf.fire.org.nz/fire_weather/fwsys/). The PRFO can set three fire seasons:

- Prohibited – no fires in the open air are permitted\(^7\)
- Restricted – some fires in the open air will be permitted with strict conditions, often requiring a specific or seasonal permit
- Open – lawful open air fires are permitted without prior consent from the PRFO, in some cases specific RFA conditions can exist in certain areas.

In conjunction with the setting of fire seasons, the specific risk presented by stubble burning is often managed through additional regulations. Key RFAs\(^8\) have established a relatively standard set of criteria to govern the practice which include

- minimum width, non-combustible fire breaks at burn ground margins,
- requirements for people and fire suppression equipment to be on hand,
- a maximum wind speed level at the time of lighting
- an awareness of weather conditions, particularly wind speed and direction,
- a requirement to light in daylight hours only.

There are legislative enforcement tools in place including the provision for full cost recovery of suppression costs by the RFA (Forest and Rural Fires Act 1977, Section 41), recovery of loss and damage costs by effected property owners (Section 43) and prosecution for those that are found to be operating outside regulations (Section 61). For the Ashburton District Council at least, there is a general policy of strict enforcement (http://www.ashburtondc.govt.nz/services/firecontrol/policies+bylaw.htm).

Alongside regulations, a certain standard of good practice for stubble burning is fostered by farmers’ organisations, such as Federated Farmers, through relevant information dissemination and communication with PRFOs. Farmers also contribute representatives to key regional and sub-regional fire committees\(^9\) where they receive direct feedback from PRFOs to communicate back to the farming community. In the Ashburton District, Federated Farmers and the PRFO jointly developed the *Crop Residues Burning Code of Practice* (COP) which operates alongside regulations set by the RFA to ensure that stubble burning remains a relatively low risk activity. The COP goes beyond the minimum requirements set by RFAs and is rigorously promoted through Federated Farmers’ leadership and communications strategy. This COP has now been adopted by the Regional Rural Fire Committee.

As the harvest season progresses, the activity of stubble burning itself reduces the instances and the intensity of wild fire events in cropping areas through efficient and controlled removal of combustible plant material (the fuel loading) that builds up in Canterbury at a time of year where the risk of wild fire (through any ignition source) is high, reduces the risk of wildfire and can limit the speed and distance that a wildfire event will spread. In the early history of mid-Canterbury, wild fires started by steam trains burned from the Main South Road to the sea during nor’west gales and were unstoppable.

\(^7\) Rural Fire Authorities have the ability during a Prohibited Fire Season to issue special permits where weather conditions have some temporarily reduced the fire hazard as to make it apparently safe to light a fire (Forest and Rural Fires Act 1977, Section 24 (1)(b)).

\(^8\) RFAs in Canterbury which have the vast majority of the area of New Zealand’s arable production under their authority.

\(^9\) The Northern South Island Regional Rural Fire Committee is comprised of all South Island Rural Fire Authorities in eastern territories north of the Waitaki River and Westland (www.ruralfire.org.nz)
5.3.2 Reducing smoke nuisance
Smoke nuisance and issues of public safety can be managed through District Council Bylaws, and RFAs have some discretion to address concerns of public safety. For example Ashburton District Council Bylaw 703.1 controls discharge of smoke from fire lit in the open air (http://www.ashburtondc.govt.nz/council/Bylaws/) and makes it an offence to for any person to light a fire in the open air where it causes or could cause “a smoke or ash nuisance to any person (a.iii) or a hazard to traffic (a.iv)”. The activity is also regulated (as a permitted activity) through Environment Canterbury’s Natural Resources Regional Plan (NRRP). Rule AQL28.1: The dispersal or deposition of particles shall not cause an objectionable or offensive effect beyond the boundary where the discharge originates” (http://ecan.govt.nz/publications/Pages/chapter-3-nrrp.aspx).

Smoke discharge also is partly managed through the application of good management practice. Farmers are encouraged to take note of possible nuisance created by smoke discharge, particularly in relation to wind direction and to communicate clearly with neighbours who may be affected (Federated Farmer Mid Canterbury Newsletter, March 2012).

5.4 Further mitigation of adverse effects

5.4.1 Wildfire risk
The powers and responsibilities afforded to Rural Fire Authorities and Principal Rural Fire Officers seem to be sufficient to address adverse impacts with regard to the risk of wild fire (Don Geddes, personal communication, 11 June 2013). However, Farmers’ organisations, including FAR and Federated Farmers, also have a key role to maintain close contact with key PRFOs and ensure that the farmers they serve understand their obligations with regard to fire risk and to ensure that there is a culture of adherence to RFA regulations.

5.4.2 Smoke nuisance
Smoke nuisance is a particular issue as urban areas encroach on previously rural areas, putting pressure on the existing burning activities of rural land owners. It is inevitable that there will be smoke trespass. The situation is further complicated by the requirement for light wind conditions to manage wild fire risk, which often leads to poor conditions for smoke dispersal. While a reasonably brisk wind speed will help significantly with smoke dispersal, a rapid wind speed creates an undue risk for escape and also compromises the ability of responders to contain any escaped fire. Over the course of a burn, wind speed will not remain constant and a narrow range would be problematic. It is inevitable that in the interests of achieving a safe burn that safety will from time to time prevail over the need to minimise nuisance.

5.4.3 Further development of good practice
Given the role of the Crop Residues Burning Code of Practice in managing the risk of wild fire, it would not be prudent to set aside or complicate the existing management framework. It may be necessary however to review this document in order to specify measures that could be taken to mitigate the risk of smoke nuisance to further supplement regulations and bylaws which. Smoke discharge was briefly contemplated during the initial consultation with the Rural Fire Authority, in the form of a recommendation to be mindful of smoke discharge but it would be appropriate to enter into consultation with relevant regulators, including District and Regional Councils, to amend the Code of Practice to consider smoke discharge and add specificity. Language would be a matter for consultation but in revising the document the parties might consider:
Avoiding fires in circumstances where smoke could present a danger to the public because of wind speed and/or direction
Avoiding fires where discharge of smoke into populated areas where it might cause nuisance because of wind speed and/or direction
Monitoring the likelihood of wind change with specific regard to smoke

The *Crop Residues Burning Code of Practice* and RFA regulations already require that short and medium term weather forecasts be consulted so farmers are already required to be aware of wind conditions. Evidence suggests that compliance is high.

The Ashburton District Council has also suggested that it would be appropriate for growers who are burning in fields particularly close to a high traffic road, especially a state highway, to display signs advising motorists of a potential visibility hazard (Don Geddes, personal communication, 11 June 2013). However, such action would not release the grower from his or her obligation to ensure that smoke does not present a danger to road traffic.

**5.4.4 Communication of good practice**

For all potential adverse impacts produced by stubble burning, it is important to note that farmers’ representative bodies’ promotion to stakeholders and the establishment of a culture among growers is as important as the development of a reference document to achieve desired outcomes. Any revision of the existing Code of Practice would need to be clearly communicated to growers, not only to inform but to ensure that growers are pressured by their peers and others to adhere to the Code of Practice.

To this end, there is an opportunity to broaden and enhance grower engagement with other regulators, using the Code of Practice as basis for that engagement. We suggest that that it would be appropriate for Environment Canterbury (and other regional authorities) to be brought in to regular consultation as part of further development and promotion of the *Crop Residues Burning Code of Practice*. Although all Canterbury RFAs have now adopted the Code of Practice, there is a need for further promotion outside of Mid Canterbury to other key arable areas.

The authors consider that Federated Farmers should make better use of an expanded network of communication by involving other key arable farming organisations, particularly the Foundation for Arable Research (FAR) and Canterbury’s rural supplies merchants. Similar to Federated Farmers, FAR regularly issues grower advisories and hosts grower field days at trial sites. The agronomic aspects of stubble burning are often the subject of FAR communication, and there is an opportunity to also address the mitigation of the adverse effects. FAR’s annual Field Day at Chertsey and similar events would be especially appropriate to transfer knowledge of appropriate burning practices and to entrench an awareness of the responsibilities incumbent upon the arable farming community to mitigate potential adverse impacts.

While the Federated Farmers Mid Canterbury Newsletter is delivered monthly to all rural box holders, and there are regular email notifications during the fire season, the use of other methods of communication should be explored. Social Media should also be considered as a useful and relatively immediate medium, particularly with the advent of smart-phones and other methods of communication. FAR has a database of the majority of growers’ mobile details and text communication could be an ideal medium for communication, particularly for time sensitive information such as changes in the fire season or as a warning on days when weather conditions, principally forecasted changes in wind speed and direction, may mean that there is an unexpected elevated risk level.
Effective communication with rural community stakeholders other than growers, as well as the general public is likely to mitigate some adverse impacts. Farmers should be further encouraged, where practical, to contact affected neighbours prior to individual stubble burns, as is currently in the Code of Practice. More active engagement with townships in the key areas would also be useful prior to the stubble burning season, particularly in areas with an accumulation of farmlets and lifestyle blocks. An advertised field day was suggested by one PRFO (Don Geddes, personal communication, 11 June 2013) to educate non farmers about the rationale behind burning and to address the potential adverse effects. In the past a Federated Farmers representative has presented to community organisations in Ashburton and more of this type of engagement may produce closer ties with rural towns and help to alleviate some of the adverse effects.

5.5 Proposed action plan

- Promote good stubble burning practice, including adherence to RFA regulations, through publications, emails, and events organised by Federated Farmers and FAR. These could include FAR’s ‘Arable Updates’ and a stubble burning feature at the annual FAR ‘Crops’ event held December 2013 & then again in 2014.
- Improve public understanding of the practice of, and rationale for, stubble burning. This could include appropriate publications and field events such as, for example, a joint Federated Farmers and FAR presence at public shows such as South Island field days.
- Take a collaborative approach to further development of the *Crop Residues Burning Code of Practice*, including specifying measures to reduce risk of smoke nuisance.
- Promotion of the *Crop Residues Burning Code of Practice* amongst RFAs beyond mid-Canterbury.
6 Gaps in knowledge
During the course of this technical review, the panel reviewed a considerable amount of data from New Zealand and overseas. This highlighted some important gaps in our knowledge of the impacts of different crop residue management options have become apparent.

6.1 Slug management
Some evidence from the review of international literature challenges the conventional view that retention of crop residues increases slug problems. In contrast, data from trials in Canterbury show elevated slug damage in the presence of residues. Further work is needed to clarify the impact of residue retention on slug damage. If this confirms suspicions that slug pressure is increased where residues are retained, then new slug management strategies would be needed to support a reduction in stubble burning. There is therefore a need for further research work was to identify the impact of crop residue management on slug populations and behaviour and, if necessary, develop novel slug management approaches for situations where crop residues are partially or full retained.

6.2 Long term impacts of residue management
There has only been one long term study of the impact of residue management on a range of agronomic and soil quality parameters in New Zealand. This was limited to one site and six years. It would be particularly informative to establish some long term trials on a range of soil types in areas of differing climate to investigate the long term impacts of different residue management techniques on:
- Soil quality and biological processes including decomposition and the accumulation of organic matter;
- The dynamics of weed grass populations;
- The diversity, abundance, and behaviour of beneficial insects.

6.3 Composition of cereal straws
This review summarises available evidence of the value of crop residues in terms of plant nutrients that become available as residues decompose and in terms of nutritional value to livestock. However, good data on the range of cereals grown across New Zealand’s soils and climate zones is exceedingly limited. Further analysis of cereal straw collected from around New Zealand and over a number of growing seasons would greatly increase confidence in our knowledge of the variation in nutrient content of different crop residues i.e. the fertiliser replacement value.

6.4 Land use change
Arable cropping competes with a range of other land uses within Canterbury and across New Zealand. The sector is under acute and increasing pressure due to rising costs of inputs (especially water and fertilisers), loss of agrichemicals for pest, weed and disease control, and, for some key crops, declining pollinator activity. It would be informative to understand the potential impacts of any changing residue management practises on the blend of land uses.

6.5 Amount of straw removed by baling
It is difficult to find definitive figures on the proportion of dry matter removed from a harvested paddock by baling. The commonly quoted figure in New Zealand is 80%, however Lafond et al. (2009) found that in Canada, the amount of wheat straw removed by baling is lower, 22 – 40%.
Appendix 1

Harvest index, average grain yield, and production area for the most commonly burned cereal crops in New Zealand and comparative data (where available) for Australia, and the UK.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Harvest index</th>
<th>Average grain yield (tonnes per ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NZ</td>
<td>Australia</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.54-0.60&lt;sup&gt;6&lt;/sup&gt;</td>
<td>0.37</td>
</tr>
<tr>
<td>Barley</td>
<td>0.46-0.53&lt;sup&gt;6,7&lt;/sup&gt;</td>
<td>0.38</td>
</tr>
<tr>
<td>Maize (grain)</td>
<td>0.50&lt;sup&gt;8,9&lt;/sup&gt;</td>
<td>0.49</td>
</tr>
<tr>
<td>Oats</td>
<td>0.43-0.47&lt;sup&gt;7&lt;/sup&gt;</td>
<td>0.30</td>
</tr>
</tbody>
</table>

<sup>1</sup>Unkovich et al., 2010; <sup>2</sup>Stoddart & Watts, 2012; <sup>3</sup>Curtin et al., 2011; <sup>4</sup>Australia Grain Yearbook – data for 2011; <sup>5</sup>ADAS Harvest Report 2012; <sup>6</sup>FAR Cereals Update No. 113; <sup>7</sup>Gallagher et al., 1983; <sup>8</sup>Underwood, 1985; <sup>9</sup>Pearson & Glassey, 2008. Note: Significant regional variations exist across Australia. Figures represent the range or average.
Appendix 2
Annual production (tonnes) from Statistics New Zealand Agricultural Production Survey/Census\(^\text{10}\). As: (1) no survey or census were conducted in 1997, 1998, 2000, or 2001 for these crops, (2) in 1999 a survey was conducted but data were not located, and (3) the Statistics New Zealand website does not provide information for all crops in all years; total production for these years was filled from New Zealand Inventory Spreadsheet and is shown in italics.

<table>
<thead>
<tr>
<th>Year</th>
<th>Barley</th>
<th>Wheat</th>
<th>Maize (grain)</th>
<th>Oats (grain)</th>
<th>Barley + Wheat + Oats</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>434,856</td>
<td>188,047</td>
<td>161,651</td>
<td>65,892</td>
<td>688,795</td>
</tr>
<tr>
<td>1991</td>
<td>382,043</td>
<td>180,690</td>
<td>183,388</td>
<td>78,877</td>
<td>641,610</td>
</tr>
<tr>
<td>1992</td>
<td>318,787</td>
<td>191,039</td>
<td>163,842</td>
<td>57,187</td>
<td>567,013</td>
</tr>
<tr>
<td>1993</td>
<td>389,523</td>
<td>219,414</td>
<td>133,069</td>
<td>57,625</td>
<td>666,562</td>
</tr>
<tr>
<td>1994</td>
<td>395,476</td>
<td>241,853</td>
<td>142,768</td>
<td>56,793</td>
<td>694,122</td>
</tr>
<tr>
<td>1995</td>
<td>302,804</td>
<td>245,173</td>
<td>160,797</td>
<td>57,718</td>
<td>605,695</td>
</tr>
<tr>
<td>1996</td>
<td>367,181</td>
<td>277,014</td>
<td>209,710</td>
<td>38,735</td>
<td>682,930</td>
</tr>
<tr>
<td>1997</td>
<td>411,000</td>
<td>317,379</td>
<td>193,806</td>
<td>41,217</td>
<td>769,596</td>
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<tr>
<td>1998</td>
<td>340,000</td>
<td>302,100</td>
<td>176,148</td>
<td>49,065</td>
<td>691,165</td>
</tr>
<tr>
<td>1999</td>
<td>304,000</td>
<td>320,000</td>
<td>197,000</td>
<td>42,223</td>
<td>666,223</td>
</tr>
<tr>
<td>2000</td>
<td>302,000</td>
<td>326,000</td>
<td>181,000</td>
<td>41,702</td>
<td>669,702</td>
</tr>
<tr>
<td>2001</td>
<td>365,000</td>
<td>364,000</td>
<td>177,000</td>
<td>35,398</td>
<td>764,398</td>
</tr>
<tr>
<td>2002</td>
<td>440,883</td>
<td>301,498</td>
<td>148,847</td>
<td>34,987</td>
<td>777,368</td>
</tr>
<tr>
<td>2003</td>
<td>371,837</td>
<td>318,916</td>
<td>197,182</td>
<td>29,934</td>
<td>720,687</td>
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<tr>
<td>2004</td>
<td>226,082</td>
<td>255,860</td>
<td>234,248</td>
<td>30,844</td>
<td>512,786</td>
</tr>
<tr>
<td>2005</td>
<td>302,739</td>
<td>318,947</td>
<td>210,253</td>
<td>28,714</td>
<td>650,400</td>
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<tr>
<td>2006</td>
<td>277,020</td>
<td>261,798</td>
<td>227,054</td>
<td>28,478</td>
<td>567,296</td>
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<tr>
<td>2007</td>
<td>335,627</td>
<td>344,434</td>
<td>185,627</td>
<td>27,531</td>
<td>707,592</td>
</tr>
<tr>
<td>2008^</td>
<td>408,700</td>
<td>343,400</td>
<td>205,600</td>
<td>25,500</td>
<td>777,600</td>
</tr>
<tr>
<td>2009^</td>
<td>435,300</td>
<td>403,500</td>
<td>237,800</td>
<td>33,700</td>
<td>872,500</td>
</tr>
<tr>
<td>2010^</td>
<td>308,300</td>
<td>444,900</td>
<td>188,800</td>
<td>47,600</td>
<td>800,800</td>
</tr>
<tr>
<td>2011^</td>
<td>368,000</td>
<td>383,300</td>
<td>210,200</td>
<td>28,500</td>
<td>779,800</td>
</tr>
<tr>
<td>2012</td>
<td>435,700(^p)</td>
<td>485,600(^p)</td>
<td>215,800(^p)</td>
<td>18,300(^p)</td>
<td>939,600(^p)</td>
</tr>
<tr>
<td>Average</td>
<td>357,516</td>
<td>305,864</td>
<td>188,765</td>
<td>41,588</td>
<td>704,967</td>
</tr>
</tbody>
</table>

\(^{10}\) The Agricultural Production Census is currently conducted by Statistics NZ every 5 years. Since 1990 there have been a total of four census (1994, 2002, 2007 and 2012; Note – only part of the 2012 data has been released to date). Although a Census was conducted in 1999, no agricultural statistics were collected. The 2007 Census involved approximately 80,000 farmers and foresters. The purpose of census data collection is to provide information for “monitoring, planning and forecasting by central and local government, business, researchers, agricultural sector organisations and the farming and rural community. In most other years where no census was conducted, much smaller sample surveys were carried out by Statistics NZ. However, there are years where census/survey data are not totally consistent resulting in slightly higher margins of error for between year comparisons.
## Appendix 3

Area of crops grown in New Zealand (hectares per year).

<table>
<thead>
<tr>
<th>Year</th>
<th>Barley</th>
<th>Wheat</th>
<th>Oats</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>96,735</td>
<td>40,650</td>
<td>20,656</td>
<td>158,041</td>
</tr>
<tr>
<td>1991</td>
<td>83,740</td>
<td>37,527</td>
<td>14,790</td>
<td>136,057</td>
</tr>
<tr>
<td>1992</td>
<td>67,380</td>
<td>37,797</td>
<td>14,033</td>
<td>119,210</td>
</tr>
<tr>
<td>1993</td>
<td>79,785</td>
<td>40,861</td>
<td>14,179</td>
<td>134,825</td>
</tr>
<tr>
<td>1994</td>
<td>76,858</td>
<td>44,668</td>
<td>12,947</td>
<td>134,473</td>
</tr>
<tr>
<td>1995</td>
<td>68,206</td>
<td>52,362</td>
<td>10,063</td>
<td>130,631</td>
</tr>
<tr>
<td>1996</td>
<td>76,601</td>
<td>50,607</td>
<td>10,094</td>
<td>137,302</td>
</tr>
<tr>
<td>1997</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>1998</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>1999</td>
<td>55,792</td>
<td>52,797</td>
<td>9,929</td>
<td>118,518</td>
</tr>
<tr>
<td>2000</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2001</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2002</td>
<td>78,097</td>
<td>42,187</td>
<td>7,353</td>
<td>127,637</td>
</tr>
<tr>
<td>2003</td>
<td>63,400</td>
<td>42,600</td>
<td>5,900</td>
<td>111,900</td>
</tr>
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<td>2004</td>
<td>48,500</td>
<td>39,100</td>
<td>7,500</td>
<td>95,100</td>
</tr>
<tr>
<td>2005</td>
<td>49,800</td>
<td>39,400</td>
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<td>97,100</td>
</tr>
<tr>
<td>2006</td>
<td>47,100</td>
<td>38,000</td>
<td>6,300</td>
<td>91,400</td>
</tr>
<tr>
<td>2007</td>
<td>51,500</td>
<td>40,500</td>
<td>5,800</td>
<td>97,800</td>
</tr>
<tr>
<td>2008</td>
<td>67,400</td>
<td>42,300</td>
<td>5,200</td>
<td>114,900</td>
</tr>
<tr>
<td>2009</td>
<td>77,700</td>
<td>53,900</td>
<td>7,400</td>
<td>139,000</td>
</tr>
<tr>
<td>2010</td>
<td>52,300</td>
<td>54,800</td>
<td>8,900</td>
<td>116,000</td>
</tr>
<tr>
<td>2011</td>
<td>64,900</td>
<td>52,600</td>
<td>6,100</td>
<td>123,600</td>
</tr>
<tr>
<td>2012</td>
<td>66,300P</td>
<td>54,900P</td>
<td>3,900P</td>
<td>125,100</td>
</tr>
<tr>
<td>Average</td>
<td>67,033</td>
<td>44,714</td>
<td>9,725</td>
<td>118,455</td>
</tr>
<tr>
<td>Percentage change since 1990</td>
<td>-31.46</td>
<td>35.06</td>
<td>-81.12</td>
<td>-20.84</td>
</tr>
</tbody>
</table>

*P = provisional; Source of data: Stats NZ*
### Appendix 4

**Area of crop residues burned in New Zealand**

<table>
<thead>
<tr>
<th>Year</th>
<th>Cereals</th>
<th>Other</th>
<th>All including Cereals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North Island</td>
<td>South Island</td>
<td>Total New Zealand</td>
</tr>
<tr>
<td>2005</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>2006</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>2007</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>2008</td>
<td>3,699</td>
<td>43,743</td>
<td>47,442</td>
</tr>
<tr>
<td>2009</td>
<td>S</td>
<td>46,273</td>
<td>53,782</td>
</tr>
<tr>
<td>2010</td>
<td>3,869</td>
<td>49,339</td>
<td>53,207</td>
</tr>
<tr>
<td>2011</td>
<td>3,762</td>
<td>38,101</td>
<td>41,863</td>
</tr>
<tr>
<td>2012</td>
<td>4,183</td>
<td>50,385</td>
<td>54,567</td>
</tr>
</tbody>
</table>

*Source: Stats NZ;  S = suppressed;  NA = not available*
## Appendix 5

This appendix uses a pairwise comparison of each of the five residue management options for their ability to deliver a given outcome. The best of the pair of residue management options for that outcome is given a score of 1 and the other option a score of zero. If both options are equally effective for delivering a particular outcome, each is given a score of 0.5. Thus, for any given agronomic and/or environmental outcome, a total of 10 points are assigned with a minimum of 4 points available to any single residue management technique. This scoring system then enables the five different residue management techniques to be ranked according to their ability to deliver any given outcome.

<table>
<thead>
<tr>
<th>Residue management option (see chapter 4)</th>
<th>Retaining small seeded crops within sustainable rotations*</th>
<th>Maximising soil and seeded quality</th>
<th>Enabling sustainable weed management</th>
<th>Enhancing productivity</th>
<th>Reducing cost of production**</th>
<th>Reducing pest and disease pressure</th>
<th>Mean ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burning the residue (followed by non-inversion cultivation or direct drilling)</td>
<td>4.0</td>
<td>2.0</td>
<td>4.0</td>
<td>2.0</td>
<td>2.0</td>
<td>3.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Incorporating the residue via non-inversion cultivation (top work)</td>
<td>1.0</td>
<td>1.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Incorporating the residue via ploughing (full inversion cultivation)</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Boiling and removing the residue (followed by non-inversion cultivation or direct drilling)**</td>
<td>3.0</td>
<td>2.0</td>
<td>3.0</td>
<td>2.0</td>
<td>3.0</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Retaining the residue on soil surface and direct drilling</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

*Small seeded crops e.g. grass, clover and vegetables are essential for diversity and sustainability of cropping rotations.

**Increasing intensity of cultivation tends to be associated with increases in use and machinery wear.

***A failed analysis for a parameter is not possible as testing is the only option.

****Assuming good conditions for baling resulting in no soil damage from wheelings.

### Conditional formatting

- **<1.5 red**: One tick
- **1.5-2.5 amber**: Two ticks
- **>2.5 green**: Three ticks

### Exec summary table
Appendix 6

CROP RESIDUES BURNING CODE OF PRACTICE

2005/2006

The Ashburton District Council, as the Fire Authority for the District, can implement measures controlling the lighting of fires in the open as fire danger levels rise during the summer fire season. These are:

FIRE RESTRICTIONS

The burning of crop residues only, is allowed during a Restricted Fire Season, providing certain conditions are met and safe practices are exercised.

FIRE PROHIBITION: (TOTAL FIRE BAN)

Declared in the interests of public safety when the fire danger levels are extreme. It is an offence to light any fire in the open during a Prohibited Fire Season.

1. **Check Out the Current Status of Fire Control Measures**
   1.1 During the summer fire season when Restrictions or Prohibitions are declared, notices will be published as required, setting out the dates and provisions of the Fire Control Measures.
   1.2 Ten Fire Danger Indicator Boards placed alongside major roads within the district will keep the public informed of the fire danger status.
   1.3 No person shall light an agricultural crop residue fire unless he/she has ascertained the current fire control status.
   1.4 Ignorance of the current fire control status shall not be a defence against any liability for any consequences that may occur from an illegally lit fire.

2. **Fire Break**
   2.1 No agricultural crop residue fire shall be lit until a completely non combustible continuous fire break of no less than 5 metres width has been established around the area to be burned. Ensure it remains clean and clear of all combustible material.
   2.2 Any breach of the fire break requirement under the Ashburton District Council Fire Plan will be deemed to be a breach of the fire burning regulations.
   2.3 The safe practice of backburning is considered a good fire management strategy and should be encouraged at all times.
   2.4 Immediately following the burn the firebreak and adjacent burnt area of windrow is to be cultivated to minimise the risk of reignition.
   2.5 **Remain in attendance until the fire is completely out**, as reignition of a controlled burn can occur after a wind change. Always check the fire ground after violent wind changes.
3. **Safe Conditions to Light a Fire**

3.1 Good fire management practices must be observed at all times. **No fires should be lit in times of strong or gusty winds or unsettled weather.** Weather forecasts are available by ringing “Met Service infoline” 0900 999 25 (plains) or 0900 999 26 (high country). It is also advised that weather conditions existing in other parts of the District should be checked.

3.2 Where no fire control measures are in place and a stubble fire is lit that, in the opinion of the Principal Rural Fire Officer, does not satisfy provisions of this Code of Practice, the person lighting the fire will be responsible for any consequent firefighting costs.

3.3 It is recommended that an adequate supply of water, and a means of delivery, be on hand at all times during any crop residue burnoff.

3.4 Other fire fighting equipment, ie tractor, cultivator, grubber, beaters, fire extinguishers, should be available on site.

3.5 It is recommended that no fires be lit where the smoke could cause a nuisance to adjacent towns or neighbouring residences, or compromise traffic safety on roads.

3.6 Smoke drift from stubble fires can cause a significant traffic hazard on public roads. Where there is a possibility of smoke drift across a public road, appropriate road signs should be used to warn motorists of the hazard.

3.7 It is recommended a minimum of 2 adults be present during the controlled burn

3.8 Stubble burning is only to be carried out during the hours of daylight.

4. **Liability on the Person Lighting an Agricultural Crop Residue Fire**

4.1 In the case of a call out to a fire, the person lighting the fire shall be liable for any costs charged by the New Zealand Fire Service or the Ashburton District Council.

4.2 In the case of a call out to a fire where regulations have been breached, all firefighting labour and plant costs will be recovered by the District Council in line with standard rates as set by the National Rural Fire Authority.

4.3 The Ashburton District Council reserves the right to take prosecutions against a person or persons lighting fires that breach the Ashburton District Council Fire Restrictions, lighting a fire in unsuitable conditions, or with an inadequate fire break. Where no clear blame can be attributed to any one individual there should be no legal liability on the person lighting the agricultural residue fire.

5. **Good Management Practice**

5.1 Formulate a Burn Plan and inform neighbours of the date and time of the fire. Have an action plan in event of the fire escaping.

5.2 Ensure that those assisting are adequately dressed and briefed on safety aspects.

5.3 Regularly check machinery for possible build-up of straw and/or combustible material around manifolds or exhausts.

5.4 All agriculture stubble fires once lit must be supervised at all times.

5.5 Seek advice or training on safe burning practices.

Federated Farmers undertakes to inform and encourage farmers to adopt good crop residue fire management practices, within guidelines laid down by the Ashburton District Council. Responsibility for good fire management has been transferred back to farmers. Decisions must be made with the best interests of the community in mind.

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_D Geddes_  
Principal Rural Fire Officer

_G Wilson_  
Chairman, Grains Section

**ASHBURTON DISTRICT COUNCIL**  
FEDERATED FARMERS OF NZ MID  
CANTERBURY PROVINCE
References


