P A Handford & Associates Ltd

CARBON FARMING INFORMATION REPORT

Further Reading Material supporting Info Sheets

Carbon Farming – Opportunities & Issues for Rural NZ
Information Transfer for Landowners and Managers

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Disclaimer:
In preparing this report it has been necessary to make a number of assumptions. The projections and recommendations contained in this report are subject to uncertainty and variation depending on evolving events but have been conscientiously prepared based on our best understanding of current science, government policy and regulation.

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Introduction

Carbon Farming has received a lot of publicity in NZ forestry and agriculture with reports of both great opportunities and significant financial penalties likely. The truth is likely to be somewhere in between. The NZ Landcare Trust and NZ Farm Forestry Association are an integral part of the NZ rural community and have partnered with P.A. Handford and Associates under a MAF Sustainable Farming Fund grant, co-funded by the Carbon Farming Group, to help farmers, agribusiness managers and farm foresters to understand carbon farming, and how it can be integrated with current agricultural production systems. A particular need for clear, independent information for farmers, farm foresters and others was strongly identified, particularly the rural land management community. An education package was developed including a series of seminar presentations and information sheets. This report supports the information sheets which can be found at http://www.carbonfarming.org.nz/articles.html. These info sheets cover a range of relevant topics from understanding of the carbon cycle in farming enterprises through to carbon trading and forest management.

All info sheets were reviewed by Ministry of Agriculture and Forestry (MAF) officials prior to publication. The authors appreciate the assisstance of Andrew Hume, Gerald Rhys, Gillian Smith and Peter Gorman in this regard.

1 Greenhouse Gases and Farming Livestock

1.1 Introduction

This section describes the background to Info Sheet 1 and covers carbon cycling in a grazed pasture, the grazing animal, greenhouse gases and global warming and carbon calculators.

1.2 Carbon cycling in a grazed pasture

1.2.1 Carbon flux

Carbon fluxes with approximate quantities (tonnes C/ha/year) for a grazed dairy pasture are shown in Figure 1.1 (Harris, 2008). The figure illustrates relative flux of carbon between different sources and sinks and movement of carbon in and out of the atmosphere. About half the carbon dioxide (CO_2) gas taken from the atmosphere by plants is converted to a more complex form of carbon called biomass, or herbage in the case of pasture. The rest is returned to the atmosphere as carbon dioxide through plant respiration. About half the carbon in herbage is stored as plant roots while the other half is in shoots that can be consumed by animals. Pasture that is not eaten dies and goes onto the soil surface as litter. Soil respiration also returns carbon dioxide to the atmosphere as roots and litter are broken down by soil microorganisms. In this case we have assumed soil carbon levels remain relatively stable unless productivity is changed (see section 2 on soil carbon for more detail).

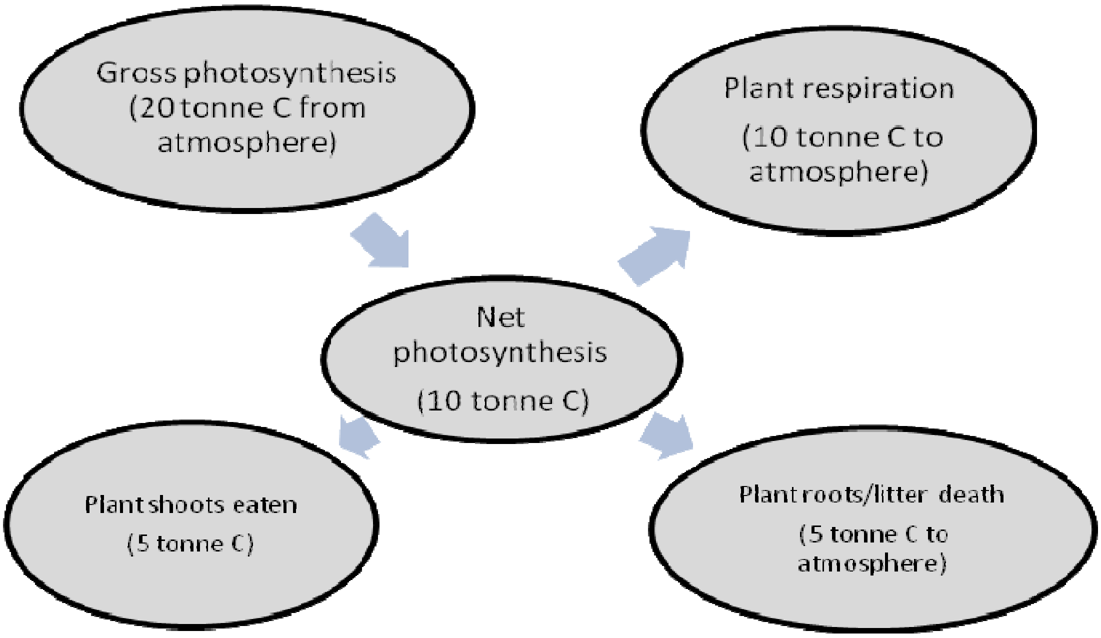
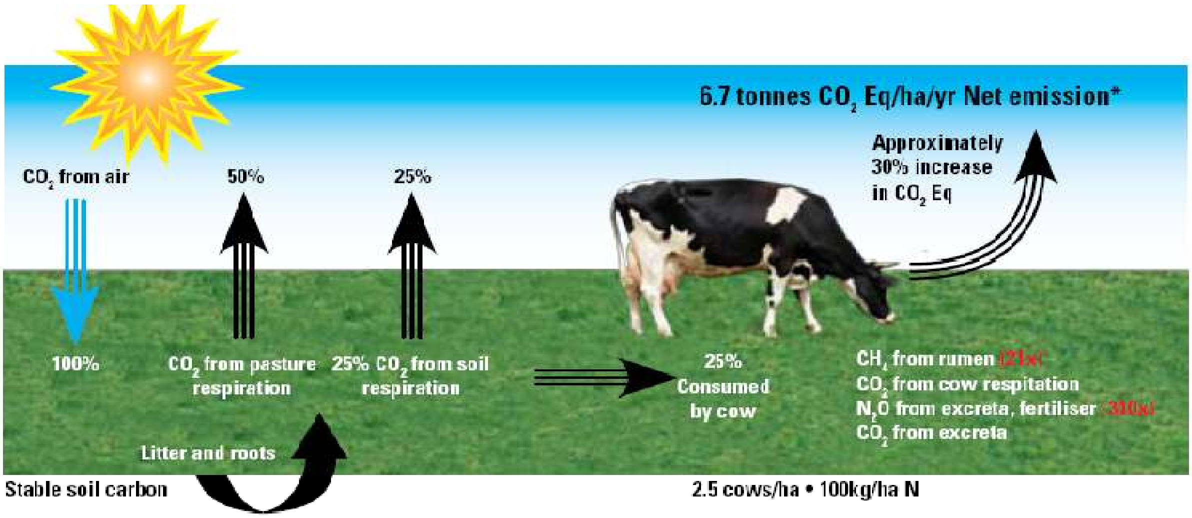


Figure 1.1 Annual carbon fluxes and sinks/ha in a grazed pasture (NZ dairy, adapted from Harris, 2008)

1.2.2 The grazing animal

If pasture was cut and left to decompose the carbon would return to the atmosphere as carbon dioxide and there would be no net change in greenhouse gases, only cycling. The digestion of pasture by ruminants makes the difference. Agricultural livestock transform pasture carbon into different greenhouse gases more potent than the original carbon dioxide. Methane (CH_4), which is emitted from the rumen as a by-product of ruminant digestion, is more efficient at absorbing infrared radiation than carbon dioxide. Nitrous oxide (N_2O), released from the breakdown of animal excreta and fertiliser is similar in this respect. The Figure 1.2 below summarises carbon flows for pasture grazed by ruminants.



*** Net emissions calculated by Carbon Farming Group and Overseer® carbon calculators**

Figure 1.2 Schematic of the carbon cycle under grazed pasture (net annual agricultural GHG emissions includes methane and nitrous oxide).

1.2.3 Comparison of Carbon calculators

The GHG emissions shown in Figure 1.2 were calculated using the online Carbon Farming Group calculator. There are a number of farm carbon calculators available (see below). Data for Figure 1.2 were calculated with both Carbon Farming Group (CFG) calculator and Overseer®. Results from these calculators were in agreement (see below). The CFG has limited scope for variation of inputs eg dairy cows only, whereas in Overseer you can choose from a number of cow types eg. fresian or jersey. Inputs for Overseer® were Friesian-Jersey cross cows and 600kg/ha milk solids. Fuel, electricity and capital development were omitted from this simple calculation as a demonstration of agricultural GHG emissions. The result is that from 2.5 cows per ha and with the application of 100kgN/ha there is a net release of greenhouse gases equivalent to 6.7 tonnes of CO_2 annually.

More complex estimations of greenhouse gas emissions (GHG) were compared for three carbon calculators. All calculators are based on New Zealand Greenhouse Gas Inventory Tables (Petrie et al., 2007). As indicated above an initial simple case comparison is followed by more complex and closer to real farm situation. Rather than a thorough treatise of available calculators this section merely collates and demonstrates three of the most widely available in NZ.

1. Simple comparison. This is the base data (dairy cows) carried out in February 2009 and used for presentations and info sheets .
2. Whole farm comparison between CFG and Overseer® (Allan dairy operation)

1 Simple comparison

Three calculators were compared:

1. Carbon Farming Group (www.carbonfarming.org.nz)
2. Lincoln Carbon Calculator (http://www.lincoln.ac.nz/carboncalculator)
3. Overseer, version 5.3.7.0 (www.agresearch.co.nz/overseerweb)

Table 1.1 compares outputs from three carbon calculators. Base situation used for comparison is 100 cows, 40 ha, 100 kg nitrogen (N) /ha with no fuel or electricity included. Overseer requires a great deal more input data than the carbon farming group calculator. More than 100 data points can be entered (see Appendix three), whereas CFG calculator requires less than 10. The Lincoln Calculator can have up to 35 inputs including tractor use. The carbon farming group calculator is easier to use than either the Lincoln or Overseer calculators as are less inputs are required.

Table 1.1 Comparison of carbon calculators (no electricity or fuel inputs)

	Carbon Farming Group	Lincoln Carbon Calculator*	Overseer (FxJ cross cows)
Inputs			
Cows (Fresian/Jersey Cross)	100	100	100 (600 MS/ha)
Area (ha)	40	40	40
Nitrogen	100kgN/ha	100kgN/ha	100kgN/ha
Young stock	none	none	none
Outputs GHG emissions			
Dairy	6.175	4.721	4.117 (CH4)
			0.483 (CO2)
Nitrogen Fertiliser (N_20 direct)	0.575	0.338	0.572
Other N_2O emissions		2.575	
Excreta & Effluent (direct)			1.432
Excreta & Effluent (indirect)			0.542
Capital			0.304
Total GHG emissions (t CO_2 Eq/ha)	6.75	7.634	7.451

* - Lincoln Carbon Calculator – no contractor hours were used,
# - See Appendix One for screen outputs from Lincoln and Overseer calculators

The Lincoln and CFG calculators are not sensitive to production (milk solids/ha). Inputs to Overseer can be manipulated by adjusting production (MS/ha) and dairy cow breed type so that outputs are equal to either CFG or Lincoln calculators. The carbon farming group (CFG) calculator result was conservative as compared with the Lincoln Calculator and Overseer (12 and 7 % less respectively when estimate for “Capital” emissions subtracted from Overseer result)

When the assumed allocation of GHG emissions from “capital” are subtracted from the Overseer value, the carbon farming group calculator and Overseer results are within 5% of each other. It was decided to base data for presentations and info sheets for publication by this project on carbon farming group calculator results as this was the most conservative and simple of the three calculators. This was considered a pragmatic approach given the sensitivity around calculations in this area.

2 Whole Farm Comparison - Allan Dairy Farm.

The Allan Dairy farm operation consists of 230ha farm with 100ha (75ha effective) runoff. There are 430 cows, 75 R2 heifers, 105 R1 heifers, 10 bulls, are run on 305 ha where 73kg/ha/yr nitrogen is applied. Energy and fertiliser use are shown in Table 1.2. Table 1.2 shows all inputs and outputs for the carbon farming group calculator (CFG calculator). The inputs for Overseer are shown in Appendix Three.

Table 1.2 A "snap shot" of annual greenhouse gas emissions (tonnes CO_2 Eq/yr) for the Allan Dairy Operation in 2008 (CFG calculator).

Greenhouse Gas Source			**Allan Dairy Operation**	
Source	Unit	Factor	Units	NZU
Petrol	Litres	0.00234	2600	6
Diesel	Litres	0.00268	5800	16
Electricity	kWhr	0.00023	88227	20
Nitrogen	Tons	5.63900	21	117
Dairy	Cows	0.33000	430	1062
Cattle	Heifers	1.71000	145	248
		Total		**1468**

Table 1.3 compares the output from CFG and Overseer for the Allan Dairy farm operation comparison. Overseer estimates 190 ton CO_2 Equivalents more per year for the farm. The CFG calculator shows 12% less total GHG emissions. This result is similar to that for the simple comparison shown above. Overseer has more variables and in some cases adjustment of variables changes the estimation of total farm emissions (Table 1.4).

Table 1.3 Comparison of CFG and Overseer output (see Appendix Two for detail)

	Carbon Farming Group	Overseer *
	tonnes CO_2 Eq/yr	tonnes CO_2 Eq/yr
Animals emissions	1310 (CH_4 + N_20+ CO_2)	892 (CH_4)
N_2O emissions	117 (N_20, fert)	535 (N_20)
CO_2 emissions	42	231 (CO_2)
Total tons/yr	1468	1658

* Does not include the emissions listed as "Capital" in the Overseer output which on this farm were estimated to be 49 ton/yr.

Table 1.4 shows that changing the breed of cow and level of production has a significant impact on output result from Overseer in terms of total farm emissions. However, effluent disposal method, soil type, soil drainage irrigation and timing of nitrogen applications did not impact on the total farm emissions.

Table 1.4 Effect of variable on total farm emissions

Variable	Base situation	Change	Effect (%)
Effluent Disposal	Spray on pasture	Export Effluent	0
Cow breed	Jersey	Friesian	9.35%
Cow breed	Jersey	Friesian Jersey cross	6.55%
Production (milk solids)	135,000 kg	148500 kg (10% increase)	3.5%
Soil Type and texture	Recent soil, silty clay loam	Peat / peat loam	0
Drainage	Moderately well	Poor	0
Irrigation	300mm/yr	0	0
Winter N (May, June July)	20 kg/ha	0	0

1.3 Greenhouse gases and global warming

In order to compare the relative climate change effects of different gases the “global warming potential” (GWP) rates them on a common scale. The use of the global warming potential for this purpose is internationally agreed (see info sheet 3 for more detail). The warming effect over 100 years of 1kg of methane emitted into the atmosphere is the same as for 21kg of carbon dioxide. Using the same scale, 1kg of nitrous oxide has the equivalent effect of 310kg of carbon dioxide. Approximately two thirds of agricultural greenhouse gas emissions are as methane and one third is nitrous oxide.

1.4 Measuring Agricultural Greenhouse gas emissions

The descriptions in section 1.4 are taken from the Pastoral Greenhouse gas Research Consortium (PGgRc) 5 year Science Progress Report 2002-2007 (Aspin and Leslie, 2007).

1.4.1 Animal methane emissions

There are two main techniques for estimating animal methane emissions. The sulphur hexafluoride (SF_6) tracer gas tracer technique and direct time series measurements using a respiratory chamber. The SF_6 gas tracer technique is only the only standard method for grazing animals which involves drenching a slow SF_6 gas releasing capsule into the animal and attaching an evacuated tube yoke around the animals’ neck with a sniffer pipe that constantly samples the air exhaled (see Figure 1.3). SF_6 gas is release at a constant rate and is measured to benchmark the methane collected.

Figure 1.3 Cow, sheep and deer harnessed and yoked during trials to measure enteric methane emissions (photo courtesy of PGgRc)

Info sheet 1 pictures emissions measurement using a respiratory chamber. This is far more sophisticated than the SF_6 yoke method. Animals are placed in a special air tight box with controlled air flow and the exiting gases are analysed in real-time. Tubes connected to the chamber can be seen in (Figure 1.4). Although more expensive, this technique offers instant results that are far more accurate and responsive to changes. The SF_6 techniques integrates data over time whereas the respiratory chamber provides a continuous stream of data with time.

Figure 1.4 A sheep in respiratory chamber (photo courtesy of PGgRC)

1.4.2 Nitrous oxide

Livestock excreta is the primary source (over 80%) of nitrous oxide (N_2O) emissions. Soils contribute about 65% of the total N_2O produced by terrestrial ecosystems. N_2O gas is formed in soils during the microbiological processes associated with the nitrogen cycle. N_2O production by nitrifying bacteria may arise either during NH_4 oxidation to NO_3 (nitrification) or during NO_3 reduction in anaerobic conditions (denitrification). Dentrification is the process by which nitrate is reduced to nitrite thence to nitrous oxide and eventually to elemental nitrogen : $NO_3 \rightarrow NO_2 \rightarrow N_20 \rightarrow N_2$. Relatively high N_2O emissions rate are often observed in late autumn/winter in New Zealand when soil moisture is high and evapotranspiration is low. Figure 1.5 details the sources of N_2O emissions in a grazed pasture system.

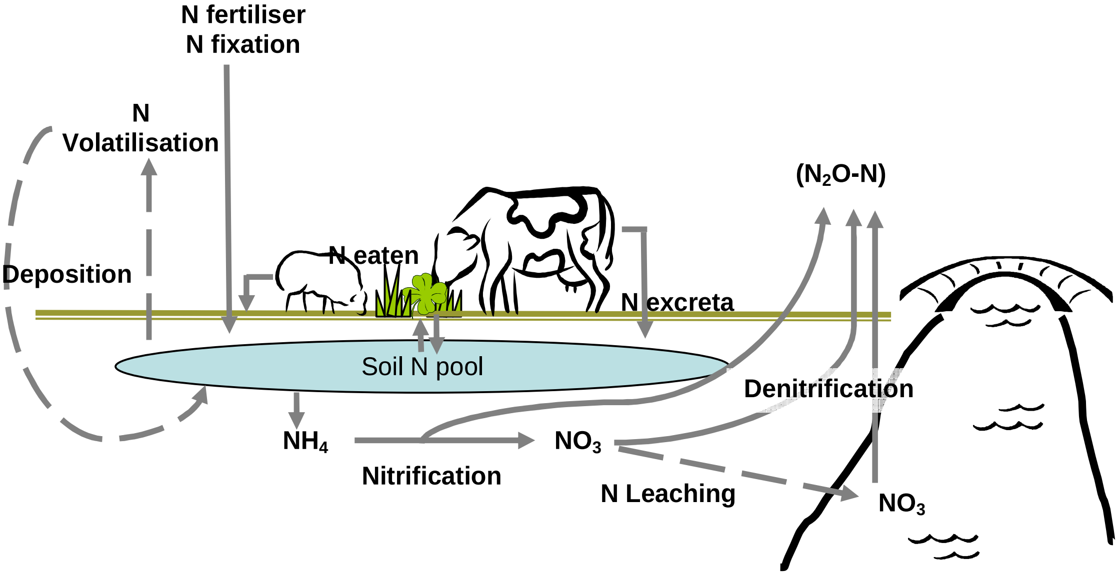


Figure 1.5 Nitrogen cycle in a grazed pasture (courtesy of MAF)

Measurements of N_20 emissions from the soil are carried by covering pasture soil with an airtight cover and sampling the gas above the soil (Figure 1.6). This trapped gas is then analysed for N_2O. There are variations on this basic concept which take in larger areas of pasture (up to $10m^2$).

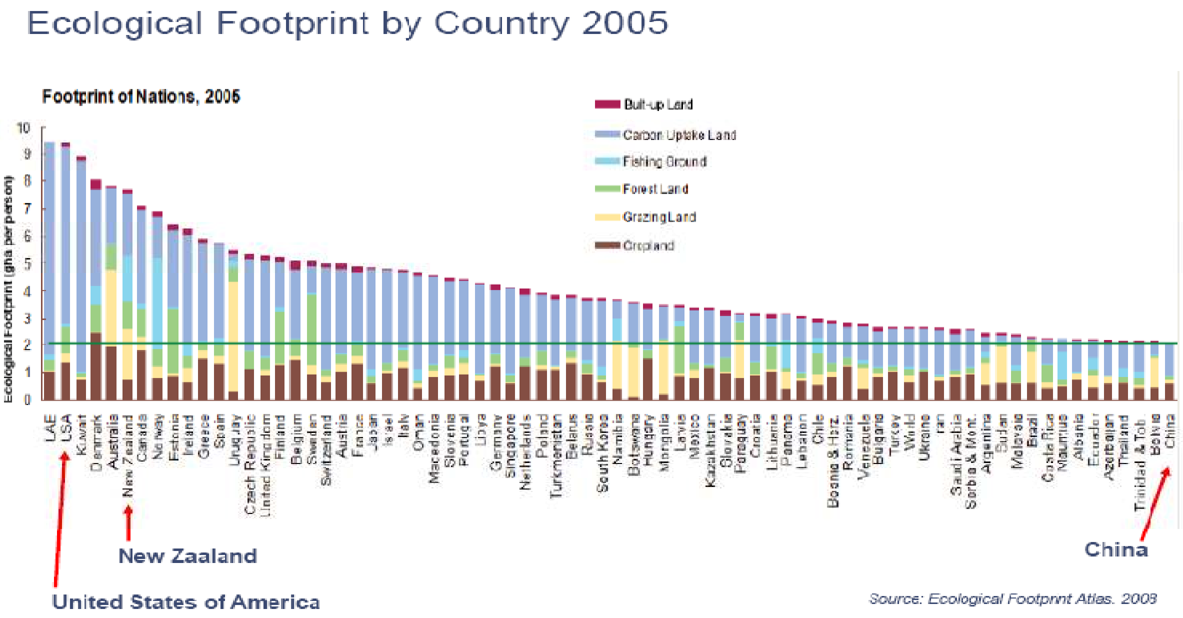
Figure 1.6 Measuring nitrous oxide emissions with collection chambers (photo courtesy of AgResearch).

Nitrification inhibitors (NI) have been shown to be a viable strategy to mitigate N_20 emissions. For example, Di et al., (2007) showed that the application of a fine-particle suspension nitrification inhibitor, dicyandiamide (DCD), to grazed pasture soils reduced N_2O emissions from animal urine patches by an average of 70%. Some studies show reductions of up to 90% over a 2-3 month measurement period (Smith, et al., 2008). However, research has highlighted that effectiveness varies with soil, climate and management factors.

2 Soil carbon

2.1 The big picture – ecological footprint

How many planets are we using? The earth's surface is approximately 51 billion ha of which there are approximately 13.6 billion biologically productive hectares for a population 6.5 billion. That's roughly 2.1 biologically productive hectares per capita. However, demand (in terms of crops for grazing, forestry, fishing, urban areas and CO_2 absorption) is 2.7 biologically productive hectares per capita (Source: Living Planet Report 2006 from Simon Upton's presentation titled 'Sustainability: here today, gone tomorrow" to Hawkes Bay Regional Forum, 11 Nov, 2008). Figure 2.1 compares the ecological footprint of a range of nations in 2005. In this New Zealand ranks 6th highest in the world in terms of the land area required to support each citizen.



Ecological Footprint by Country 2005

New Zaaland

China

United States of America

Source: Ecological Footprint Atlas. 2008

Figure 2.1 Ecological footprint of nations 2005

On a global scale soils contain more C (1580 billion tonnes) than vegetation (610 billion tonnes) and the atmosphere (750 billion tonnes) combined and so are a vital factor to consider in balancing carbon (Henry, 2008). Aside from major perturbation like deforestation, soil respiration is the main pathway by which soil C moves between the soil and the atmosphere.

2.2 Life in the soil

Bardgett (2008) estimated that there might be as many as 10^{10}-10^{11} bacteria and 3-5 km fungal mycelium in a single gram of forest or grassland soil. He noted that the soil fauna are also extremely abundant and species rich with as many as 10,000 bacterial species within a single handful of soil, 89 nematode species found in a single soil core in and upwards of 150 mite species were identified in a patch of grassland soil. These soil microbes turnover soil carbon. In a hectare of grazed dairy pasture, microbial respiration in the soil turns over 15 to 18 tonnes CO_2-Equivalents of roots and litter annually (Parsons and Rowarth, 2008a)[1] . New Zealand pastoral soils typically contains 80-100 tonnes C/ha or 300 to 400 tonnes CO_2-Equivalents in the top 30cm (Shepherd et al., 2008). The amount of carbon in the soil is a slowly changing balance of this large flow in and out of the soil (Parsons and Rowarth, 2008a).

2.3 Carbon in NZ soils and changing management practices

There is much discussion about the propensity for New Zealand farmers to build up carbon in their soils (Parsons and Rowarth 2008a, McGill, 2008). However, soil carbon under pasture is essentially stable unless there are changes in fertiliser policy, stocking rate and/or productivity (Parsons and Rowarth, 2008b). There is scope to increase soil organic carbon in pasture soil, but not indefinitely. In all cases the observations are that soil organic carbon tends towards a new equilibrium representing a balance between inputs and outputs (pers. com. D. Powlson, 2009). Where changes in soil management do occur, changes in soil carbon levels are unlikely to become apparent or measureable for up to 10 years and are subtle (4 tonnes CO_2 Eq /ha/yr). For example Schipper et al. (2008) reported that since 1990 dairy on flat-land non-allophanic soils have lost significant soil CO_2-Equivalents (about 3.7 t ha^{-1} yr^{-1}). Soil carbon C had not changed for dairy on flat-land allophanic soils, non-dairy on flat-land non-allophanic soils (23 profiles) and non-dairy on allophanic soils (2 profiles). On non-dairy pastures on hill country (8 profiles) soils have gained C (about 4.8 t ha^{-1} y^{-1} CO_2-Equivalents). Changes in total N followed changes in carbon. Shepherd (per com. 2008) commented that these findings were contrary to studies prior to 1980 of NZ soils. So changes under pasture are likely to be subtle unlike activities such as cultivation which may release 40 tonnes CO_2 Eq in the first year (Beare, et al., 2008) or during the growth of a forest which may accumulate as much as 35 tonnes CO_2 Eq/year (MAF, 2008).

Parsons and Rowarth (2009) and McGill (2008) pointed out that there was a second problem concerned with the economics of the amount of C sustained in the soil. Changes in soil C are largely to do with altering the amount of organic matter (OM) in the soil. This is not made up of C alone, but contains considerable amounts of other minerals such as nitrogen (N), phosphorus (P) and sulphur (S). For every 1 tonne/ha of C sequestered in soil OM, that same OM typically also contains approximately 80kg N/ha, 16 kg/ha of P and 12 kg/ha S. Hence, unlike with trees where the wood sequesters few minerals other than C (and hydrogen and oxygen), to get a 1 tonne/ha increase in the amount of C stock sustained in the soil, means explaining the source of the extra 80 kg/ha of N and other minerals sequestered with it.

Data from Info sheet 2 shows how changing crop establishment techniques can influence soil carbon. Also other management practices within farming systems can make a

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[1] Estimated on the basis of 4-5 tonnes carbon /ha/yr flux and conversion to carbon dioxide equivalents by multiplying carbon by 3.67 (44/12).

difference to soil carbon levels. For example Powlson et al., (2008) took a closer look at crop residue management and showed that burning cereal straw for electricity generation instead of coal would actually lead to considerably greater climate change mitigation than incorporation of straw into soil. This demonstrates that all farm management practices need to be thoroughly analysed in terms of net mitigation benefit and that the context is important.

Powlson and Whitmore (2008) developed this idea further by suggesting that an increase in soil C caused by farm animal manure application is not real C sequestration if the manure would have been produced anyway. Manure applied in one field causes an increase in soil C in that field. However, if it would otherwise have been applied to a different field, soil C would have increased there instead - so from a global viewpoint there is no change in overall soil C stock, just a movement from one place to another.

2.4 Soil organic carbon and organic matter in New Zealand soils

Soil organic matter (OM) is calculated from soil organic carbon. Hill laboratories soil testing information shows that organic carbon x 1.72 = organic matter %. Hill Laboratories (2009) have categorised New Zealand soils in to five groups in terms of organic matter levels (Table 2.1).

Table 2.1 Comparison of Soil organic carbon and organic matter for New Zealand

	Organic C (%)	Organic Matter (%)
Very Low	<2	<3
Low	2-4	3-7
Medium	4-10	7-17
High	10-20	17-35
Very High	>20	>35

Climate, soil type and rainfall have a strong influence on soil organic matter and these factors must always be taken into account when comparing soil organic matter. Farm management systems can also affect organic matter levels. Some good data has come through from the Agriculture Research Group on Sustainability (ARGOS) which compares production systems across four sectors of New Zealand agriculture. Of particular interest are comparitive data for a range of features of New Zealand pastoral farms which have either conventional or organic management systems (Carey et al. 2009a). Table 2.2 shows that organic dairy farms had significantly higher organic matter than conventional dairy farms. Management system had no effect of soil organic matter in sheep and beef farms. Data for kiwifruit orchards was similar to that for dairy farms indicating that as farming intensity increased so did the differences between organic and conventional management systems on soil carbon (Carey et al. 2008).   The dairy farms in the ARGOS study would be classed as high OM and sheep and beef farms medium OM according to Table 2.1. Carey et al., (2009b, 2009c) showed that while soil organic matter levels were higher under organic as compared with conventional kiwifruit production, productivity was lower indicating with organic kiwifruit illustrating that soil carbon should not be considered in isolation and is associated with the production system.

Table 2.2 Effect of farm system on organic matter (0-7.5cm depth)[1]

	Organic	Conventional	Significance (lsd)	range
Dairy[2]	15.6	14.4	* (1.2)	5.8 – 32.7
Sheep and Beef[3]	8.4	8.4	n.s. (0.7)	4.6 – 19.4
Kiwifruit(green)[4]	8.8	9.8	* (0.05)	3.4 – 15.5

* Significant at 5% level (lsd = least significant difference), n.s. = not significant

1 Adapted from Carey et al 2008

2 12 North Island dairy farms are compared

3 12 South Island Sheep and Beef farms are compared

4 12 New Zealand Kiwifruit orchards (data shown for Green kiwifruit only)

2.5 Other parts of the world

In other parts of the world stories of 'growing soil carbon' abound so why can't we? Several reasons: New Zealand grassland already has relatively high soil carbon contents (average around 11% organic matter, Table 2.2). Adding more is not as easy as it might be in areas with very low carbon to start with (eg <3%OM). Also, carbon accumulation rates are greater in cool than in warm climates, poorly drained rather than well-drained soils and in light rather than heavy textured soils. Parsons and Rowarth (2008a) noted that in contrast, New Zealand has a benign climate with relatively well-drained, medium to heavy textured soils and so has less opportunity to accumulate soil carbon.

3 Greenhouse Gases – International Agreements

3.1 Background

There is wide international science and governmental agreement on climate change and that the activities of man, particularly over the last 150 years, has led to an unnatural rate of warming in the biosphere. The key human impact identified as influencing climate change is the increased concentration in the atmosphere of greenhouse gases (GHG) that trap the sun's heat (IPCC, 2007). The main greenhouse gases, apart from water vapour, are carbon dioxide (CO_2) methane (CH_4) and nitrous oxide (N_20). The global climate has always been changing but the rate of change in temperature and sea levels, witnessed since the mid-20th century, has surpassed the myriad of natural causes such as orbital variations, solar activity and volcanic eruptions (Forster et al., 2007). For example global average temperature has risen by 0.74C in the hundred years from 1906 to 2005 whereas previous to that it took at least 1000 years to rise the same amount. Frankham (2008) noted that in the last 6000 years two thirds of the earth's surface has been deforested significantly changing the balance of greenhouse gases along with the burning of fossil fuels and agriculture. Greenhouse gases trap the sun's heat and despite only accounting for 0.04% of our earth's atmosphere, they represent the difference between the world being an almost lifeless planet of -19℃ and the comparatively comfortable one we live in today of about +14℃ (Forster et al., 2007). This indicates the sensitivity of the system.

3.2 International Agreements and New Zealand's emission profile

As indicated in info sheet 3, background on information on the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, can be found at www.mfe.govt.nz/publications/climate. Aspin and Leslie, (2007) also provide a useful summary. New Zealand has set up legislation aimed at limiting greenhouse gas emissions (GHG) to 1990 levels. Under the Kyoto Protocol the country faces financial penalties, the first due in 2015, for emissions in excess of 1990 levels. While the relative merits or otherwise of Kyoto protocol can be argued, the agreement indicates that climate change is being taken seriously worldwide.

The Kyoto Protocol covers a period of commitment to maintaining 1990 emission levels period between from January 2008 to December 2012. Negotiations to agree emissions targets for the next commitment period 2013 to 2018 are due to take place in December 2009 in Copenhagen. Agreement in Copenhagen will influence government policy in this area which is still evolving.

Petrie et al., (2007) described the greenhouse gas emissions profile for New Zealand shows agriculture as a key factor. It is key because agriculture, predominantly methane and nitrous oxide from livestock, forms a large part (48.5%) of the greenhouse gas (GHG) emissions and we rely heavily on agriculture for export earnings. In all other developed countries agricultural emissions are currently much less prominent, typically 12% or less of national emissions and energy emissions dominate (EEA, 2009). Between 1990 and 2006 NZ's GHG emissions had risen 26.7% (UNFCCC, 2008). The latest report on New Zealand's greenhouse gas balance shows that New Zealand's gross emissions at the end of 2007 were up by 22% and that emissions from NZ agriculture has rose by 7% since 1990 (MFE, 2009). This was a significant downward revision from an earlier report (Petire et al., 2007). New Zealand's net balance for the first commitment period will not be finalised until 2015 and likely continue to fluctuate depending economic growth, productivity and with advances in the quality of measurement.

Info sheet 3 indicates New Zealand's response to climate change and the Kyoto protocol. Other initiatives are also in place raising awareness of the steps that individuals can take (MFE, 2007) that in s http://www.mfe.govt.nz/publications/climate/climate-change-solutions-overview-sep07/climate-change-solutions-overview-sep07.pdf.

4 New Zealand's carbon programmes and how to get involved using forestry as an offset

The Emissions Trading Scheme (ETS), legislated in 2008 is the central government initiative for managing greenhouse gas emissions. However, a change of government in late 2008 led a review of this legislation. The uncertainty created by the review reduced activity and progress in ETS and its associated initiative, the Permanent Forest Sink Initiative (PFSI). A third initiative, the Afforestation Grants Scheme (AGS) has proved popular reflected by reports of over subscription (MAF, 2009). The information published in Info Sheet 4 comes from the Ministry of Agriculture and Forestry and the Ministry for Economic Development.

4.1 Land eligibility and free allocation of credits

Under the Kyoto Protocol, New Zealand must account for carbon stock changes in new forests planted after 1989. This requirement is mirrored in the domestic ETS and PFSI where New Zealand units (NZUs) are issued for carbon increases, and surrendered for carbon decreases. For a forest to qualify for carbon credits it must consist of a forest species capable of reaching 5m in height and 30% tree crown cover where it is growing. It also needs to be at least 1ha, with a minimum width of 30 metres. The forest must be new, representing a change in land use since 1989. Where land was destocked by excluding grazing animals and subsequently planted, change of land use is clear. However, if forest species were present on the land in 1989, and it was not regularly grazed, and it was planted after 1989, the change in land use is less clear. Deciding on land eligibility can be difficult in these cases. The Ministry of Agriculture and Forestry will publish a pictorial guide to help with decisions in this area for the ETS, PFSI and AGS. The guide can be found at http://www.maf.govt.nz/sustainable-forestry.

Forests which existed before 1990 do not have to account for carbon stock changes other than from deforestation. However, some credits will be issued by the government to pre-1990 forest land under the current ETS as “free allocation” as recognition of the impact of the ETS on land values. The government has indicated this allocation will be at a rate of approximately 60 NZUs per hectare for most of the land involved, however final allocations will be set in the government “allocation plan” likely to be released in the next couple of months. Native forests that existed prior to 1990 do not qualify for this one off issue of credits.

At this stage MAF must be notified of deforestation of pre-1990 land which occurred during 2008 and 2009 by 31 January 2010. Emission units must be surrendered for such deforestation by 30 April 2011. Exemptions for areas of 50 ha or less can be applied for until at least 1 July 2010. Figure 4.1 is a diagram taken from the MAF Afforestation Scheme Guide which is the most useful guide to show the relationships between different initiatives and fundamentals of forest and land eligibility.

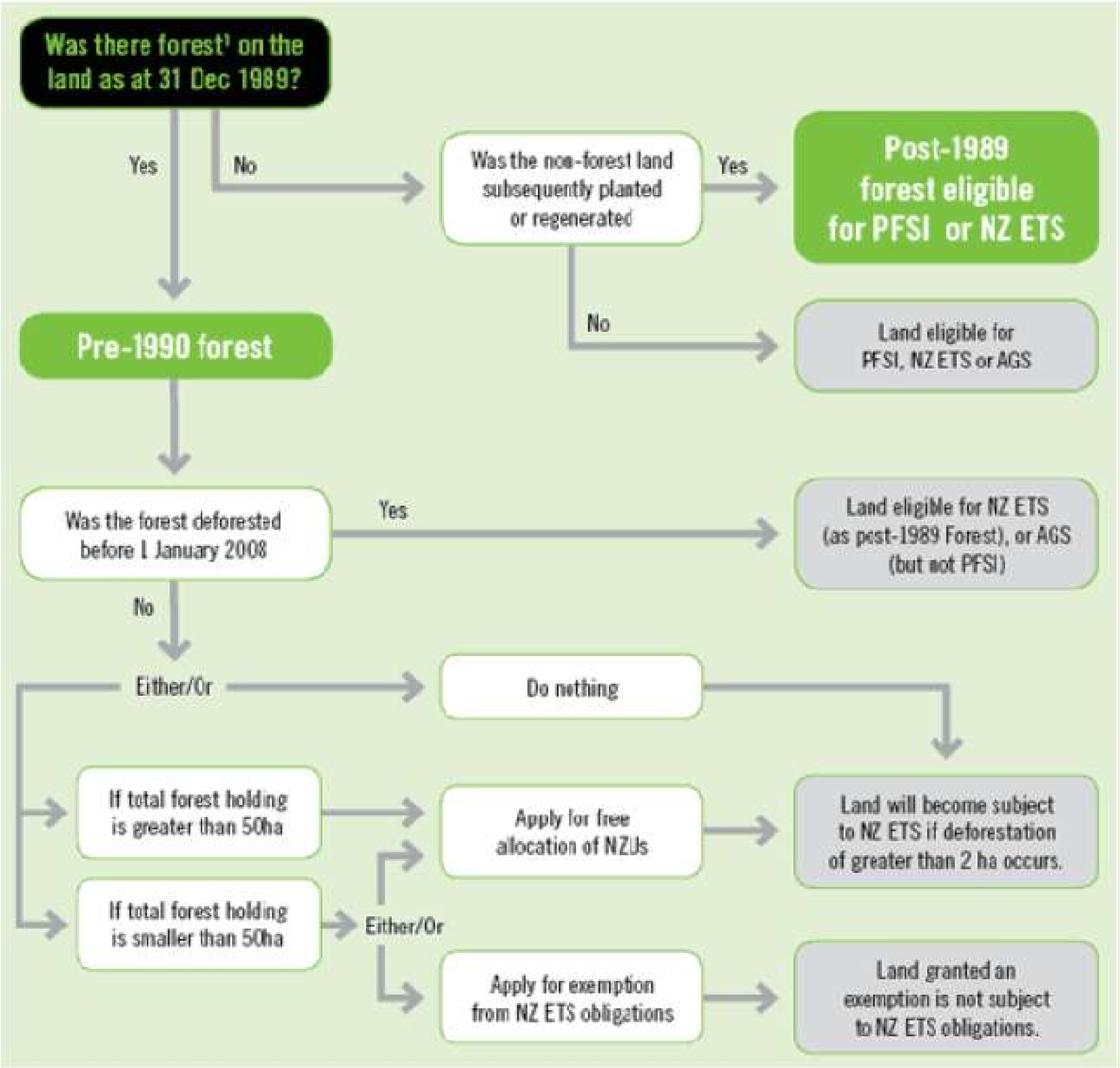

Figure 4.1 Forestry programmes decision flow chart (available at page 15 in http://www.maf.govt.nz/climatechange/forestry/initiatives/ags/AGS-Guidelines-April-08.pdf)

4.2 Calculation of carbon credits for post 1989 forest

Once a forest block is registered and has been approved a land or forest owner can apply for carbon credits. The quantity of credits claimable can be calculated using “Look-up” tables published by MAF (http://www.maf.govt.nz/sustainable-forestry/ets/guide/lookup-table-guide.pdf). These tables are also provided in Appendix Four. It is proposed that on-site measurement of actual carbon stock will be mandatory for forests above a threshold size, probably 50 hectares, but as yet measurements standards are not available. We use an example of a 50 ha forest planted on land which was previously grazed. The forest was planted between 1994 and 1998. Table 1.1 shows the carbon stock at the beginning of the commitment period (January 2008) and at the end (December 2012). The increment per hectare is shown and multiplied by the number of hectares. Notice that carbon stock increments change with forest age. For this example carbon stock accumulation peaks at age 17 at 37 tonnes/ha/year.

Table 4.1 Carbon credits available from post-1989 exotic forestry

Pinus radiata (plant year)	**ha**	**Age** (Jan. 2008)	**Carbon Stock Jan. 2008**[1] (tonnes CO_2/ha)	**Carbon Stock Dec 2012**[1] (tonnes CO_2/ha)	**Credits over 5 years** (tonnes CO_2/ha)	**Total credits over 5 years** (2008 – 2012) **tonnes CO_2**
1994	2	13	249	428	179	358
1995	15	12	218	391	173	2595
1996	15	11	188	354	166	2490
1997	15	10	163	318	155	2325
1998	3	9	142	283	141	423
Totals	50					**8191**[2]

1 Carbon Stock per hectare for post-1989 forest land (*Pinus radiata*) for Waikato/Taupo (Schedule 6, of the Climate Change Regulations), see Appendix Four.
2 Equates to NZ Units

Table 4.1 shows a total accumulation of 8191 tonnes carbon stock over the five year Kyoto commitment period from January 2008 to December 2012. This equates to 32.7 tonnes CO_2/ha/yr.

4.3 Registering as a participant in the ETS

A few pointers to note when registering as a participant in the ETS and claiming carbon credits.

4.3.1 Matching names

Delays have been experienced where names listed on the emissions unit register do not match title documents. If for example the name under “Account Holder” is different from that on the land or forest right title then at applicant must start a new application. So where there are 20 names on forestry right or land title, all names must be listed as the account holder.

4.3.2 Carbon accounting areas

When entering a forest estate in the ETS it is most important to consider carefully how forest blocks are specified as “carbon accounting areas” during the process of registration. Carbon accounting areas should be the smallest sensible areas based on a range of aspects such as species, age, management and potential harvest difficulty. This subdivision will often be at a forest stand level.

4.3.3 Emissions Trading Scheme compared with Permanent Forest Sink Initiative

Carbon credits are available under both schemes from January 2008**.** At this stage there is no clear advantage for entering the Permanent Forest Sink Initiative (PFSI) over the Emissions Trading Scheme (ETS) as it is not clear if credits generated under the PFSI will attract the necessary premium to off-set additional administration requirements. The key restrictions of the PFSI include a requirement for a 50 year covenant agreeing the land will remain in forest and restricting harvesting to the removal of only 20% of the pre-harvest basal area. However, Assigned Amount Units (AAUs) are provided by the PFSI rather than New Zealand Units (NZUs) as provided under the ETS. AAUs can be traded internationally while NZUs can only be traded within NZ. The PFSI may have an advantage if other sectors within NZ are not brought into the ETS as international trade of AAUs will still be possible. However, depending on final government regulation, an amount of NZ units (NZUs) will be eligible for conversion to assigned amount units (AAUs). Again the best approach (ETS or PFSI) will remain unclear until the result of the ETS review is announced.

4.3.4 Liabilities

By entering forestry into either the ETS or PFSI the forest owner accepts the risk of carbon loss from fire, wind or other natural disasters with the loss being payable as carbon liabilities. Harvest liabilities will apply under both schemes.

5 Carbon trading

Info Sheet 5 covers carbon trading including pricing and trading mechanisms. All material is referenced on the Info Sheet as it is largely web based. This is a function of the fact that it is a relatively new phenomenon. It is important to note that carbon pricing in New Zealand will remain uncertain until the outcome of the review process is known and sectors other than forestry have entered the ETS.

5.1 Other notes

A further indicator of carbon price is that New Zealand Treasury valued NZUs at $25.31 when estimating New Zealand’s fiscal exposure to Kyoto obligations (Carbon Monitor, May 2009, www.eitg.co.nz). The net price received from any sale of credits is likely to be less than market value as costs associated with trading (eg brokerage) are likely to be incurred. Also other costs may be incurred from aggregation of credits depending on the market accessed.

6 Voluntary Trading

Info Sheet 6 covers voluntary carbon market in relation to the Kyoto Protocol including examples potential trading situations. All material is referenced on the Info Sheet as it is largely web based. Once again this is a function of the fact that it is a relatively new phenomenon. The observations of Info Sheets 4, 5 and 6 would be that trading carbon under simpler and easier under the NZETS than on the voluntary market. However, depending on how the ETS is implemented it may still be a viable option for some (trading soil carbon, forests planted after 1990 and prior to 2008).

Further reading can be found at http://www.maf.govt.nz/climatechange/reports/voluntary-carbon-mkt-opps/index.htm

7 Managing Emissions from Farming Livestock

7.1 The Big Picture

Globally there are 3.5 billion ha available for grazing and only 1.5 billion available for growing crops (FAO, 2004). The number of grazing animals has increased nearly two fold since the 1900s (FAOSTAT, 1998). Despite ruminants posing a problem in terms of greenhouse gas emissions they will continue to be an important food source.

Our studies have shown that livestock produce over 90% of greenhouse gas emissions from New Zealand Pastoral farms (Table 7.1). Other sources such as electricity and fuel are minor.

Table 7.1 Effect of farm type on greenhouse gas emissions[1]

	Sheep and beef (Info Sheet 8)	Dairy + dairy run-off (Info Sheet 9)	Dairy + dairy run-off + beef (Info Sheet 10)
Livestock	97%	86%	90
Nitrogen	2.4	11	8
Other (Electricity, fuel)	0.6	3	2

1 Data from Info Sheets 8 to 10.

7.2 Livestock

Significant research effort ($50M over 10 years Pastoral Greenhouse Gas Research Consortium) is going into development of techniques to suppress methane and nitrous oxide emissions (Aspin and Leslie, 2007). At this stage technology is at least 10 years away from practical application at farm level. Research strategy ranges from fundamental studies to understand processes through development of the technology to a usable form (www.pggrc.co.nz). Areas of work include methanogen genomics, feed evaluation and animal breeding.

The most promising approach being studied in New Zealand is the use of a new soil treatment method, known as a nitrification inhibitor. Using a nitrification inhibitor has been shown to correspond with significantly-reduced direct N_2O emissions and nitrate leaching from dairy farms. After applying dairy cattle urine and a nitrification inhibitor to soil, on average, direct N_2O emissions were about 70 % lower than that from soil receiving only urine (Di et al., 2007). This figure is based on field trials that determined a treatment effect for soil urine patches over 2 to 3 month periods in autumn and winter. A further benefit is that nitrate leaching was on average about 50% lower although the effect was much more variable. While N_2O emissions should be highest in autumn and winter, year-round feeding of dairy cattle outdoors means N excretion onto soils and N_2O emissions will also occur in spring and summer. Nitrification inhibitors breakdown rapidly in the soil at temperatures > 12^oC meaning that the reduction of annual N_2O emissions will be less than the 70% found in autumn and winter. In addition, because the currently available nitrification inhibitors are applied to the soil using specialist equipment they are most applicable to dairy farm systems and may have limited applicability in hill country beef and sheep systems. (Smith et al., 2008)

Several strategies are mentioned in Info Sheet 7 for consideration at farm level in relation to livestock management. Environment Waikato (EW, 2006) have published a comprehensive list of these strategies, provide background information and a list of further sources for information www.ew.govt.nz/PageFiles/1189/farmmanagementissues5.pdf. However these strategies have relatively minor impact or pose other problems. For example substituting ryegrass with feeds which are relatively high in energy and low in nitrogen like maize silage may reduce methane and nitrous oxide emissions but require cultivation, processing and transport that release carbon dioxide. Any mitigation strategy or tool requires a system to make it count so assessments need to be carried out within systems, not simply in isolation.

7.3 Fertiliser

Examples of fertilisers produced using non-renewable fossil fuel include reactive phosphate rock, animal manure and lime. Some farmers are boosting legume production and nitrogen fixation through annual reseeding of clover. Retaining crop residues, using cover crops and fallow periods can also improve soil fertility. These sources nutrient require less energy from fossil fuels as compared with synthetic fertilisers.

Losses and emissions can be reduced through efficient use of nitrogen fertiliser. This includes avoiding it's use in cold wet conditions to ensure that nitrogen is taken up by actively growing pasture and not lost to leaching and/or to the atmosphere through denitrification. A nutrient budget can be used to predict requirements and potential losses resulting from different farm management practices including application timing and rates. Fertiliser companies such as Ballance Agrinutrients and Ravensdown Fertiliser provide nutrient budgeting services. An extensive list of NZ fertiliser companies can be found at http://www.fertqual.co.nz/page.php?6. Overseer® (www.agresearch.co.nz/overseerweb) is widely used by the NZ agricultural industry for this purpose (Wheeler, 2009). Fertiliser and nutrient management advice is freely available at the Dairy NZ website (http://www.dairynz.co.nz/page/pageid/2145836784).

Improving the accuracy of fertiliser application can improve the efficiency of fertiliser use and therefore potentially reduce overall fertiliser requirement or improve productivity. For example a loss of \$66.18 ha^{-1} was calculated when comparing perfect spreading performance to actual performance (Lawrence, 2007). Losses were form lost production from less than perfect nitrogen application and additional base fertiliser required to maintain nutrient levels. If a global positioning system (GPS) guidance and control system was used to provide optimised field application the loss could be reduced to \$46.41 ha^{-1}. During 2008 when fertiliser prices were high, the difference between perfect and actual performance was estimated at \$116.58 ha-1 for a typical Waikato dairy farm (Ian Yule, Pers. comm., 2009). Basic fertiliser optimisation includes SPREADMARK accreditation means that spreading operators have been trained, their equipment independently assessed and systems audited (http://www.fertqual.co.nz/page.php?5).

7.4 Energy

On-farm energy sources account for the least quantity of emissions on livestock farms (Table 7.1). There are however significant savings to be had by upgrading equipment to more energy efficient technologies. There is a significant resource of New Zealand information available (see Table 7.2 for list of websites). For example there may be up to 25% savings in electricity in the dairy shed (EW, 2006).

Table 7.2 List of websites with information on how to save energy

Website	Description
www.dairysavings.co.nz	**Genesis Energy tips to save power and savings calculator**
www.meridianenergy.co.nz/yourfarm	**Meridian Energy power saving ideas**
www.climatechange.govt.nz	**case studies on energy efficiencies on farms**
www.ruralenergy.co.nz/dairyaudit/index	**technology for energy saving on dairy farms**
www.energywise.org.nz	**general tips on energy efficiency**
www.emprove.org.nz	**tips for reducing business energy use**
www.eeca.govt.nz	**the Energy Efficiency and Conservation Authority**
www.4million.org.nz	**the "4 million careful owners campaign" - how individuals can cut energy use**
www.agrilink.co.nz	**energy reports and tools**

Switching from cultivation to no-till crop establishment practices could save up to 80% fuel use but more typically two thirds fuel use is saved in this way (John Baker, pers. comm., 2009).

While scheduling irrigation application depth and timing to optimise pasture response is critical, accuarcy and uniformity are important to irrigation efficiency and cost. The less uniform the application, the greater the depth of water required to get the same pasture response. For example if the goal is to irrigate 90% of a field that has a 50mm soil water deficit, increasing uniformity from 70% to 90% would decrease the required average application depth from 95mm to 60mm and could increase application efficiency from 51% to 83%. It would also decrease the irrigation time and therefore increase the total area that can be irrigated with a given irrigation machine by about 50% reducing capital and running costs per hectare and per kg of dry matter produced (McIndoe, 1998).

Research into systems incorporating biochar may also provide strategies for reducing the impact of GHGs (Lehmann, 2007, Hedley et al, 2008). New Zealand has recently established a Biochar Network to share knowledge and international research in this area. However, most these strategies currently have minor impact or are not practical. Current opportunities to offset carbon emissions lie in afforestation either on or off-farm.

7.5 Offsetting liabilities using Forestry

As indicated in Info Sheet 7, carbon credits gained from the growth of new forests established after 1989 can be used to off-set potential on-farm emission liabilities.

7.5.1 How much forestry will I need?

Firstly you have to assess what the emissions a farm will be liable for[2]. This will be unclear until the outcome of the ETS review is announced. For this example we have chosen two scenarios. The first is based on the current ETS legislation as it would apply to a farm at 2030, ie it would have to account for 100% of all emissions and become carbon neutral. The second is based on an extrapolation of New Zealand's agriculture net position report by the Ministry for the Environment to meet our Kyoto obligations for the first commitment period (2008 to 2012), this is currently sitting at an average for the whole agriculture sector at around 9% over and above 1990 levels.

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[2] For an idea of a farms carbon footprint visit www.carbonfarming.org.nz

Using the case study information in Info Sheet 8 the total on farm emissions on a typical sheep and beef farm (600ha) are detailed in Table 7.3. The total on-farm emissions under scenario 1, is 1,802 tonnes of CO_2-equivalents or NZU's. This is the quantity required to be offset or mitigated or bought to become carbon neutral. The amount required to meet the average agriculture sector Kyoto obligations under scenario 2 is 162 tonnes of CO_2-e or NZU's (1802 x 9%).

Table 7.3 Greenhouse gas emissions for a sheep and beef farm

Greenhouse gas source (annual emissions)			Tonnes CO_2 (NZU)
Petrol	2,540	Litres	6
Diesel	52	Litres	0
Electricity	19,660	kWh	5
Nitrogen	8	Tonne	45
Sheep	2,862		944
Cattle	469		802
			1,802

To estimate what size forest is needed to offset these on-farm emissions the average carbon absorption (sequestration) rates for various species are required. These sequestration rates will vary as they depend on several factors such as species, location, climate, soil fertility and management. However we have chosen a conservative figure of 22 tonnes CO_2 /ha/yr for radiata pine. This has been calculated based on indicative forest sequestration tables for pruned and thinned radiata pine plantation on medium fertility site (Paul et al., 2008). By way of comparison we have chosen to use the average rate of 3 tonnes CO_2 /ha/yr for reverting native bush, as described in the look up tables. There are other rates available for radiata in different regions and for alternative species and can be calculated using "Look-up" tables published by MAF (http://www.maf.govt.nz/sustainable-forestry/ets/guide/lookup-table-guide.pdf) (see Table 4.1).

Table 7.4 shows how much forestry is required to offset emissions from scenarios one and two. The percentage of effective farm area required for forestry for the sheep and beef example is sown in brackets.

Table 7.4 Effect of species and compliance target on area of forestry required to off-set farm emissions

Scenario	Radiata Pine	Native Regeneration
1) 100% "Carbon Neutral"	82ha (14%)[1]	600ha (100%)
2) 9% "Kyoto Complaint"	8ha (1%)	54ha (9%)

1 Percent of 600ha farm required for forest as emissions off-set shown in barckets

Table 7.4 shows that faster growing exotic species such as radiata pine are most suited to efficiently offset on-farm greenhouse gas emissions when compared to the low sequestration rate of native reversion. This also shows that there is a large difference in areas to be planted when comparing the farm being carbon neutral to being Kyoto compliant. For an average 600ha sheep and beef farm it only requires 8 hectares of radiata pine to become Kyoto compliant, compared to 10 times that amount to be carbon neutral.

7.5.2 Alternative species

If you are considering planting trees to off-set future livestock emissions and you have sufficient area avaialble then consider alternative species to radiata pine which are likely to have longer rotation length and produce potentially higher value timber (eg cupressus macrocarpa or lusitanica). Existing legislation provides 90% free allocation to the agricultural sector for the first 5 years from 2013 to 2018 which matches the growth profile of alternative species which tend to be slower than radiata pine. Some species of eucalyptus may also be suitable. When planting alternative species to radiata pine more consideration of site selection is required as they tend to be more sensitive to soil and envirnomental restrictions such as low soil fertility, droughts and exposure to wind.

7.5.3 Off-farm investment

Few dairy or arable farms have land suitable for establishing a new forest. New forests could be established on less productive land purchased in partnership with other farmers. The Afforestation Grant Scheme could provide the capital required to establish a new forest (see info sheets 4 and 5). Alternatively joint ventures could be developed whereby forestry right is granted against the title of the land by a landowner to another person to establish, maintain and harvest a crop of trees. This possible under the Forestry Rights Registration Act 1983 . Professional forestry and legal advice should be sought before carrying out such investments.

7.5.4 The Forestry Rights Registration Act 1983

In 1983 the Forestry Rights Registration Act was passed to facilitate the use of joint ventures for the development of plantation forestry. This was a very simple piece of legislation to provide for a forestry right to be granted by the owner or lessee of land to another person to establish, maintain and harvest, or just to maintain and harvest, a crop of trees on that land. It also incorporated rights of access and provisions for payments, royalties, or a division of the crop or the proceeds from the crop. The Act provides for the registration of a forestry right against the title of the land to which it relates, but without the high standard of survey normally required for registering instruments against land titles. The Act has had only modest use by companies and private investors.

http://legislation.govt.nz/act/public/1983/0042/latest/DLM72449.html?search=ts_act_Sentencing_resel

8 Sheep and Beef farm case study

This farm data was modelled on a East Coast (Gisborne) Hill country farm. The property actually has 170 ha of new forestry planted on land which was initially being grazed. Total farm size is actually 800 ha while effective grazing area is 600 ha. Discussions with the owner revealed that 6000 SU were carried on the property before the 170 ha of forestry was established. Initially it was envisaged that carrying capacity would be reduced by 800 SU. However, it is estimated that carrying capacity was reduced by 400 SU or 7% while 21% of land area has been planted. This is thought to be due to focus on remaining, relatively higher fertility and more stable land with increased subdivision and fertiliser in those areas.

8.1 Livestock on the farm

Table 8.1 details the livestock on the sheep and beef case study farm. Note while several years data are shown 2008 data was used for info sheet 8.

Table 8.1 Livestock on sheep and beef Farm case study

	Hoggets	Ewes	Rams	R1 Bulls	R2 Bulls	R1 Hfrs	R2 Hfrs	R1 Steers	R2 Steers	MA Cows
Stock Unit	0.7	1	0.8	4.5	5.5	3.5	4.5	4.5	5.18	5.18
2006	903	2220	41	56	27	56	52	64	72	139
2007	783	2165	37	40	59	41	37	50	60	130
2008	900	2200	40	56	64	56	50	68	72	140

Total stock units and proportion of stock types on the property.

Year	Total SU	Proportion Sheep	Proportion Cattle
2006	5096	0.57	0.43
2007	4766	0.57	0.43
2008	5291	0.54	0.46

Table 8.2 Greenhouse gas emissions for sheep and beef farm

			Sheep and Beef	
	Unit	Factor	#	NZU
Petrol	Litres	0.00234	2540	6
Diesel	Litres	0.00268	52	0
Electricity	kWhr	0.00023	19660	5
Nitrogen	Tons	5.63900	8	45
Cattle	Cattle	1.71000	469	802
Sheep	Ewes	0.33000	2862	944
		Total		**1802**

9 Dairy Farm case study

This case study is based on a South Waikato dairy farm producing 210,000 kg milk solids (2007/08) from 535 cows on 178 ha. Included in the operation is a 40 ha dairy run-off, 140 yearling heifers and 120 rising two year old heifers.

9.1 Livestock on the farm

Table 10.1 details the livestock on the dairy case study farm (info sheet 9). Note that total stock units were approximately 5000.

Table 9.1 Livestock on dairy Farm case study

	R1 Bulls	R2 Bulls	R1 Hfrs	R2 Hfrs	XB Cows	Fr Cows	Jer Cows	**Total**
Stock Unit	4.5	5.5	3.5	4.5	7.5	8.5	6.5	
Dairy					535			
Run-off			140	120				
SU			490	540	4012.5			5042.5

Table 9.2 Greenhouse gas emissions for dairy farm

		Dairy		**Run-off**		**Total**	
	Factor	#	NZU	#	NZU	#	NZU
Petrol	0.00234	1400	3	100	0	1500	**4**
Diesel	0.00268	10000	27	1000	3	11000	**29**
Electricity	0.00023	62000	14	240	0	62240	**14**
Nitrogen	5.63900	28	156	12	65	39	**220**
Dairy	2.47000	535	1321	0	0	535	**1321**
Cattle (hfrs)	1.71000	0	0	199	340	199	**340**
	Total		**1521**		**408**		**1929**

10 Dairy, Sheep and Beef farm

This case study operates on three properties comprising of a 178 ha dairy farm with 535 cows producing 210,000kg milk solids (2007/08), a 40ha dairy run-off and a 362 ha sheep and beef farm. The properties include 30ha of forest planted during the 1990s.

10.1 Livestock on the farm

Table 10.1 details the livestock on the dairy, sheep and beef case study farm (info sheet 10).

Table 10.1 Livestock on dairy, sheep and beef farm case study

	Ewes	R1 Hfrs	R2 Hfrs	R2 Steers*	XB Cows	Fr Cows	Jer Cows	Total SU
Stock Unit (SU)	1	3.5	4.5	5.18	7.5	8.5	6.5	
Dairy					535			
Run-off				300				
Sheep and Beef	1300	100	50	250				
SU	1300	350	225	2849	4012	0	0	8736

* equates to “cattle” in carbon farming group calculator and includes dry cows

Table 10.2 Greenhouse gas emissions for dairy, sheep and beef farm

		Dairy		Run-off		Sheep beef		Total	
	Factor	#	NZU	#	NZU	#	NZU	#	NZU
Petrol	0.00234	1400	3	100	0	800	2	2300	**5**
Diesel	0.00268	10000	27	1000	3	1500	4	12500	**33**
Electricity	0.00023	62000	14	240	0	1680	0	63920	**15**
Nitrogen	5.63900	28	156	12	65	6	31	45	**252**
Dairy	2.47000	535	1321	0	0	0	0	535	**1321**
Sheep	0.33000	0	0	0	0	1300	429	1300	**429**
Cattle	1.71000	0	0	300	513	250	428	550	**941**
Heifers R1	1.15541	0	0	0	0	100	116	100	**116**
Heifers R2	1.48552	0	0	0	0	50	74	50	**74**
	Total		**1521**		**581**		**1084**		**3186**

11 Arable Farm

This case study farm size was 290 ha with 214 ha used for crop production and was assumed to be irrigated. A flock of 860 ewes are the only livestock in the operation. Table 11.1 shows the greenhouse gas emissions for the arable farm (info sheet 11).

Table 11.1 Greenhouse gas emissions for arable farm

		Arable	
	Factor	#	NZU
Petrol	0.00234	4922	12
Diesel	0.00268	18190	49
Electricity	0.00023	428000	98
Nitrogen	5.63900	28	156
Dairy	2.47000	0	0
Sheep	0.33000	860	284
Cattle	1.71000	0	0
Horses	0.59000	0	0
	Total		**598**

12 Carbon Forest Management

Managing forests for carbon can be quite different from managing forests for timber. However the two should not be mutually exclusive.

Traditional forest management involves planting an area of a single species (normally ratiata pine) at the same time. This results in a forest which is condusive to silvicultural management i.e. the whole forest can be pruned and thinned in one operation, and at the end of the rotation can be harvested all at once. When managing for timber this makes economic sense. You want to minimise costs during establishment and tending phases and maximise returns at harvest time through efficient harvesting techniques. With this type of forestry, income is only gained at the end of the rotation, in the case of radiata pine, it is a wait of around 30 years.

Trading carbon has the ability to increse the profitabilty of forestry (Maclaren and Manley 2008) by creating revenue annually as the forest matures and may alter the management regieme significantly. For example, a rising carbon price favours late thinning or production thinning, high final stocking, and discourages pruning. As the carbon price increases, there is a general lengthening of optimum rotation age (Maclaren, Manley 2008). This rotation age could be pushed out to ages around 50 to 60 years.

Maclaren and Manley (2008) rank the profitability of various species and regimes depending on carbon price. If the price of carbon is zero, the most profitable species/regimes are, in order: radiata pine grown on a clearwood regime; radiata pine grown on a framing regime; radiata pine with a plant and leave regime; Douglas fir; Eucalyptus nitens; and indigenous forestry. This ranking alters substantially with higher carbon prices. Radiata regimes which have higher volume become favoured over regimes that produce trees of large piece-size or clearwood. Eucalypt regimes become relatively more profitable than low-volume radiata regimes. West et.al. (2008) also showed that eucalpts and radiata are likely to be favoured for planting with the advent of the ETS and carbon trading.

An example from the Maclaren and Manley study shows how the value of carbon sales to effect investment reurns from a conventional radiata clearwood regime. When a discount rate of 8% is used along with a value for carbon of $20/tonne, Land Expectation Value[3], the rate that can be paid for land going into a forestry investment, increases from $1215 to $3400/ha. This shows that returns from carbon durng the growth of the crop improve the value of the investment despite the requirement to repay liabilities for wood (carbon) sold at the time of harvest.

Using higher stocking rates, delaying thinning, not pruning and extending harvesting timeframes may sacrifice timber quality as processing of (older) larger logs may not suit current processing facilities. Most modern radiata pine sawmills cannot handle logs with a large end diameter over 80cm. In some fast growing areas in New Zealand this diameter is achieved before year 30. Clearly, careful consideration should be given to forest management to maximise benefits from the objectives of both timber and carbon. Growing a forest crop without consideration of wood value puts the venture at great risk from a collapse of the carbon market.

12.1 Even aged vs Mixed aged forests

As already mentioned in the previous section traditional forest management has resulted in even aged forests. This has a significant impact on the ability to maximise the returns from carbon. Under the current rules of the ETS (and the Kyoto protocol) it is assumed as soon as timber is harvested the carbon dioxide is immediately released back into the atmosphere. The impact of this ruling on even aged forests (Figure 12.1) is that the forest owner has to pay back any carbon claimed before harvest which is equivalent to the volume of timber removed.

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[3] Land Expectation Value is similar to the better-known Net Present Value (NPV) – it assuesm perpetual series of forest rotations on land that is currently bare of trees. It is the maximum that can be paid for land to achieve a given rate of project return.

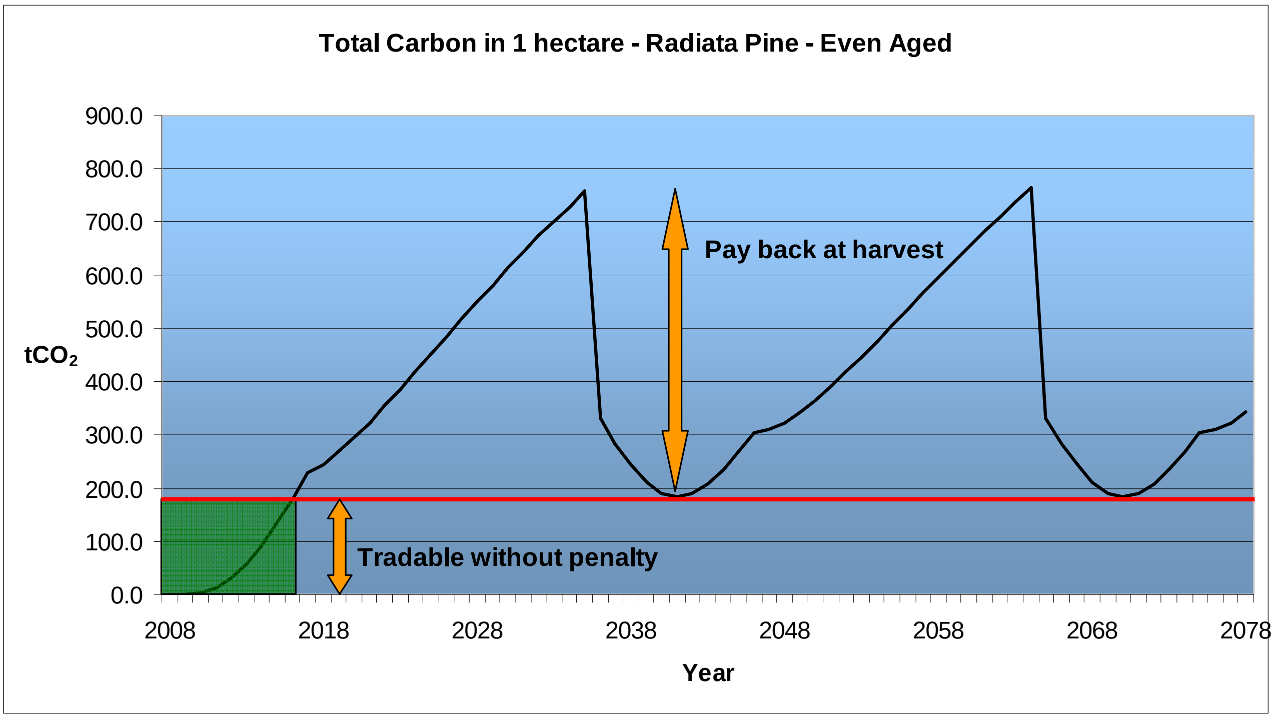

Figure 12.1 Effect of even aged forest on carbon sales

However, there is a component of this forest which can be traded without penalty. This is shown in the graph above as the green area. The reason the black line dosen't drop right back to zero is that there is some residual tree matter left on the site after harvesting. This includes branches, stumps and roots. In this example around 185 tonnes of carbon dioxide (carbon credits) can be sold. A significant point to remember is that once this volume is sold it cannot be grown again and re-sold, the sale of a carbon credit is a one off. Also note that forests planted prior to January 2008 will provide less in the way of carbon available for trade without penalty as January 2008 is the balance date around which additional carbon stock is calculated. Depending on region, little carbon will be tradeable without penalty from forests older than about 10 years at January 2008 as existing carbon stock will be around 124 to 219 tonnes CO_2/ha and equivalent to that remaining after harvest (see Appendix Four). Carbon is primariliy sequestered during the first rotation (Mason and Evison 2009).

One way of reducing the pay back at harvest time is to modify the forest to smooth out the future profile of the carbon stocks (Maclaren and Manley 2008). With the theoretical example below this is achieved by planting one hectare each year for 30 years. By the time the first hectare is harvested there is 30 hectares of forest at each age class, therefore smooting the volume (and carbon) over the entire forest. This results in a forest that is continually growing and being harvested with no noticable drop in volume, by doing so this almost eliminates the need to pay back carbon at harvest time. By having 1 hectare in each of the age classes 1 through to 30 it averages the forest volume to around half of the total volume if the whole 30 hectares was mature. In this example around 400 carbon credits are avaliable for sale with out penalty (Figure 12.2).

This mixed age class forest can also be achieved through the planting of a vairety of sepcies which grow at different rates and/or combining this with variable harvest dates.

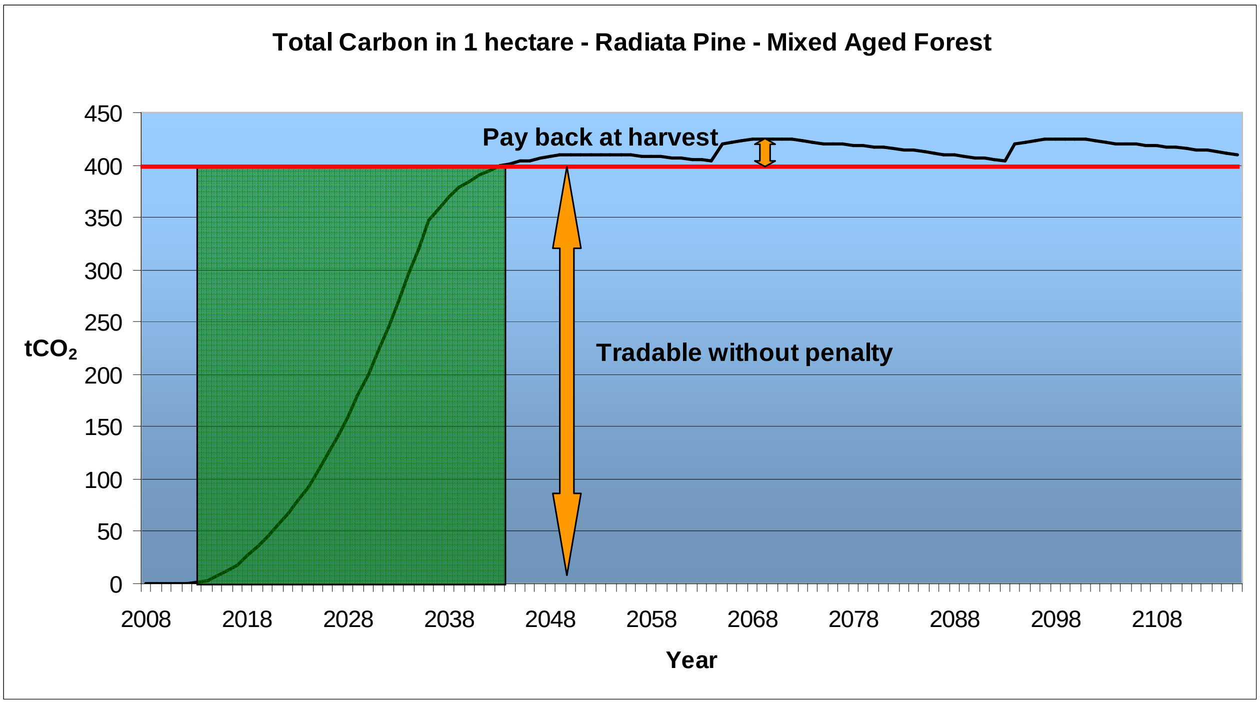

Figure 12.2 Effect of mixed age forest on carbon sales

13 Other benefits from incorporating forestry for carbon management.

While on-farm planting of trees can reduce exposure to external carbon costs imposed by markets or governments it can also form part of a sustainable land management strategy with positive environmental and economic outcomes. Farming operations which integrate forestry can become more resilient to climatic and market changes. In some farming situations the incorporation of forests into the farming business (either on or off farm) may offer resilience to climatic events. For example, through soil stabilisation, waterway protection, or emergency stock fodder from poplars during drought. Income from forest harvest can provide resilience to fluctuations in prices of other farm commodities. The timing of harvest is flexible so forests can be retained when income from other commodities is good, and then harvested in a year of poor returns from other commodities. Retiring less productive areas of the farm to forestry can improve overall profitability as inputs are focused on the more productive features. This can in some cases free up more time for leisure. Additional benefits from tree planting include provision of shelter for stock, increasing on-farm biodiversity and improvement of the amenity or aesthetic values of a property. Relations with regional council are also likely to be improved in recognition of improved on-farm environmental performance.

13.1 Carbon Footprint

The carbon footprint of farm products should also be considered. While planting forests to reduce the carbon footprint of a product is not accepted internationally (Ledgard, 2008) the carbon released by deforestation is attributed to products arising from that area for a period of 20 years (Watson, 2009). Even although carbon credits from new forests may be be directly accounted for in carbon footprinting. Trade in credits may provide income with which to invest in mitigation techniques which lead a reduction on the carbon footprint of farm products. Income and expenditure on carbon management strategies should be relative while credits from new forests are considered as a valid off-set to GHG emissions.

Soil Conservation

The strengthening effect of tree roots and protection provided by forest canopies can significantly reduce erosion and soil loss. These benefits are attributable to improved land stability. The scope of improvement has been quantified in surveys of Manawatu and Wairarapa hill country farms. In comparison to unplanted sites wide spaced poplars, willows and eucalypts reduced soil slippage by 95% (Douglas, 2009). Plantings reduced gully erosion by 50%, streambank collapse by 24%, mass movement of footslopes by 67% and mass movement of hill faces by 71% (DSIR, 1992).

13.2 Wide Spaced Poplars

Wide spaced poplars planted for erosion control are Kyoto compliant as long as they provide continuous cover over an area of 1 ha or more, have or will achieve 30% canopy cover and occur in a block wider then 30m at any point. Note that gaps of 15m or more between trees constitute a new block. An example calculation follows. If canopy radius id 5m, stocking rate is 50 stems/ha then canopy cover is 39% and so the trees will be Kyoto compliant (Area = Pi r^2 = 3.145 x 25 = 78m^2/tree x 50 trees = 3927m^2/ha = 39%). At present only the “Look up Tables” may be used to calculate carbon stock, the table titled exotic hardwoods should be used. This will provide an optimistic figure for carbon as it assumes higher density. So if you claim credits for wide spaced poplars using the Look-up tables, you should be conservative as in the future actual measurements may have to be taken and if you have over-claimed then you may incur liabilities.

Shade effects – Verkerk (2009) reported on Waikato trials which showed that cows provided with artificial shade produced 1.7 per cent more milk solids per day than cows without shade. The propensity to develop heat stress was higher for Holstein-Fresian as compared with Jersey cows. The Dairy NZ website (www.dairyNZ.co.nz) has a temperature-humidity-index calculator which estimates the risk of heat stress and production loss based on weather data. This in turn could be used to estimate the value of shade on dairy farms.

14 Risks and Liabilities

This area of work was not part of the initial project scope but was included in response to quaestions from those who attended early seminars. Therefore info sheet 14 is an expression of the authors opinions rather than a summary of research in this area.

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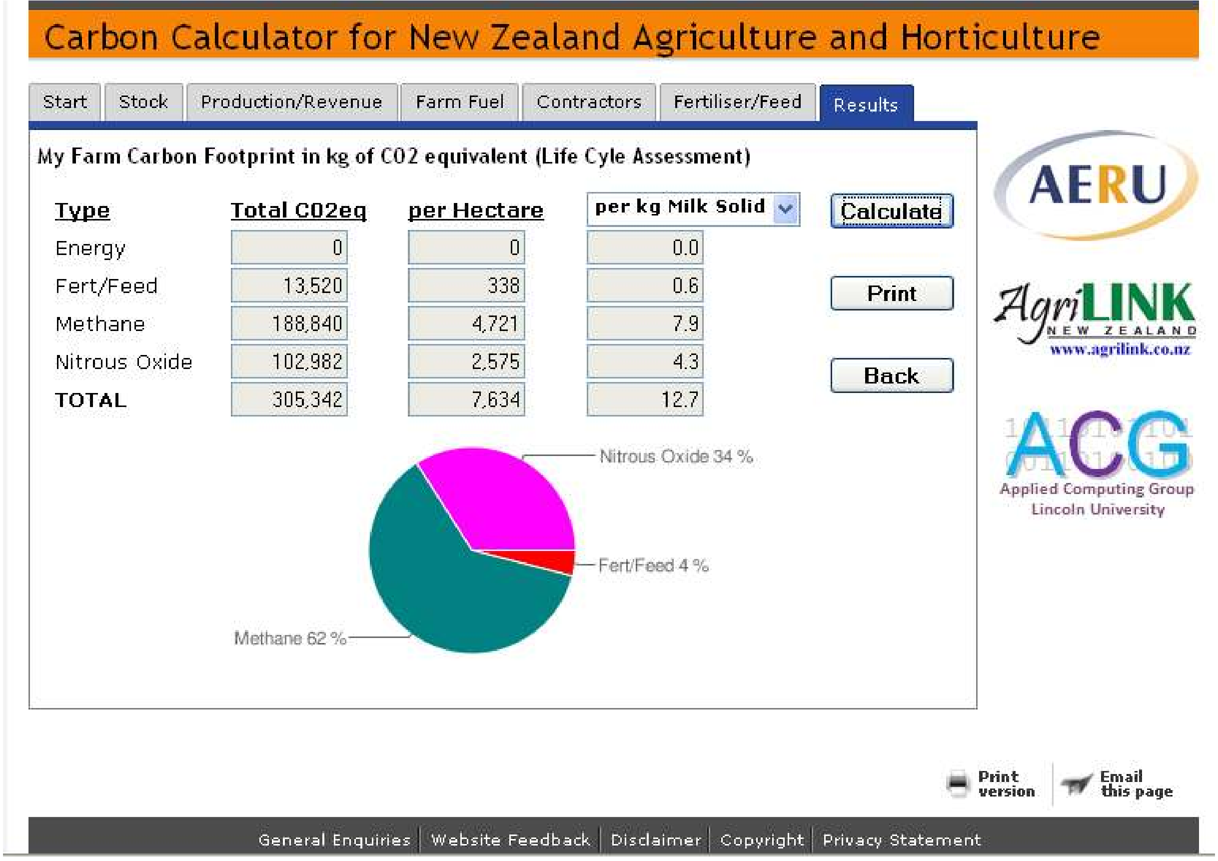
1 Appendix One: Screen output from Lincoln and Overseer® calculators

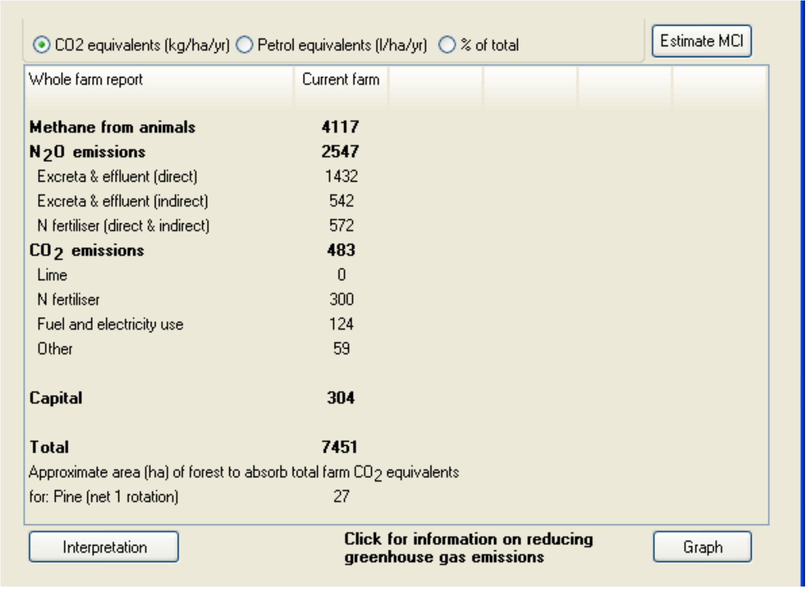
Lincoln Carbon Calculator output, 100 cows, 40 ha, 100kgN/ha



My Farm Carbon Footprint in kg of CO2 equivalent (Life Cyle Assessment)

Type	Total CO2eq	per Hectare	per kg Milk Solid
Energy	0	0	0.0
Fert/Feed	13,520	338	0.6
Methane	188,840	4,721	7.9
Nitrous Oxide	102,982	2,575	4.3
TOTAL	305,342	7,634	12.7

Overseer output, 100 cows, 40 ha, 100kgN/ha, 600MS/ha



Whole farm report	Current farm
Methane from animals	**4117**
N_2O emissions	**2547**
Excreta & effluent (direct)	1432
Excreta & effluent (indirect)	542
N fertiliser (direct & indirect)	572
CO_2 emissions	**483**
Lime	0
N fertiliser	300
Fuel and electricity use	124
Other	59
Capital	**304**
Total	**7451**
Approximate area (ha) of forest to absorb total farm CO_2 equivalents for: Pine (net 1 rotation)	27

2 Appendix Two: Effect of variable adjustment on Overseer output

(430 cows, 305ha, 100 kg/ha N, replacements on farm)

Per hectare report				Base CO2 Eq/ha/yr								
Methane from animals				2926	2926	3262	3162	3061	2926	2926	2926	2926
N20 emissions				1753	1753	1924	1872	1807	1753	1753	1753	1753
	Excreta & eff (direct)		967									
	Excreta & eff (indirect)		368									
	N fertiliser		418									
CO2 emissions				756	756	757	757	756	756	756	756	756
	Lime		421									
	N fertiliser		219									
	Fuel and electricity		72									
	Other		44									
Capital				161	136	166	165	159	161	161	136	161
Total		kgs		5596	5571	6109	5956	5783	5596	5596	5571	5596
Pines needed		ha		155	154	169	165	160	155	155	154	
Whole farm report												
Area (ha)				305	305	305	305	305	305	305	305	305
		CFG										
Methane from animals			1310	892	892	995	964	934	892	892	892	892
N2O emissions			117	535	535	587	571	551	535	535	535	535
CO2 emissions			42	231	231	231	231	231	231	231	231	231
Total	Tons/yr		1468	1658	1658	1813	1766	1715	1658	1658	1658	1658
Variables	effluent			spray	**export**	spray	spray	spray	spray	spray	spray	spray
	cow breed			jersey	jersey	**friesian**	**F X J**	jersey	jersey	jersey	jersey	jersey
	prod			135000	135000	135000	135000	**148500**	135000	135000	135000	135000
	soil type			recent	recent	recent	recent	recent	**peat**	recent	recent	recent
	soil drain			mod	mod	mod	mod	mod	mod	**poor**	mod	mod
	texture			siltclay	siltclay	siltclay	siltclay	siltclay	**Peat lm**	siltclay	siltclay	siltclay
	irrig			300mm	300mm	300mm	300mm	300mm	300mm	300mm	**nil**	300mm
	winter N			20kg/ha	20kg/ha	20kg/ha	20kg/ha	20kg/ha	20kg/ha	20kg/ha	20kg/ha	**nil**

3 Appendix Three: List of variables for Overseer input

(Allan Dairy Farm, 430 cows, 305ha, 100 kg/ha N, replacements on farm)

Level	Feature	Input	Value (base)	
FARM	1. Region	Region	East Coast	
	2. Fuel etc,	Petrol L	2600	
		Diesel L	5800	
		Electricity kW	88227	
		Seed	0	
		Herbicides	0	
		Acids	0	
		Animal remedies	0	
		Animal health	0	
		Race aggregates	0	
	3. Capital	Tractors	0	
		Motorbikes	0	
		Track length	0	
		# paddocks	0	
		Length open drain	0	
		Length pipe drain	0	
		Mole drain area	0	
		Hump and hollow area	0	
		Boundary fence length	0	
		Internal fence length	0	
		Shed (cups, m^2)	0	
	4. Blocks	Total area	305	(230 ha platform
		Effective area	305	75 ha run-off
		Productivity	1	
		Effluent blocks	spray	
		Animal class distributions	0	
	5. Dairy	Number cows	430	
		Replacement grazing policy	On-farm	
		Breed	Jersey	

		Feed pad description	0	
		Production (MS)	135000	
		Effluent disposal method	spray	
		Milking style	2x /day	
	6. Other	Monthly stock reconciliation	0	
	7. Supplements imported	Category	0	
		Type	0	
		Amount	0	
		Destination	0	
	8. DCD	Yes/no	no	
	9 Wetlands	Area	0	
		Condition	0	
		Catchment area	0	
		Type	0	
		Aquitard depth	0	
BLOCK	10. General	Topography	Flat	
		Distance to coast	10km	
		Spray effluent depth	<12mm	
		Drainage class	Moderately well	
		Irrigation depth	300mm/yr	
		Irrigation timing	Nov-mar	
	11. Climate	Rainfall	1200	
		Mean temp	14	
		Seasonal variation rain	moderate	
		Annual potential evapotranspiration	Unknown	
		Seasonal variation in PET	Unknown	
		Hydrophobic condition	Unknown	
		Latitude	41°	
		Altitude	6m	
		Animal-water connectivity	0	
		Pasture development	Developed	
		Pasture type	Rye/white cl	

	12. Soil	Group / order	Recent YGE/BGE	
		Top soil texture	Silty clay loam	
		Topsoil depth	Deep	
		Soil fertility test data	default	
		K reserve	Default	
		Anion storage	default	
	13. Fert and Lime inputs	N,P,K,S,Ca,Mg,Na,	Maintenance with 73kg/haN/yr	
		Timing	20 kg N june	
		Lime	1000kg/ha/yr	
		External effluent	0	
	14. Supplements removed	Type	silage	
		Amount	196	
		DM%	35% DM	
		Destination	On-farm	

4 Appendix Four: Look-up tables to determine carbon stock.

Schedule 6 (from Forestry Regulations, 2008)
Tables of carbon stock per hectare for post-1989 forest land
Table 1
Carbon stock per hectare for Pinus radiata by region

Age(yrs)	Ak	W/T	BOP	Gis	H/SNI	N/M	C/W	O	S
1	0.5	0.4	0.4	0.6	0.5	0.2	0.2	0.3	0.2
2	3.0	2.6	2.3	3.7	3.2	1.0	0.9	1.7	1.0
3	8.3	7.2	6.3	10.2	8.7	2.6	2.4	4.5	2.8
4	29.3	25.1	24.0	37.3	33.6	11.8	4.9	9.1	13.7
5	58.9	50.2	51.4	77.2	71.4	27.7	15.0	26.5	34.5
6	98.4	83.5	83.8	120.6	113.5	48.3	31.0	49.1	65.1
7	131.3	111.5	117.6	161.6	155.5	73.2	52.7	71.6	98.6
8	152.5	129.6	143.1	190.3	184.8	99.8	76.1	94.2	134.4
9	166.3	142.0	155.1	201.4	197.5	117.3	100.9	123.7	160.3
10	188.4	162.9	169.2	219.0	210.4	132.2	124.5	141.3	173.5
11	216.9	188.5	188.4	241.5	233.3	144.0	138.9	146.0	181.1
12	248.5	217.5	212.2	269.9	260.3	160.9	150.0	156.4	198.0
13	283.1	249.2	239.2	301.5	291.5	181.7	158.0	171.9	218.8
14	319.6	283.0	268.9	336.1	325.3	205.5	170.3	191.6	243.8
15	357.4	318.2	300.4	372.3	361.2	231.9	186.2	214.5	271.5
16	396.0	354.3	333.2	409.6	398.1	260.4	204.9	240.3	301.7
17	434.8	391.0	366.8	447.2	435.7	290.4	226.1	268.3	333.7
18	473.4	427.8	400.8	484.8	473.2	321.5	249.2	298.2	367.0
19	511.5	464.4	434.6	522.0	510.4	353.4	273.8	329.3	401.0
20	548.7	500.5	468.0	558.4	546.8	385.7	299.5	361.2	435.5
21	584.8	535.8	500.8	593.8	582.3	418.1	326.1	393.5	470.0
22	619.7	570.2	532.8	628.0	616.7	450.2	353.1	426.0	504.2
23	653.1	603.5	563.7	660.8	649.7	482.0	380.4	458.2	538.0
24	685.0	635.6	593.5	692.2	681.4	513.1	407.6	490.0	571.2
25	715.4	666.4	622.0	722.1	711.6	543.4	434.6	521.3	603.5
26	744.6	696.4	649.7	751.0	740.8	573.3	461.5	552.2	635.4
27	773.1	725.8	676.9	779.3	769.4	602.9	488.4	582.9	667.0
28	800.9	754.7	703.5	807.0	797.4	632.2	515.3	613.4	698.2
29	828.1	783.1	729.6	834.1	824.7	661.1	542.0	643.6	729.2
30	854.5	810.9	755.1	860.6	851.6	689.7	568.7	673.5	759.7

Age(yrs)	Ak	W/T	BOP	Gis	H/SNI	N/M	C/W	O	S
31	880.3	838.0	780.0	886.5	877.8	717.8	595.0	703.0	789.9
32	905.3	864.6	804.2	911.8	903.5	745.3	621.0	732.2	819.5
33	929.7	890.6	827.8	936.6	928.7	772.3	646.7	760.9	848.8
34	953.5	916.0	850.9	961.0	953.4	798.7	672.0	789.2	877.6
35	976.8	940.9	873.5	985.0	977.8	824.7	697.0	817.1	906.0
36	999.7	965.4	895.5	1,008.7	1,002.0	850.1	721.5	844.6	934.1
37	1,022.3	989.5	917.2	1,032.1	1,025.8	875.0	745.7	871.8	961.8
38	1,044.5	1,013.3	938.5	1,055.4	1,049.6	899.5	769.6	898.7	989.2
39	1,066.5	1,036.8	959.5	1,078.6	1,073.2	923.6	793.0	925.2	1,016.3
40	1,088.3	1,060.1	980.2	1,101.8	1,096.8	947.2	816.1	951.4	1,043.2
41	1,110.2	1,083.4	1,000.8	1,125.1	1,120.6	970.6	838.8	977.5	1,070.0
42	1,132.0	1,106.5	1,021.2	1,148.5	1,144.3	993.5	861.1	1,003.3	1,096.5
43	1,153.8	1,129.6	1,041.5	1,172.0	1,168.3	1,016.2	883.0	1,028.9	1,123.0
44	1,175.7	1,152.7	1,061.8	1,195.8	1,192.4	1,038.5	904.6	1,054.3	1,149.4
45	1,197.7	1,175.9	1,082.1	1,219.9	1,216.9	1,060.7	925.8	1,079.6	1,175.7
46	1,220.0	1,199.4	1,102.6	1,244.3	1,241.6	1,082.7	946.7	1,104.8	1,202.1
47	1,242.6	1,223.1	1,123.2	1,269.2	1,266.8	1,104.5	967.2	1,130.0	1,228.6
48	1,265.5	1,247.1	1,144.0	1,294.6	1,292.4	1,126.4	987.6	1,155.2	1,255.2
49	1,288.9	1,271.5	1,165.2	1,320.6	1,318.6	1,148.2	1,007.7	1,180.5	1,282.1
50	1,312.8	1,296.4	1,186.7	1,347.2	1,345.3	1,170.1	1,027.5	1,205.9	1,309.1

Table 2

Carbon stock per hectare for Douglas fir, exotic softwoods, exotic hardwoods and indigenous forests.

Age(yrs)	Douglas fir	Exotic softwoods	Exotic hardwoods	Indigenous forests
1	0.1	0.2	0.1	3.0
2	0.4	1.2	3.1	6.0
3	1.1	3.4	12.8	9.0
4	2.2	12.3	33.5	12.0
5	3.6	26.5	63.2	15.0
6	5.4	44.7	98.5	18.0
7	7.5	63.1	136.7	21.0
8	23.2	77.4	175.7	24.0
9	37.8	86.6	214.1	27.0
10	56.6	95.5	251.0	30.0
11	76.8	105.9	286.1	33.0
12	99.7	118.0	319.7	36.0
13	124.3	131.7	351.1	39.0
14	150.3	146.7	380.7	42.0
15	178.7	162.8	408.5	45.0
16	207.9	179.6	434.7	48.0
17	238.0	196.9	459.3	51.0
18	267.6	214.3	482.6	54.0
19	285.3	231.8	504.8	57.0
20	290.2	249.1	525.9	60.0
21	283.9	266.2	546.0	63.0
22	276.7	282.9	565.3	66.0
23	282.1	299.0	583.7	69.0
24	288.4	314.7	601.4	72.0
25	299.3	329.7	618.4	75.0
26	311.7	344.4	-	78.0
27	327.6	358.8	-	81.0
28	344.2	372.9	-	84.0
29	362.8	386.8	-	87.0
30	382.6	400.5	-	90.0
31	403.8	413.8	-	93.0
32	425.6	426.9	-	96.0
33	446.7	439.7	-	99.0

Age(yrs)	Douglas fir	Exotic softwoods	Exotic hardwoods	Indigenous forests
34	470.0	452.3	-	102.0
35	491.5	464.7	-	105.0
36	515.5	476.8	-	108.0
37	537.2	488.8	-	111.0
38	559.7	500.7	-	114.0
39	581.8	512.4	-	117.0
40	604.0	524.0	-	120.0
41	626.0	535.6	-	123.0
42	647.7	547.2	-	126.0
43	668.9	558.7	-	129.0
44	689.9	570.2	-	132.0
45	710.4	581.8	-	135.0
46	730.5	593.5	-	138.0
47	750.1	605.2	-	141.0
48	769.3	617.1	-	144.0
49	788.0	629.1	-	147.0
50	806.2	641.4	-	150.0
51	824.2	-	-	153.0
52	842.2	-	-	156.0
53	860.0	-	-	159.0
54	877.8	-	-	162.0
55	895.4	-	-	165.0
56	913.0	-	-	168.0
57	930.3	-	-	171.0
58	947.5	-	-	174.0
59	964.6	-	-	177.0
60	981.5	-	-	180.0
61	998.1	-	-	183.0
62	1,014.6	-	-	186.0
63	1,030.9	-	-	189.0
64	1,047.0	-	-	192.0
65	1,062.9	-	-	195.0
66	1,078.5	-	-	198.0
67	1,094.0	-	-	201.0
68	1,109.2	-	-	204.0

Age(yrs)	Douglas fir	Exotic softwoods	Exotic hardwoods	Indigenous forests
69	1,124.3	-	-	207.0
70	1,139.1	-	-	210.0
71	1,153.7	-	-	213.0
72	1,168.0	-	-	216.0
73	1,182.2	-	-	219.0
74	1,196.2	-	-	222.0
75	1,209.9	-	-	225.0
76	1,223.4	-	-	228.0
77	1,236.7	-	-	231.0
78	1,249.9	-	-	234.0
79	1,262.8	-	-	237.0
80	1,275.5	-	-	240.0

Table 3
Carbon stock per hectare in below ground, dead woody litter, and fine litter pools of cleared *Pinus radiata* by region

Age(yrs)	Ak	W/T	BOP	Gis	H/SNI	N/M	C/W	O	S
1	0.5	0.4	0.4	0.6	0.5	0.2	0.2	0.3	0.2
2	3.0	2.6	2.3	3.7	3.2	1.0	0.9	1.7	1.0
3	8.3	7.2	6.3	10.2	8.7	2.6	2.4	4.5	2.8
4	29.3	25.1	24.0	36.7	33.6	11.8	4.9	9.1	13.7
5	47.6	43.5	43.2	55.3	52.5	27.7	15.0	26.5	34.5
6	68.6	61.3	61.4	80.9	76.8	42.9	31.0	42.5	49.6
7	92.4	81.6	82.1	108.2	103.5	57.0	44.0	57.3	68.4
8	113.1	99.2	103.2	134.3	129.7	71.0	56.4	72.3	88.4
9	128.2	112.0	120.6	154.8	150.3	88.7	70.8	83.9	111.5
10	132.8	116.9	131.3	165.2	160.3	100.0	85.3	104.7	130.1
11	140.5	123.9	133.6	166.9	162.9	112.5	101.5	119.2	141.2
12	149.8	132.8	138.9	172.7	167.8	115.0	111.7	123.6	142.1
13	160.8	143.2	146.0	180.4	175.5	119.8	122.8	124.4	145.0
14	172.9	154.6	154.7	189.9	184.8	126.4	122.5	128.0	150.6
15	185.8	166.8	164.4	200.6	195.5	134.3	124.6	133.4	157.9
16	199.2	179.6	175.1	212.2	207.0	143.4	128.3	140.6	166.7
17	213.0	192.8	186.3	224.3	219.2	153.4	133.6	149.0	176.7
18	226.8	206.1	197.9	236.8	231.6	164.1	140.0	158.5	187.5
19	240.6	219.6	209.7	249.4	244.3	175.3	147.5	168.8	198.9
20	254.3	233.0	221.6	262.0	256.9	186.9	155.7	179.7	210.8
21	267.6	246.2	233.4	274.4	269.4	198.6	164.4	190.9	223.0
22	280.6	259.2	245.1	286.6	281.6	210.5	173.7	202.4	235.2
23	293.2	271.9	256.5	298.4	293.5	222.3	183.2	214.1	247.5
24	305.3	284.2	267.6	309.8	305.0	234.0	192.9	225.7	259.7
25	316.8	296.1	278.3	320.8	316.0	245.5	202.6	237.2	271.7
26	328.0	307.8	288.9	331.5	326.8	257.0	212.5	248.7	283.6
27	339.0	319.3	299.3	342.1	337.5	268.4	222.6	260.2	295.6
28	349.8	330.7	309.5	352.5	348.0	279.8	232.7	271.8	307.6
29	360.5	341.9	319.7	362.8	358.4	291.2	242.9	283.3	319.5
30	370.9	353.0	329.7	373.0	368.7	302.4	253.2	294.8	331.4
31	381.8	364.6	340.2	383.7	379.5	314.4	264.4	307.2	343.9
32	392.4	376.0	350.5	394.2	390.1	326.2	275.5	319.4	356.4
33	402.7	387.2	360.6	404.6	400.5	337.8	286.6	331.5	368.7
34	412.9	398.2	370.5	414.8	410.9	349.3	297.6	343.5	380.9

35	423.0	409.0	380.3	424.9	421.1	360.6	308.4	355.4	393.0
36	432.8	419.7	389.8	435.0	431.3	371.7	319.2	367.1	405.0
37	442.6	430.2	399.3	445.0	441.4	382.6	329.8	378.8	416.9
38	452.3	440.7	408.6	454.9	451.5	393.3	340.3	390.3	428.7
39	461.9	451.0	417.8	464.9	461.6	404.0	350.7	401.7	440.4
40	471.5	461.3	426.9	474.9	471.8	414.4	361.0	413.1	452.0
41	481.1	471.6	436.0	485.0	482.0	424.8	371.1	424.4	463.7
42	490.7	481.9	445.1	495.2	492.3	435.0	381.1	435.6	475.2
43	500.3	492.1	454.1	505.5	502.7	445.1	391.0	446.7	486.8
44	510.0	502.5	463.1	515.9	513.2	455.1	400.7	457.8	498.3
45	519.8	512.8	472.2	526.4	523.8	465.0	410.3	468.9	509.9
46	529.7	523.3	481.4	537.1	534.6	474.9	419.7	480.0	521.5
47	539.8	534.0	490.6	548.1	545.6	484.8	429.1	491.1	533.1
48	550.1	544.8	500.0	559.3	556.9	494.6	438.3	502.2	544.9
49	560.5	555.8	509.6	570.8	568.3	504.5	447.5	513.3	556.7
50	571.2	567.0	519.3	582.5	580.1	514.4	456.6	524.5	568.7

Table 4

Carbon stock per hectare in below ground, dead woody litter, and fine litter pools of cleared Douglas fir, exotic softwoods, exotic hardwoods and indigenous forests.

Age(yrs)	Douglas fir	Exotic softwoods	Exotic hardwoods	Indigenous forests
1	0.1	0.2	0.1	0.0
2	0.4	1.2	3.1	0.0
3	1.1	3.4	12.8	0.0
4	2.2	12.3	33.5	0.0
5	3.6	26.5	47.8	0.0
6	5.4	41.2	64.3	0.0
7	7.5	52.3	82.7	0.0
8	23.2	63.6	101.4	0.0
9	35.3	73.3	119.4	0.0
10	43.8	79.6	136.2	0.0
11	52.9	83.0	151.6	0.0
12	63.0	86.3	165.8	0.0
13	73.4	90.0	178.4	0.0
14	84.5	94.1	189.9	0.0
15	96.4	98.9	200.4	0.0
16	108.6	104.2	209.9	0.0
17	121.2	109.8	218.6	0.0
18	133.7	115.6	226.7	0.0
19	169.1	121.6	234.3	0.0
20	197.9	127.7	241.5	0.0
21	220.3	133.8	248.4	0.0
22	205.2	139.8	255.1	0.0
23	198.6	145.7	261.5	0.0
24	191.9	151.5	267.7	0.0
25	189.2	157.1	273.7	0.0
26	187.7	162.7	0.0	0.0
27	188.9	168.1	0.0	0.0
28	190.7	173.6	0.0	0.0
29	194.2	179.0	0.0	0.0
30	198.6	184.3	0.0	0.0
31	204.0	190.2	0.0	0.0
32	210.1	196.1	0.0	0.0
33	216.2	201.8	0.0	0.0

34	223.9	207.5	0.0	0.0
35	230.6	213.1	0.0	0.0
36	239.1	218.7	0.0	0.0
37	246.3	224.1	0.0	0.0
38	254.5	229.6	0.0	0.0
39	262.4	235.0	0.0	0.0
40	270.7	240.3	0.0	0.0
41	278.9	245.7	0.0	0.0
42	287.1	251.1	0.0	0.0
43	295.3	256.4	0.0	0.0
44	303.4	261.8	0.0	0.0
45	311.4	267.2	0.0	0.0
46	319.4	272.7	0.0	0.0
47	327.2	278.2	0.0	0.0
48	334.8	283.8	0.0	0.0
49	342.4	289.5	0.0	0.0
50	349.7	295.2	0.0	0.0
51	357.1	0.0	0.0	0.0
52	364.4	0.0	0.0	0.0
53	371.7	0.0	0.0	0.0
54	379.1	0.0	0.0	0.0
55	386.4	0.0	0.0	0.0
56	393.6	0.0	0.0	0.0
57	400.9	0.0	0.0	0.0
58	408.1	0.0	0.0	0.0
59	415.2	0.0	0.0	0.0
60	422.3	0.0	0.0	0.0
61	429.4	0.0	0.0	0.0
62	436.3	0.0	0.0	0.0
63	443.2	0.0	0.0	0.0
64	450.0	0.0	0.0	0.0
65	456.7	0.0	0.0	0.0
66	463.4	0.0	0.0	0.0
67	470.0	0.0	0.0	0.0
68	476.5	0.0	0.0	0.0
69	482.9	0.0	0.0	0.0

70	489.2	0.0	0.0	0.0
71	495.4	0.0	0.0	0.0
72	501.6	0.0	0.0	0.0
73	507.6	0.0	0.0	0.0
74	513.6	0.0	0.0	0.0
75	519.5	0.0	0.0	0.0
76	525.3	0.0	0.0	0.0
77	531.0	0.0	0.0	0.0
78	536.6	0.0	0.0	0.0
79	542.2	0.0	0.0	0.0
80	547.7	0.0	0.0	0.0