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Land-Use Intensity Module: Land Use in Rural New Zealand Version 1

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UPDATE: The y-axis units in Figure 6 have been corrected for this 2009 reprint.

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Abstract

This document outlines the development of the dynamic functions and simple algorithms that make up the Land Use in Rural New Zealand (LURNZ) land-use intensity module. The module includes stocking rate functions for dairy, sheep, and beef livestock; fertiliser intensity functions for dairy and sheep/beef; and algorithms for the evolution of the age classes of the plantation forestry estate, and of reverting scrubland. This module is designed so that: (1) output from models of rural production and rural land use can be compared using the land-use intensity functions as conversion factors; (2) output from the land use module of LURNZ can be converted into the implied levels of rural activities that can be directly related to certain environmental impacts. This module is part of the LURNZv1 simulation model and can be used in conjunction with the LURNZ land use and greenhouse gas modules.

JEL classification

Q24, Q25, Q15, Q23

Keywords

Land use intensity, rural production, forestry, pastoral farming, fertiliser

Contents

Figures

Tables

1 Introduction

Rural landowners can respond to changes in socio-economic conditions in two main ways: they can change land use and they can change the intensity of their land use. For example, as dairy prices rise, some landowners with high quality sheep/beef farms may find that converting to dairy will increase their profits. Other landowners already running dairy farms may find that increasing intensity by increasing stocking rates increases their profits. As a result, national dairy production will increase.

We can infer changes in rural activity by using models of production, land use, and land-use intensity. Both the Ministry of Agriculture and Forestry's Pastoral Supply Response Model (PSRM) and Lincoln University's Lincoln Trade and Environment Model (LTEM) model New Zealand rural production using a partial equilibrium approach. The Australian Bureau of Agricultural and Resource Economics' Global Trade and Environment Model (GTEM) and the various New Zealand computable general equilibrium (CGE) models (including those run by the New Zealand Institute of Economic Research, Infometrics, and Business and Economic Research Limited) produce forecasts of agricultural commodities. The land-use change module in the Land Use in Rural New Zealand model (LURNZ) models rural New Zealand land use. None of these models explicitly model changes in land-use intensity.

If we used common measures of intensity as conversion factors, we could draw comparisons between these models. To enable researchers to compare results, we have developed the LURNZ land-use intensity module. Using this module, land-use predictions from the land-use change module in LURNZ can be converted into animal numbers and compared with output from models such as PSRM and LTEM, and vice versa. Every model has different strengths and weaknesses and being able to compare and contrast results can give additional insight into the implications of the results.

Another application of the land-use intensity module is to convert LURNZ land-use change module output into activity measures that are directly related to particular environmental impacts. Increased stock numbers, animal productivity, and fertiliser use lead to increased animal greenhouse gas (GHG) emissions, increased pollution of waterways, and pressure on water resources from increased irrigation demand. Short-term carbon sequestration potential from plantation forestry and reverting scrubland depends on the age-class distribution of forest; the timing of harvest; and when deforestation, reforestation and afforestation occur. Thus, to be able to calculate these environmental impacts, we need to know animal numbers, fertiliser use, and forest/scrubland age classes, as well as the land-use pattern.

The relationships among animal numbers, fertiliser use, and land-use patterns depend on land-use intensity, and land-use intensity changes over time. To account for this, the land-use intensity module consists of functions that can be used to project the likely evolution of the production intensity on dairy and sheep/beef farms. The functions are estimated from past trends in land-use intensity, constrained to match actual activity levels in 2002, and represent national average patterns. They are dynamic, in the sense that time is a variable in each, and consequently they go further than assuming constant conversion factors between activity measures. The module also contains algorithms, based on qualitative expert knowledge, designed to represent the likely evolution of age classes on plantation forestry land and reverting scrubland.

The functions and algorithms do not account for any behavioural response to changes in socio-economic conditions. They are not intended to be used as a forecasting tool. As with the LURNZ model as a whole, their primary purpose is to allow meaningful simulations of policy options. Our functions currently represent national land-use intensity with no spatial differentiation. This makes them relatively unhelpful for environmental problems that are spatially heterogeneous (e.g. water quality), but is a useful model for greenhouse gas emissions where the relationship between land-use intensity and damage is less sensitive to local conditions.

To produce projections of animal numbers, fertiliser use, and forest/scrubland age classes over the entire estate, LURNZv1 combines the functions and algorithms from the land-use intensity module with predictions of land-use change from the land-use change module. In the land-use change module, land use responds to changes in commodity prices, interest rates, and trends in technology and costs. The magnitude of the response and timing of adjustment are driven by an econometric model estimated at national level using 29 years of data (Kerr and Hendy 2005).

Currently, we have one environmental impacts module that can be used, in conjunction with the land-use intensity and the land-use change modules, to directly assess environmental impacts of rural activity predictions. The module, detailed by Hendy and Kerr (2005), consists of simple functions that enable us to translate changes in animal numbers, forest area, and fertiliser use into their associated changes in methane, nitrous oxide, and carbon dioxide net emissions. These functions depend only on time, and their functional forms are based on expert assumptions about likely future changes in animal productivity.

When we simulate a GHG emissions tax, the greenhouse gas and land-use intensity modules will jointly determine the magnitude of the tax per hectare, affect the relative economic returns to each land use, and thus influence land-use responses predicted by the land-use change module. Hendy, Kerr, and Baisden (2005) give more details about how the modules fit together in LURNZv1 and the data that the modules use. Where possible, we have endeavoured to ensure that, in the land-use intensity module, the assumptions underlying the functional forms we chose and the explanatory data to which we fitted the functions are consistent with the assumptions and data in the other LURNZv1 modules.

In this paper, we begin by outlining the data on rural activity that we use to create the functions. Next, we discuss how we fit functions to capture the evolution of stocking rates and fertiliser intensity. Finally, we outline the algorithms for planting and harvesting on the plantation forestry estate, and for reversion on scrubland.

2 Data

We derive annual, national-level stocking rates by dividing national livestock numbers by national land-use areas for each land-use type (given in Table 4 in Appendix B). Our livestock data comes from the PSRM database (Gardiner, Peter, and Su, 2003). The database is annual, covers the period 1980–

2002, and is designed to reflect livestock numbers at 30 June of the specified year. The data are originally from the Statistics New Zealand (SNZ) agricultural production surveys.

We also use stock unit ratios between livestock species from the Pastoral Supply Response Model database to aggregate sheep and beef livestock numbers. A stock unit is a relative measure that is based on the feed requirements of different livestock types. Regardless of species, one stock unit requires approximately the same amount of feed. Thus, converting livestock numbers into stock units allows us to aggregate different species.

Our land-use data is from the LURNZ database, is also annual, covers the period 1980–2002, and is a snapshot of land use at 30 June of the specified year. The land-use data is based on data from Statistics New Zealand agricultural production surveys and the land cover database 2 (LCDB2), which is a Geographic Information Systems (GIS) map derived from satellite images taken over the summer of 2001/02 (Thompson, 2005). We overlaid LCDB2 on the LURNZ 25ha grid, which is a 25ha grid covering the North Island, the South Island, and inshore islands but excluding conservation land. We aggregated the overlaid LCDB2 land-use data to national level. We then scaled the SNZ land-use data series so that in 2002 it matched the LCDB2 data, giving us the final time series that we include in the LURNZ database. Because the LURNZ grid excludes conservation land, any rural activity on conservation land is not included in the LURNZ database. For a full description of the database, see Hendy and Kerr (2005).

Our data on pastoral nitrogen fertiliser use was compiled for the Ministry for the Environment's *National Inventory Report* (Brown and Plume, 2004); the data were originally sourced from FertResearch. These data represent total annual nitrogen in fertiliser used for pastoral agriculture for each calendar year from 1990–2002. We derive average fertiliser per hectare of pastoral land by dividing total pastoral fertiliser use by the LURNZ pastoral area (shown in column 1 of Table 6 in Appendix B). We supplement the data with information on fertiliser use by farm type from the 2002 agricultural production census (Statistics New Zealand, 2002), where the farm-type classification classifies farms in terms of their major use (given in Table 7). This differs from land-use data, which records all areas of production, regardless of farm boundaries. Fertiliser use is given in terms of fertiliser type rather than nitrogen content, so we convert fertiliser type to implied nitrogen content using conversion factors from the New Zealand Parliamentary Commissioner for the Environment (2004), given in row 1 of Table 7.

To help investigate the relationship between fertiliser use and rural production, we use production data for dairy, sheep, and beef. We have annual series from 1980–2002 of total milksolids, lamb/mutton production (referred to as sheep meat), and beef production; these are totals over the year ending on 30 June. These data come from the PSRM database, but were originally sourced from SNZ agricultural production surveys and various industry boards. See Hendy and Kerr (2005) for more details.

3 Modelling activity levels

In this section, we fit dynamic functions, designed to represent activity on an average hectare of rural land, for the following:

- dairy stocking rate
- sheep and beef stocking rate
- ratio of sheep to total stock units per hectare of sheep/beef land
- fertiliser applied per hectare of sheep/beef land
- fertiliser applied per hectare of dairy land.

We fit each of the functions using ordinary least squares, constrained to match activity in 2002. We do this so that when this module is used in conjunction with the LURNZ GHG module, it produces results that match rural emissions reported in the national greenhouse gas inventory for New Zealand in 2002 (Brown and Plume, 2004).

For forestry, we outline a simple algorithm that evolves the age-class distribution of the national plantation forestry estate, including rules for age of harvest, deforestation, and planting. The results are designed to be compatible with Te Morenga and Wakelin's (2003) carbon age-class table (the carbon table used in the *National Inventory Report*), and the LURNZ greenhouse gas module. Together they can be used to estimate carbon sequestration in and emissions from plantation forestry (see Hendy and Kerr, 2005).

Finally, we outline an algorithm for scrubland reversion and clearing. The results can be used in conjunction with the carbon reversion table in the LURNZ greenhouse gas module, given in Hendy and Kerr (2005), and based on the Landcare Research carbon calculator (Trotter, 2004), to estimate carbon sequestration in and emissions from cutting scrubland.

3.1 Modelling dairy stocking rate trends

Between 1980 and 2002 dairy production has intensified, with dairy stocking rates increasing by 15%; this is illustrated by the solid line in Figure 1. We need to select a function that fits the historical trend in dairy stocking rates closely, but that also accounts for the expectations of the likely stocking rate trend. Because the productivity of New Zealand ruminants is not high by world standards, productivity is likely to have the capacity to increase through intensification (Clark, Brookes, and Walcroft, 2003).

Accordingly, we want a function that has a positive growth rate in the near future. Also, because of physical limits on stocking rates, when we project using the function, the growth in stocking rate must remain positive and, in the near term, a reasonable size. Our choice of an appropriate function is limited by our small sample size, which means we cannot fit a function with many parameters. Consequently, we chose a logarithmic function because it has few parameters and a decreasing but positive growth rate.

Figure 1 Dairy stocking rate

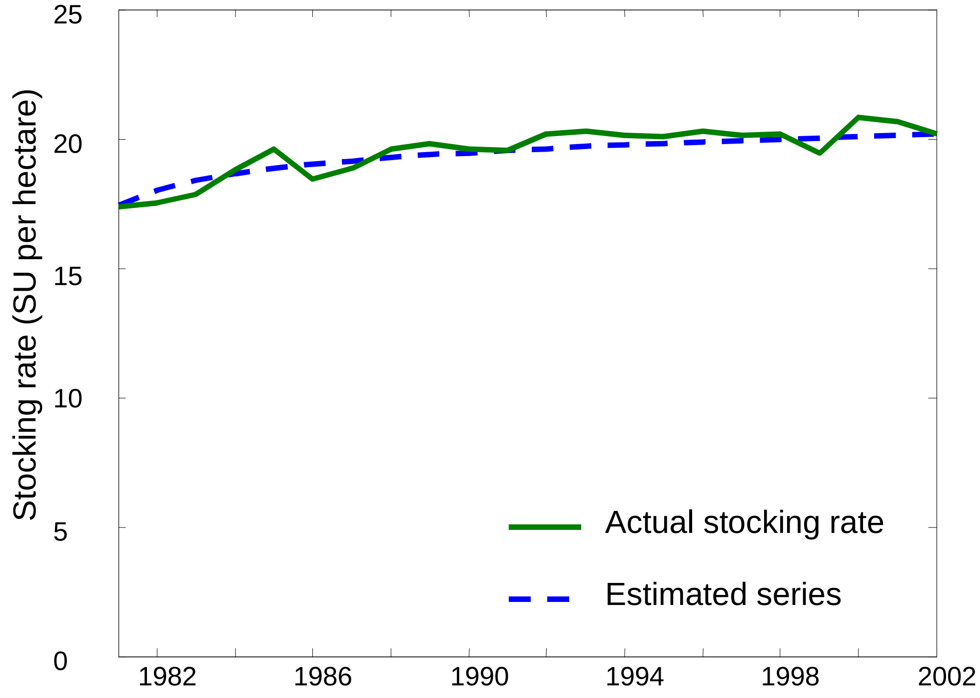


Table 1 in Appendix A shows the results from fitting the logarithmic model, constrained so that estimated stocking rates equalled actual stocking rates in 2002. For comparison, we also fitted a linear trend model and a quadratic trend model (columns 2 and 3), also constrained to match 2002 stocking rates. The linear trend model explains only 50% of the variation. The quadratic trend model has the greatest explanatory power, with an adjusted R^2 of 81%, but has stocking rates declining after 1995, which is not consistent with our prior. The logarithmic trend has only slightly less explanatory power, with an adjusted R^2 of 76%, and better fits our future expectations of stocking rate trends.

The dotted line in Figure 1 shows the fitted logarithmic function that we use in the land-use intensity module. The equation is given by:

$$SR_{dairy} = 17.4 + 0.890\ln(Year - 1980) \tag{1}$$

3.2 Modelling sheep and beef stocking rate trends

Like dairy, production on sheep/beef farms has also intensified over the last couple of decades, with sheep-meat production per hectare increasing by about 20% and beef production per hectare increasing by about 36% between

1990 and 2003 (New Zealand. Parliamentary Commissioner for the Environment, 2004). In addition, between 1980 and 2002 lambing rates increased by around 25% and calving rates were stable (New Zealand. Parliamentary Commissioner for the Environment, 2004). In contrast to these rates, stocking rates on the average farm decreased from about 10 stock units per hectare in 1980 to about 8 in 2002 (see Figure 2). Therefore, unlike dairy, the increased production was due solely to increased production per animal not stocking rates.

Because sheep and beef cattle frequently inhabit the same pasture area, we cannot independently estimate sheep stocking rates and beef stocking rates with the data we have (sheep/beef land, number of sheep, number of beef cattle). Instead, we estimate a trend in the combined stocking rate, $SR_{sheepbeef}$, and estimate a trend in the ratio of the number of sheep stock units to total stock units on sheep and beef pasture ($RATIO_{sheepbeef}$). We do this rather than directly estimating functions for sheep and beef cattle because the two key processes are that the total productivity of the land, i.e. for sheep and beef combined, is limited, and that there is a trend in sheep relative to beef farming. By combining these two functions, we can get a sheep stocking rate function, given by:

$$SR_{sheep} = SR_{sheepbeef} \, RATIO_{sheepbeef} \quad (2),$$

and a beef stocking rate function, given by:

$$SR_{beef} = SR_{sheepbeef} \, (1-RATIO_{sheepbeef}) \quad (3).$$

As we emphasised in Section 3.1, we need to select a function that will both fit past trends and match our expectations of likely changes in the future. The solid line in Figure 2 shows the decrease in the combined sheep and beef stocking rates, $SR_{sheepbeef}$ over the last 20 years. As we mentioned above, this has been associated with an increase in animal productivity, with sheep and cows becoming larger over time and lambing rates rising, and as a result a decrease in the optimal stocking rate. Because animal size and reproduction are likely to have a physical limit, we might expect the increase in animal size and associated decrease in stocking rates to slow in the future. For that reason, we need a function that decreases at a diminishing rate and, as we have a small sample, has few parameters. As a result, we selected an exponential decline model, as it will never become negative. We constrained it so that estimated stocking rates matched actual stocking rates in 2002. The results are given in Table 2 and are illustrated by the dotted line in Figure 2 below.

Figure 2 Sheep and beef stock units per hectare of sheep/beef land

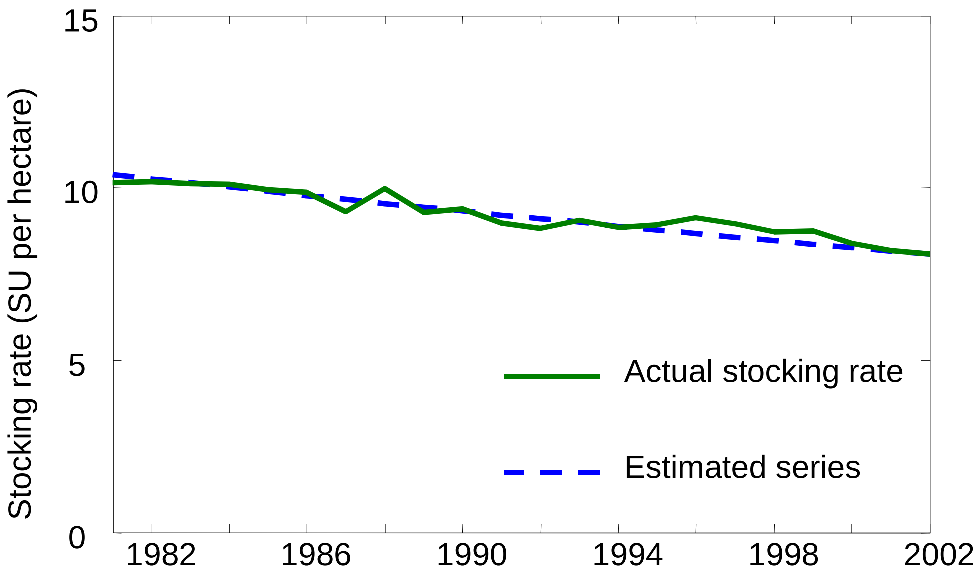


Table 2 in Appendix A also shows the results from estimating two other simple trend models for comparison: a linear trend model and a quadratic trend model, both constrained so that estimated stocking rates matched actual stocking rates in 2002. The linear model is a good fit, with an adjusted R^2 of 86%, but becomes negative during the second half of the twenty-first century; the coefficients in the quadratic trend model are all insignificant. The exponential decline model has an adjusted R^2 of 85%, and will never become negative.

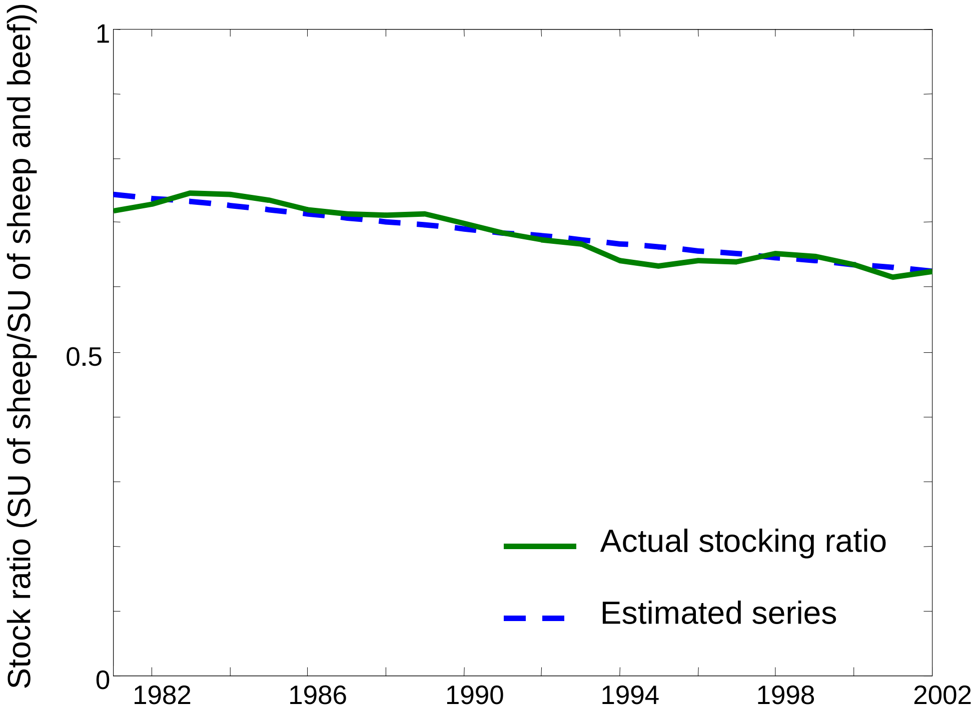
Our final function model for projecting sheep/beef in LURNZ is given by:

$$SR_{sheepbeef} = e^{26.1-0.0120Year} \tag{4}$$

Next, we need to select a function to model the trend in the sheep/beef ratio. The solid line in Figure 3 shows a slow, steady decline in the ratio of sheep stock units to total sheep/beef stock units ($RATIO_{sheepbeef}$) over the past 20 years. This steady decline cannot continue indefinitely as it must asymptote at zero.

Again, we want a function that will decline at a diminishing rate, and again, we select an exponential decline model, as it will never become negative. The results of fitting the function are given in Table 3 and also illustrated by the dotted line in Figure 3 below.

Figure 3 Ratio of sheep to total sheep and beef numbers



For comparison,

Table 3 also shows the results from estimating two other simple trend models: a quadratic trend model and a linear trend model, both constrained so that estimated stocking rates matched actual stocking rates in 2002. The linear model fits well with an adjusted R^2 of 87%. The quadratic term adds no explanatory power. The exponential decline model also fits well, with an adjusted R^2 of 87% and will not become negative at a future point, so it is preferable for projection purposes.

Our final $RATIO_{sheepbeef}$ function is given by:

$$RATIO_{sheepbeef} = e^{16.2-0.00832Year} \tag{5}$$

3.3 Modelling changes in fertiliser intensity

Between 1990 and 2002, nitrogen fertiliser use in agriculture steadily increased for two reasons. First, during this period landowners shifted toward more nitrogen-intensive uses. This shift consisted mainly of movements from sheep/beef farming and toward dairy farming. Sheep/beef farming decreased in area by 10% (800,000ha) and dairy farming increased by about 40% (450,00ha) between 1990 and 2002 (see Table 4 in Appendix B). Sheep/beef farming uses fertiliser less intensively than dairy farming. In 2002 sheep/beef farmers on average applied around 7 kilograms of nitrogen per hectare and dairy farmers on average applied around 70 kilograms of nitrogen per hectare.[1] Second, the average amount of fertiliser applied per hectare, or fertiliser intensity, for a given use increased. For example, average fertiliser intensity on sheep/beef farms increased by about 25% between 1991 and 2002 (New Zealand. Parliamentary Commissioner for the Environment, 2004).

The total fertiliser (FV) used for a particular land use will depend on the area and the fertiliser intensity (FI) for each land use:

$$FV_{lu} = Area_{lu} * FI_{lu} \tag{6}$$

The LURNZv1 land-use change module predicts changes in $Area_{lu}$, so in the intensity module we want functions that predict changes in FI_{lu} for each land use.

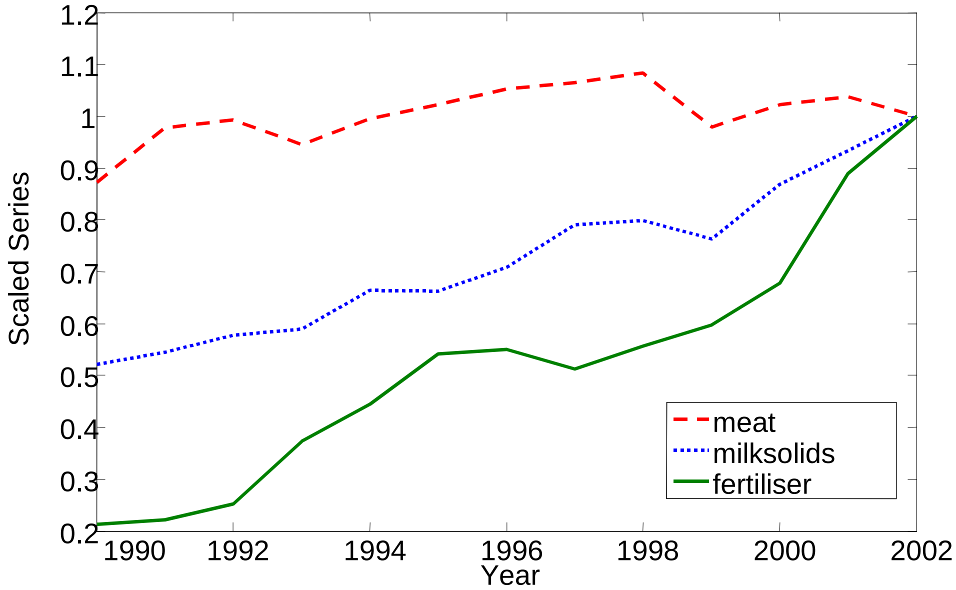
We need to develop separate fertiliser intensity functions for dairy farming and sheep/beef farming. Also, we want emissions in the GHG module to match inventory emissions in 2002 and as part of this, we need to ensure that the area-weighted average of the intensity functions evaluated at 2002 equals the actual average fertiliser intensity in 2002. Unfortunately, no readily available data exists on historical fertiliser use by land use during the 1990s. However, we do have a time series in terms of total pastoral fertiliser use from 1990–2002 and a

[1] These numbers are derived from the 2002 agricultural production census. See Table 5 for details.

snapshot of pastoral fertiliser use by farm type in 2002. We use these data to create our fertiliser intensity functions for dairy and sheep/beef fertiliser intensity.

We begin by investigating the relationship between total fertiliser use and dairy and sheep/beef production because we believe that they should be directly related. Figure 4 shows nitrogen fertiliser use and dairy and sheep/beef production. National dairy production is measured in terms of milksolids and national sheep/beef production is measured in terms of total kilograms of meat. There seems to be some correspondence between fertiliser and milksolids, with both series appearing slightly convex. However, it is hard to see any relationship between fertiliser and meat, and meat appears slightly concave.

Figure 4 National fertiliser use and dairy and sheep/beef production



To confirm our suppositions, we estimate a linear relationship between fertiliser use and milksolids, meat, and year, using ordinary least squares constrained to equal actual fertiliser use in 2002. The fitted equation, with standard errors in brackets below, is given by:

$$\begin{array}{l} FV = -7.23E9 + 342 milksolids - 168 meat + 3.65E6 year \\ \quad (1.4E10) \quad (150) \qquad\qquad (110) \qquad (6.90E6) \end{array} \tag{7}$$

The adjusted R^2 is 88%. We find that fertiliser use and dairy production were highly correlated during the 13-year period, with the milksolids coefficient being 95% significant and positive. In contrast, we found no statistically significant relationship between fertiliser use and either sheep/beef meat production or year.

Given the large increase in dairy production in the last 15 years and that dairy uses 10 times the amount of nitrogen fertiliser per hectare that sheep/beef farming uses, it is not surprising that change in sheep/beef production is not very important. Also, because dairy and sheep/beef production usually compete for land, reductions in sheep/beef production are closely correlated with growth in dairy, which empirically dominates in our small sample. Consequently, in LURNZv1 we use changes in dairy productivity to infer the changes in total fertiliser volume that are related to intensity changes.

To do this, we first separate our total fertiliser use time series into dairy fertiliser use and sheep/beef fertiliser use. Fertiliser volume is related to fertiliser intensity and volume for dairy and sheep/beef by the equation:

$$FV = FI_{dairy} Area_{dairy} + FI_{sheep/beef} Area_{sheep/beef} \tag{8}$$

Using SNZ agricultural production census data on 2002 fertiliser by farm type, we calculate that the ratio of fertiliser intensity for dairy to sheep/beef farms is *0.10* (calculated from column 2 in Table 5). Assuming that this ratio was constant throughout the period enables us to solve Equation 8 for dairy fertiliser intensity:

$$FI_{dairy} = \frac{FV}{Area_{dairy} + 0.10 Area_{sheep/beef}} \tag{9}$$

We calculate our dairy fertiliser time series by multiplied dairy fertiliser intensity by dairy area. This series is given in Table 6 in Appendix B.

Next, we fit our new dairy fertiliser series to dairy production. Fitting dairy fertiliser to a linear function of milksolids gives an adjusted R^2 of 89%, with the coefficient and constant being 99% significant. The equation, with standard errors in brackets below, is given by:

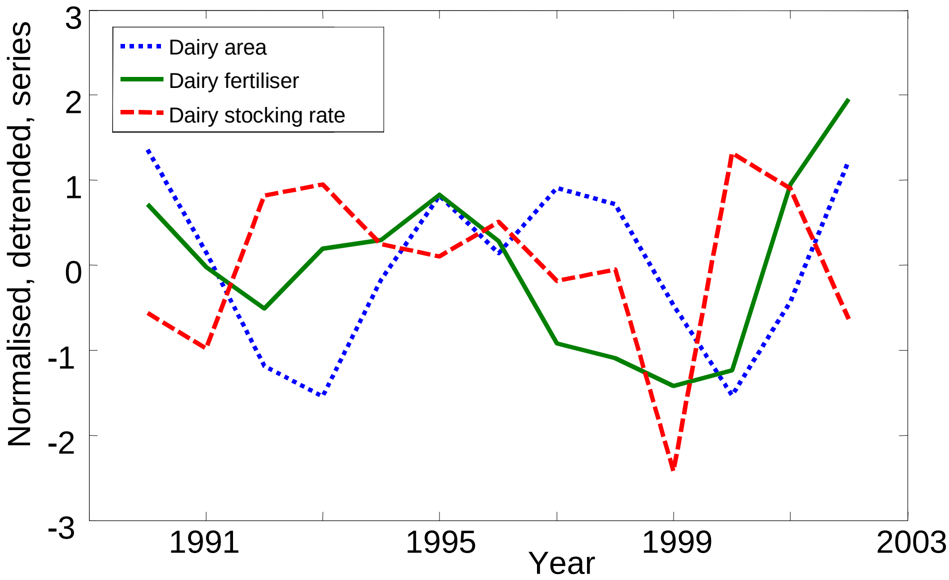
$$\begin{array}{c} Fertiliser_{dairy} = 1.5E8 \ - \ 298 milksolids \\ (0.19E8) \ (23) \end{array} \tag{10}$$

To project using this equation, for internal model consistency, we would need to model milksolids in terms of land use areas and stocking rates, as these are production-related variables that LURNZv1 already projects. An alternative to this two-step approach is to model the effects of land-use areas and stocking rates directly on fertiliser use. Changes in land-use areas and stocking rates may also have different effects on fertiliser use than on milksolids—modelling the direct effects would capture this. Therefore, instead of modelling milksolids, we fit the function directly in terms of land-use areas and stocking rates.

Figure 5 shows dairy fertiliser, dairy area, and dairy stocking rates, with their trends removed and normalised.[2] Changes in dairy area appear to follow a similar pattern to changes in fertiliser over most of the period, possibly following with a short lag. Changes in dairy stocking rates also follow a similar pattern but lead changes in fertiliser by a year or so.[3] It is possible that when dairy prices rise, stocking rates rise quickly and fertiliser application needs to respond to this. Area adjusts more gradually. Thus, dairy fertiliser may fit reasonably well to area and stocking rates.

[2] These were normalised by subtracting the mean and then dividing by the standard deviation.
[3] In 1999, there is a dip in dairy stocking rates. We derived stocking rates by dividing the stock numbers by area and this data was not collected by SNZ in 1999. We collected the two data series from different sources where different methods of interpolation were used. The dip is likely to be due to the different interpolation methods.

Figure 5 National fertiliser use, dairy area, and stocking rate



Previously, we modelled dairy fertiliser as a linear function of milksolids production. Because production depends on area and stocking rates in a multiplicative way, we select the following function to describe dairy fertiliser in terms of area and stocking rates:

$$Fertiliser_{dairy} = \gamma area_{dairy}^{\alpha} stockingrate_{dairy}^{\beta} \tag{11}$$

where the parameters α and β adjust for the fact that fertiliser use per dairy cow is not constant and depends on whether the extra cow is accommodated through more dairy land and more intensive stocking. By taking the log of Equation 11, we can fit the function using ordinary least squares, constrained to equal actual dairy fertiliser in 2002. The equation below shows fertiliser fitted to area, with a 2-year lead, and stocking rates, with a 1-year lag.

$$\begin{aligned} \log Fertiliser_{dairy,t} &= -54.2 + 3.92 \log area_{dairy,t+2} + 5.70 \log stockingrate_{dairy,t-1} \\ &\quad (5.25)\ \ (0.24) \qquad\qquad\qquad (1.65) \end{aligned} \tag{12}$$

This fits well, with all three coefficients statistically 99% significant and the adjusted R2 96%. This suggests that fertiliser use responds to prices directly rather than to area changes, which respond to prices only with a lag.

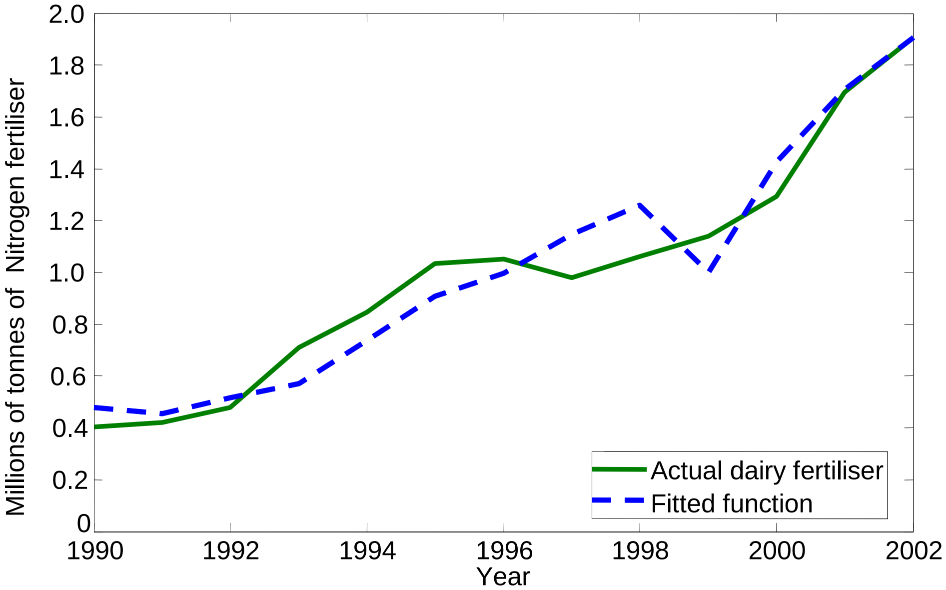
We cannot simulate land-use change using Equation 12 because when we simulate the impact of an emissions charge using LURNZv1, the charge and hence the predicted area changes depend on current fertiliser use. Thus, we cannot use future values of area to predict current fertiliser use. We would need to have a direct relationship between prices and fertiliser use. Instead, for this version we fit fertiliser use to contemporaneous area and stocking rates. The fitted equation, with standard errors in brackets below, is:

$$\log Fertiliser_{dairy} = \underset{(6.65)}{-56} + \underset{(0.36)}{4.07}\log area_{dairy} + \underset{(2.18)}{5.69}\log stockingrate_{dairy} \tag{13}$$

All three coefficients are statistically significant, with the coefficient corresponding to area and the constant being 99% significant and the coefficient corresponding to the stocking rate being 95% significant. The adjusted R^2 is 91%. Figure 6 shows the fitted function in comparison to the original series.

Both the coefficients are much greater than one. This implies that a 1% increase in area or stocking rate is associated with a greater than 1% increase in fertiliser use. This is consistent with the idea that as dairy expands onto increasingly more marginal land, for a given level of production, increasingly more fertiliser needs to be applied. Similarly, as intensity increases, increasingly more fertiliser is needed.

Figure 6 Nitrogen fertiliser use



To get the final dairy fertiliser intensity function that we use in LURNZv1, we solve Equation 13 for dairy fertiliser and then divide by dairy area, giving:

$$FI_{dairy} = e^{-56}(area_{dairy})^{3.07}(stockingrate_{dairy})^{5.69} \tag{14}$$

Using Equation 14 and the assumption that sheep/beef intensity is *0.10* times that of dairy, we get sheep/beef fertiliser intensity:

$$FI_{sheep/beef} = 0.10e^{-56}(area_{dairy})^{3.07}(stockingrate_{dairy})^{5.69} \tag{15}$$

3.4 Modelling plantation management

To estimate carbon sequestration in plantation forests, we must model the evolution of the age-class structure of the forest. We begin with the National Exotic Forestry Description (NEFD) age-class area distribution in 2002 (see Table 8 in Appendix B).[4] We assume all stands over 40 years old are non-commercial and will never be harvested. This is consistent with current NEFD assumptions. The algorithm also assumes that the current distributions of pruning regimes and species type persist.

To calculate the age-class distribution of annual harvest, we use exogenous forecasts of national harvest area from Te Morenga and Wakelin

[4] Personal communication, Steve Wakelin, Atlas Technology, January 2006.

(2003), which are based on output from the forestry management model "Forestry-Oriented Linear Programming Interpreter" (FOLPI) (Te Morenga and Wakelin, 2003). The algorithm harvests the oldest trees first. The module uses predictions of deforestation area from the LURNZ land-use module. The module calculates the likely ages of the deforested area based on two assumptions we make. First, we assume that the stands that are most likely to be deforested are the ones with the lowest marginal benefit from delaying harvest until the following year. Second, we assume that the younger the stand, the lower the marginal benefit to delaying harvest for another year. Based on these assumptions, the algorithm "deforests" the newly harvested areas first, followed by the youngest trees.

3.5 Modelling land abandonment and scrubland reversion

Changes in economic conditions may lead landowners to abandon some of their land. For instance, low returns for sheep farming may lead landowners to lower costs by reducing their stock levels and removing stock from less-productive paddocks, thus reducing the area that they have to actively manage. When this happens, the abandoned paddocks will generally revert to scrubland. Changes may also lead to landowners reclaiming areas of abandoned land. For example, periods of drought may lead to farmers reclaiming paddocks to increase feed. Which areas they reclaim will likely be driven by the land quality, with the higher-quality land being reclaimed first.

As with plantation forestry, the carbon storage (loss during deforestation) and sequestration depends on the age class of the scrub. To calculate the greenhouse gas implications of land abandonment and scrubland reversion, we have created a simple algorithm to evolve scrubland age classes.

The algorithm begins by assuming that all scrub in 2002 is 40 years old; this is what is implicitly assumed in the *National Inventory Report* when accounting for land-use change into plantation forestry.[5] Also, we assume that the

[5] Personal communication, Steve Wakelin, Atlas Technology, January 2006.

most recently abandoned land is likely to be land marginal between scrubland and other higher valued uses and also have lower clearing costs. Thus, the algorithm assumes that areas that have been abandoned most recently are the areas that will be cleared and converted first.

4 Summary

The Land Use in Rural New Zealand (LURNZ) land-use intensity module allows researchers to compare output from models of rural production and rural land use, using the dynamic land-use intensity functions to convert to a common measure. Also, researchers can use the module to convert output from LURNZ into the implied levels of rural activities directly related to certain environmental impacts. This module is part of the LURNZv1 simulation model and can be used in conjunction with the LURNZ land-use and greenhouse gas modules. To summarise, the final functions are:

Dairy stocking rate: $SR_{dairy} = 17.4 + 0.890\ln(Year - 1980)$

Sheep/beef stocking rate: $SR_{sheepbeef} = e^{26.1-0.0120Year}$

Sheep to total stock unit ratio: $RATIO_{sheepbeef} = e^{16.2-0.00832Year}$

Dairy fertiliser intensity:

$$FI_{dairy} = e^{-56}(area_{dairy})^{3.07}(stockingrate_{dairy})^{5.69}$$

Sheep/beef fertiliser intensity:

$$FI_{sheep/beef} = 0.10e^{-56}(area_{dairy})^{3.07}(stockingrate_{dairy})^{5.69}$$

For forestry evolution, total harvest comes from Te Morenga and Wakelin (2003), and the initial age-class distribution comes from the National Exotic Forestry Description (New Zealand. Ministry of Agriculture and Forestry, 2003). We assume the oldest trees are harvested first. Changes in plantation forest area come from the LURNZv1 land-use module. If the plantation forest estate area contracts, then first, the algorithm does not replant on harvested areas and, second, it clears the youngest forest. If plantation forest area expands, the algorithm adds new land.

For scrubland evolution, we assume all scrub is initially 40 years old in 2002. Changes in scrubland/abandoned land come from the LURNZv1 land-use module. If scrubland area contracts, the most recently abandoned areas are cleared first. If scrubland area expands, the algorithm adds new land.

Appendix A Estimation Results

Table 1 Estimation results: dairy stock rates trend

Explanatory variables	Dairy stock rate (SU/Ha)		
	Linear	Quadratic	Logarithmic
Year	0.0790***	39.5***	
SE	0.0220	9.4	
Year squared		-0.00990***	
SE		0.00240	
Ln(Year-1980)			0.890***
SE			0.120
C	-137.8***	-39,400***	17.4***
SE	43.15	9,400	0.3
R^2	0.57	0.85	0.79
Adjusted R^2	0.50	0.81	0.76

Coefficients rounded to 3 significant figures; standard errors rounded to corresponding decimal place.
*** 99% significant, ** 95% significant, * 90% significant
SE = Standard Error

Table 2 Estimation results: sheep/beef stocking rate

Explanatory variables	$SR_{sheepbeef}$		Ln($SR_{sheepbeef}$)
	Linear	Quadratic	Exponential
Year	-0.107***	3.87	-0.0120***
SE	0.007	5.49	0.0009
Year squared		-0.000997	
SE		0.001373	
Constant	222***	-3740	26.1***
SE	15	5220	1.7
R^2	0.88	0.89	0.87
Adjusted R^2	0.86	0.86	0.85
N	23	23	23

Coefficients rounded to 3 significant figures; standard errors rounded to corresponding decimal place.
*** 99% significant, ** 95% significant, * 90% significant
SE = Standard Error

Table 3 Estimation results: sheep/beef ratio trend

Explanatory variables	$RATIO_{sheepbeef}$		Ln($RATIO_{sheepbeef}$)
	Linear	Quadratic	Exponential
Year	-0.00558***	-0.270	-0.00832***
SE	0.00049	0.340	0.00070
Year squared		6.62E-5	
SE		8.54E-5	
Constant	11.8***	275	16.2***
SE	1.0	339	1.4
R^2	0.89	0.89	0.89
Adjusted R^2	0.87	0.87	0.87
N	23	23	23

Coefficients rounded to 3 significant figures; standard errors rounded to corresponding decimal place.
*** 99% significant, ** 95% significant, * 90% significant
SE = Standard Error

Appendix B Input Data

Table 4 National livestock numbers, land use areas, and stocking rates

	1			2		3	
	Livestock numbers (1000s of stock units)			Land use area (hectares)		Stocking rates (stock units per hectare)	
Source	*PSRM database (Gardiner and Su, 2003)*			*LURNZ database (Hendy and Kerr, 2005)*		*Derived from column 1 divided by column 2.*	
Year	Dairy	Sheep	Beef	Dairy	Sheep/beef	Dairy	Sheep/beef
1980	18,663	62,614	25,384	1,077,836	8,913,135	17.3	9.9
1981	18,402	63,723	25,020	1,059,882	8,737,680	17.4	10.2
1982	18,864	64,454	23,912	1,076,365	8,685,043	17.5	10.2
1983	19,658	64,474	22,016	1,101,201	8,544,679	17.9	10.1
1984	20,328	64,172	22,186	1,080,789	8,544,679	18.8	10.1
1985	21,025	62,554	22,560	1,072,077	8,544,679	19.6	10.0
1986	21,617	61,476	23,878	1,172,462	8,632,407	18.4	9.9
1987	20,538	58,585	23,488	1,089,457	8,807,862	18.9	9.3
1988	20,551	58,432	23,724	1,049,582	8,238,829	19.6	10.0
1989	21,138	54,822	22,075	1,066,242	8,272,803	19.8	9.3
1990	21,993	52,633	22,771	1,121,751	8,034,583	19.6	9.4
1991	21,704	49,602	22,868	1,111,081	8,065,846	19.5	9.0
1992	22,103	47,803	23,232	1,094,956	8,034,583	20.2	8.8
1993	22,685	45,821	22,941	1,118,443	7,594,508	20.3	9.1
1994	24,421	44,958	25,068	1,212,024	7,905,065	20.1	8.9
1995	25,926	44,279	25,640	1,290,646	7,834,484	20.1	8.9
1996	26,434	43,210	24,064	1,301,386	7,364,486	20.3	9.1
1997	27,607	42,690	24,188	1,370,547	7,457,342	20.1	9.0
1998	28,287	41,876	22,263	1,401,006	7,345,827	20.2	8.7
1999	27,055	41,744	22,782	1,391,059	7,378,650	19.4	8.7
2000	28,828	39,379	22,698	1,385,900	7,393,168	20.8	8.4
2001	30,379	36,906	23,045	1,469,080	7,308,743	20.7	8.2
2002	31,745	36,495	21,907	1,574,510	7,231,132	20.2	8.1

1 Sheep = 0.93 Stock units, 1 Beef Cattle = 4.8 Stock units, 1 Dairy Cattle = 6.3 Stock units (from the PSRM database - see Gardiner and Su, 2003)

Table 5 Nitrogen applied by aggregated farm type

	1	2	3
	Amount of nitrogen applied [a] (N tonnes)	Fertiliser Intensity [b] (N Kgs / per hectare)	Proportion of average [c]
Sheep/Beef	51,500	7.13	0.384
Dairy	112,000	71.2	3.83
Total	164,000	18.6	

All values rounded to 3 significant figures.
a – derived multiplying nitrogen content for Urea, Diammonium phosphate and Ammonium sulphate (row 3 Table 7) by tonnes of fertiliser type used (rows 9 and 10) and summing them. It excludes nitrogen from “All other nitrogen containing fertilisers” category.
b – derived by dividing the amount of nitrogen applied (column 1) by the total land use area (column 2 of Table 4)
c – derived by dividing fertiliser intensity for the land-use by total fertiliser intensity.

Table 6 National fertiliser use and pastoral production measures

	1	2	3	4	5	6
	Pastoral fertiliser total[a]	National milksolids production [b]	National lamb and mutton production [b]	National beef production[b]	Dairy fertiliser total[c]	Pastoral fertiliser intensity [d]
Year	N Tonnes	Millions of Tonnes	Millions of Tonnes	Millions of Tonnes	N Tonnes	N kgs per hectare
1990	59,265	0.6	0.727	0.452	34,511	4.46
1991	61,694	0.627	0.773	0.515	35,724	4.68
1992	70,122	0.664	0.76	0.538	40,421	5.27
1993	104,095	0.678	0.687	0.532	61,962	7.76
1994	124,131	0.764	0.739	0.553	75,088	9.53
1995	151,263	0.761	0.741	0.581	94,076	11.63
1996	153,780	0.814	0.714	0.627	98,156	12.05
1997	143,295	0.909	0.748	0.61	92,755	11.07
1998	155,467	0.919	0.742	0.629	101,940	11.83
1999	166,819	0.878	0.714	0.532	108,950	12.51
2000	189,096	0.998	0.73	0.571	123,250	14.28
2001	248,000	1.07	0.73	0.572	165,530	18.87
2002	279,148	1.15	0.703	0.555	191,210	21.38

Sources:
a – National Inventory Report (2002) (based on data from FertResearch)
b – Ministry of Agriculture and Forestry (Gardiner and Su, 2003)
c – derived. See text for explanation
d – derived from total fertiliser (column 2) divided by dairy area (column 2 of Table 4)

Table 7 Fertiliser use by fertiliser type and farm type 2002

	1	2	3	4
Farm type	Urea	Diammonium phosphate	Ammonium sulphate	All other nitrogen containing fertilisers
Nitrogen content[a]	46%	18%	21%	Unknown
	Tonnes			
Grain-Sheep and Grain-Beef Cattle Farming[b]	7,089	1,784	641	2,305
Sheep-Beef Cattle Farming[b]	9,827	13,176	1,502	8,439
Sheep Farming[b]	34,896	53,479	16,210	39,864
Beef Cattle Farming[b]	14,469	20,404	5,692	19,483
Total Sheep and Beef[b]	66,281	88,843	24,045	70,091
Dairy Cattle Farming[b]	207,805	74,342	14,557	120,287
Total[b]	274,086	163,185	38,602	190,378

Sources:
a – New Zealand. Parliamentary Commissioner for the Environment (2004)
b – Statistics New Zealand (2002). Note farm types are based on the ANZSIC classification.

Table 8 Plantation forest areas by age class

	1		2		3		4
Age	Area (ha) 2002	Age	Area (ha) 2002	Age	Area (ha) 2002	Age	Area (ha) 2002
0							
1	65901	21	55439	41	1055	61	70
2	69348	22	47091	42	1191	62	304
3	69688	23	48582	43	819	63	95
4	81219	24	51945	44	541	64	101
5	93062	25	46867	45	552	65	62
6	110917	26	47501	46	439	66	113
7	99698	27	39265	47	384	67	99
8	122780	28	24853	48	321	68	99
9	86065	29	16701	49	260	69	407
10	70362	30	11251	50	296	70	168
11	42969	31	6674	51	206	71	323
12	42962	32	5409	52	522	72	341
13	42134	33	5019	53	290	73	223
14	36946	34	4371	54	327	74	178
15	45300	35	3299	55	319	75	82
16	59384	36	2844	56	164	76	73
17	58932	37	3230	57	187	77	115
18	59848	38	2597	58	111	78	63
19	58865	39	1778	59	144	79	78
20	59260	40	1468	60	60	80	1260

Source: New Zealand. Ministry of Agriculture and Forestry (2003).

Table 9 Harvest area forecasts

	1	2	3
Year	Harvest area (Ha)	Year	Harvest area (Ha)
2003	35,221	2008	59,389
2004	39,303	2009	61,336
2005	43,926	2010	61,757
2006	48,744	2011	62,308
2007	53,664	2012	63,867

Source: Te Morenga and Wakelin (2003)

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