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Greenhouse Emissions in the Broad Scale Grazing Industries – effect of different Pasture systems on Soil Carbon Sequestration

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Abstract

Australia has identified an opportunity to increase C sequestration through improved management of agricultural soils. In soils under pasture, however, the effects of management practices on C sequestration are unclear.

This study was undertaken to determine the medium- and long-term effects of superphosphate application and sheep stocking rates on soil C sequestration under pasture in western Victoria, and to identify management practices that promote soil C sequestration.

Phosphorus (P) application strongly increased pasture and animal production, by allowing increased stocking rates. Soil C sequestration was not significantly affected by either P application rate or stocking rate. The RothC model was used to predict long-term changes in C sequestration. It indicated that management resulting in low pasture production would lead to slow C loss, whereas management resulting in high pasture production would lead to C gains of up to 63%. The changes would be slow, however, and only measurable over 30-50 years.

Thus, by maximising pasture production through appropriately matched P application and grazing regimes, sheep producers can not only improve animal production, but can maintain, and eventually improve, soil C sequestration. Improved soil C levels will provide direct benefits to farmers in terms of soil quality and improved sustainability of the farming enterprise.

Executive Summary

Agriculture is a major contributor of greenhouse gases, including carbon dioxide. Australia, like most other developed countries of the world, is committed to understanding and controlling emission of greenhouse gases, and there is a need to use farm management practices that minimise emissions.

The global soil carbon (C) pool is large in comparison with the atmospheric C pool, so small changes in the size of the soil C pool may have a considerable effect on atmospheric carbon dioxide levels. Apart from its potential to influence atmospheric carbon dioxide, soil organic C is of critical importance in the maintenance of soil quality in natural and agricultural systems.

Soil C sequestration (accumulation) represents the net balance between C inputs to and C losses from the soil. The main process responsible for input of C to the soil is below-ground allocation of photosynthetically fixed C through plant root growth. C loss occurs mainly through emission of carbon dioxide during microbial respiration (organic matter decomposition) and root respiration. The capacity of a soil to sequester C depends on a range of soil, management and climatic factors.

Australia has identified an opportunity to increase C sequestration through improved management of agricultural soils. In soils under pasture, increases in C sequestration have been demonstrated, but the effects of management practices are still unclear.

The existence in Hamilton of a long-term (25 year) pasture experiment comparing a range of superphosphate fertiliser application rates and sheep stocking rates presented an opportunity to assess the influence of these management factors on soil C sequestration in the high-rainfall zone of Victoria. This study documents measured pasture and animal productivity, measured organic C in various soil pools, and modelled projections of future trends in soil C using the Roth-C model.

The objectives of the study were (1) to determine the effects of superphosphate application and sheep stocking rate on soil C sequestration under pasture in the high-rainfall zone of western Victoria, (2) to compare potential long-term trends in soil C in the different pasture systems and (3) to identify management practices that landholders may use to promote soil C sequestration.

Pasture production was strongly increased by phosphorus (P) application, ranging from 4 t dry matter/ha at nil fertiliser up to 16 t dry matter/ha at the highest P application level of 33 kg P/ha annually. This increase in pasture production allowed a three-fold increase in stocking rate from 9 to 28.5 dry sheep equivalents/ha, and was accompanied by an increase in wool production from 55 to 133 kg wool/ha.

Soil C sequestration was not significantly affected by either P application rate or stocking rate, even after 25 years of treatment. However, increasing rates of P application produced a trend of slowly increasing C sequestration, that would only be detectable by soil analysis if the higher application rates were continued for periods in excess of 30 years.

The RothC model gave good prediction of soil C changes that were measured over the previous 10 years of the experiment. Long-term modelling scenarios indicated that management resulting in low pasture production would lead to slow C loss, particularly in soils of initially high C content, that would be difficult to measure over periods of less than 50 years. Management resulting in high pasture production, on

the other hand, would lead to long-term C gains, though they would not be detectable for 20-30 years. Under high productivity, C sequestration would increase by 0.4-0.5 t C/ha.year during the first 50 years, eventually leading to an increase of 18-63% in the top 30 cm, depending on the starting level of soil C. Such potential increases are significant when compared with C sequestration achieved by various management improvements to grasslands across the world.

Thus, increased plant and animal production through P fertiliser use is generally consistent with gradually increasing soil C sequestration, but the long time-scales involved make it difficult for individual farmers to influence soil C levels on their farms. Nevertheless, by maximising plant production through appropriately matched P application and grazing regimes, sheep producers can have confidence that these grazing systems are not likely to be detrimental to soil C sequestration. The maintenance, and eventual improvement, of soil C levels will provide direct benefits to farmers in terms of soil structure and fertility, water retention, reduced erosion, and improved sustainability of the farming enterprise.

This work contributes new information to the discussion of C sequestration issues relating to sheep grazing systems.

Contents

1 Background

Agriculture is a major contributor to greenhouse gas emissions, second only to stationary energy (Figure 1). Increasing release of greenhouse gases into the atmosphere, predominately carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), is the major cause of climate change.

Carbon dioxide, CH_4 and N_2O are released through livestock production (62%), land clearing and soil cultivation (20%), fertilisation and burning (18%). The largest livestock-related emissions are from beef cattle, followed by sheep and dairy cattle (Figure 2).

Australia, like most other developed countries of the world, is committed to understanding and controlling emission of greenhouse gases, and there is a need to use farm management practices that minimise emissions.

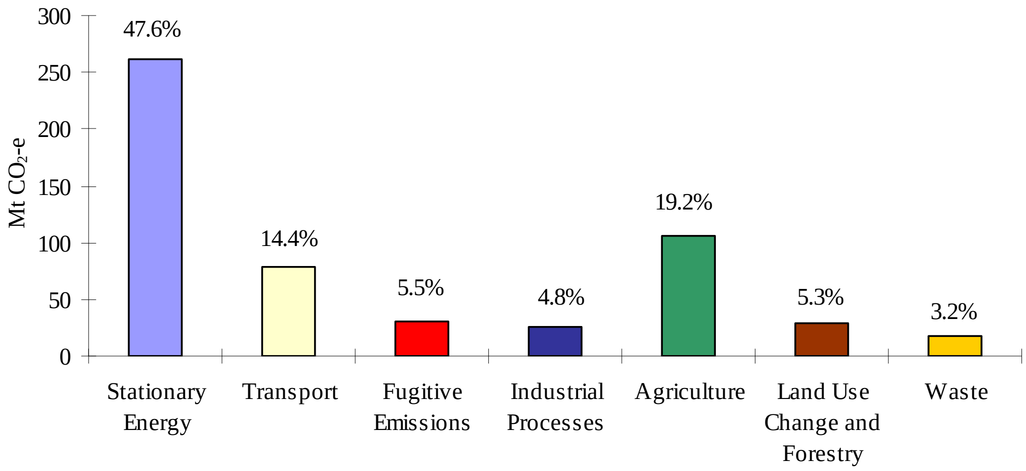


Figure 1. Greenhouse gas emissions (expressed as CO_2 equivalents) from different industries in Australia (AGO data, personal communication).

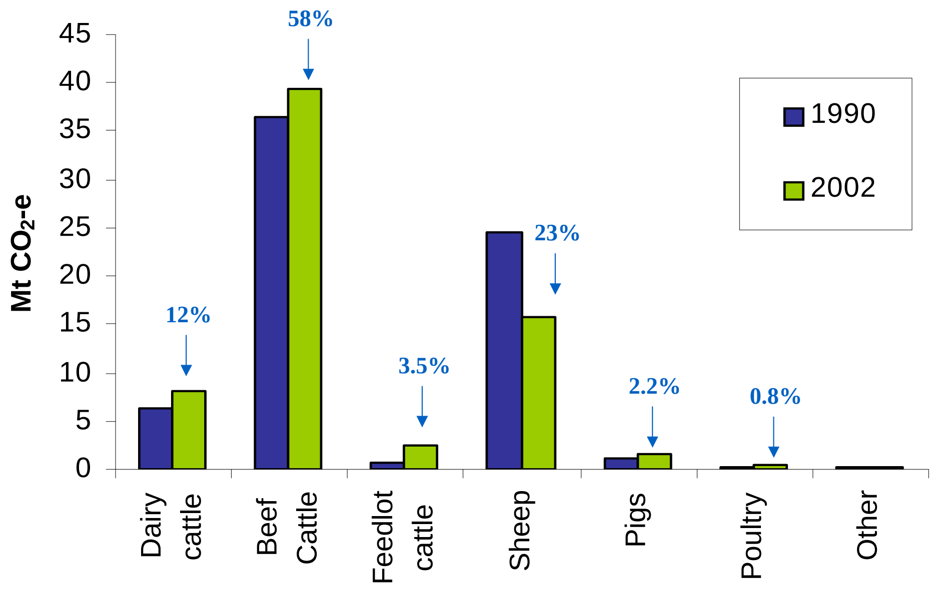


Figure 2. Greenhouse gas emissions (expressed as CO_2 equivalents) from livestock enterprises in Australia (AGO data - personal communication).

1.1 Soil C sequestration and CO_2 emissions

The global soil C pool (2500 Pg) is large in comparison with the atmospheric C pool (760 Pg), so small changes in the size of the soil C pool may have a considerable effect on atmospheric CO_2 levels (Bouwman, 1990; Lal 2004). The soil C pool includes soil inorganic C, which is mainly of importance in arid climates, and soil organic C, the most important component in non-arid climates (Lal 2004). Apart from its potential to influence atmospheric CO_2, soil organic C is of critical importance in the maintenance of soil quality in natural and agricultural systems. The functions of soil organic C have been widely studied and reviewed and will not be discussed here (see Spain *et al*. 1983 for a summary of the subject relating to Australian conditions).

Soil C sequestration (accumulation) represents the net balance between C inputs to and C losses from the soil. The main process responsible for input of C to the soil is below-ground allocation of photosynthetically fixed C through plant root growth. C loss occurs mainly through emission of CO_2 during microbial respiration (organic matter decomposition) and root respiration. Soil erosion can result in losses of soil C from a localised area, but will not represent a net emission of CO_2 unless the soil C is subsequently mineralised. The capacity of a soil to sequester C depends on a range of soil, management and climatic factors.

Australia, like many other countries, has identified an opportunity to increase C sequestration through improved management of agricultural soils (Gifford *et al*. 1992). In cropped soils, practices such as reduced cultivation, crop residue retention, use of green manures, fertiliser and manure application, and irrigation have been shown to increase C sequestration (Conant *et al*. 2001; Lal 2004). In soils under pasture, increases in C sequestration have also been demonstrated, but the effects of management practices are more equivocal. The largest increases in C sequestration under pasture appear to have occurred in soils that were degraded or previously under cultivation (Conant *et al*. 2001).

The existence in Hamilton of a long-term pasture experiment comparing a range of superphosphate fertiliser application rates and sheep stocking rates presented an opportunity to assess the influence of these management factors on soil C sequestration in the high-rainfall zone of Victoria. Preliminary measurements done on several of the plots in 2002 suggested that the most productive treatments may be sequestering considerable quantities of C, whereas the least productive treatments may be losing C (Skjemstad and Spoucer 2003). The current study is a fuller investigation of the potential of these pasture systems to sequester C. The study documents pasture and animal productivity, organic C in various soil pools and modelled projections of future trends in soil C.

1.2 The long-term phosphorus experiment

The Long-Term Phosphorus Experiment is located near Hamilton, Victoria (37º 49' S, 142º 04'E, altitude approximately 205 m), where the average rainfall is 700 mm/year. Long-term average monthly temperatures and rainfall are shown in Figure 3. The site is gently sloping to flat (<5% slope).

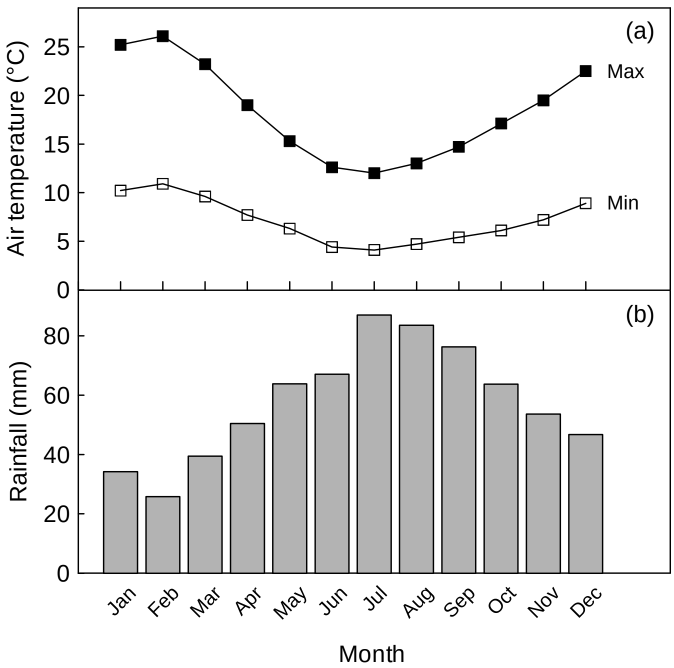


Figure 3. Average monthly rainfall and temperatures at Hamilton Department of Primary Industries.

The soil is classified as a Ferric-Sodic, Eutrophic, brown Chromosol by the Australian Soil Classification (Isbell 1996). It is a duplex soil derived from basalt. The uppermost 30-40 cm has a clay-loam texture, with a layer containing ironstone gravel, generally between 20 and 50 cm depth, overlying a clay subsoil.

In 1977, an area of 11 ha, divided into 18 paddocks (paddock size ranged from 0.45 ha to 0.81ha) was sown with a mixture of perennial ryegrass (*Lolium perenne* L.), phalaris (*Phalaris aquatica* L.) and subterranean clover (*Trifolium subterraneum* L.), and fertilised with 17 kg P/ha as superphosphate. In 1979, the first experimental treatments were imposed: 6 levels of single superphosphate application (1, 5, 9, 16, 23, and 33 kg P/ha annually) and 3 rates of stocking with sheep (10, 14, and 18 dry sheep equivalents (DSE)/ha) in factorial combinations, giving 18 treatments, which were randomly allocated to paddocks. The experiment was unreplicated. These treatments continued until 1988, when the stocking rates were changed to represent low (6.3-12.5 DSE/ha), medium (8.8-17.5 DSE/ha), and high (11.3-22.5 DSE/ha) grazing pressures within each level of P application. In 1994, the stocking rates were changed to 9.2, 16.7, 22.2 and 28.5 DSE/ha. At this time, duplicate paddocks were included at the lowest and highest P and stocking rates. The treatments have remained unchanged since 1994 (see Table 1).

The superphosphate fertiliser contained 8.8% P, 11% sulfur, and 19% calcium . The site has received occasional, uniform applications of potassium chloride. Further details of the experiment have been reported by Cayley *et al*. (1999).

Table 1. Paddock numbers of the various stocking rate and fertiliser treatments on the long term phosphorus experiment.

Stocking rate (DSE/ha)	**P application rate (kg/ha.year)**					
	0	**4**	**8**	**15**	**23**	**33**
9.2	10, 16	2		1		
16.7	14	4	18	8		
22.5		17	5		3	6
28.5			7	11	9	12,15

2 Project Objectives

The objectives of this study were (1) to determine the effects of superphosphate application and sheep stocking rate on soil carbon sequestration under pasture in the high-rainfall zone of western Victoria, (2) to compare potential long-term trends in soil C in the different pasture systems using the RothC model and (3) to identify management practices that landholders may use to promote soil C sequestration.

3 Methodology

3.1 Livestock measurements

Hogget wethers were placed on the plots (see design in Table 1) in Autumn 2004 after shearing, and were weighed monthly directly off the plots. The sheep were shorn in Autumn 2005 and fleeces weighed. Whilst animal production measurements were not necessary for calculations of soil carbon sequestration, they were taken during the course of the project so that any differences in C sequestration due to treatment could be related to animal productivity.

3.2 Pasture measurements

Pasture measurements were necessary inputs for the RothC carbon model.

3.2.1 Pasture availability and growth

Pasture availability (above-ground herbage mass) was measured monthly at 8-10 locations per paddock using calibrated visual estimation. In order to measure pasture growth, exclusion cages were placed at 8-10 locations per paddock and left undisturbed for approximately 4 weeks. On each measurement occasion, pasture growth was estimated as the difference between the initial pasture availability prior to the cage beinging placed in position and pasture availability inside the cages after the approximately 4 week period. The cages were moved after each assessment. The pasture growth and availability measurements were done on areas representative of the yield, species composition and green leaf content of the paddock. At each pasture assessment time, at least 10 calibration cuts were used to obtain a relationship between visual assessment and actual herbage mass. Where pasture differred in composition and quality, separate calibrations were done. The pasture collected for calibration was weighed after drying at 100 ºC.

3.2.2 Pasture quality

Pasture quality samples were taken in March, April, July, September and November 2004, reflecting differences in seasonal conditions. Samples of herbage were taken outside and inside the pasture cages from 3 areas of about 30 cm^2. Samples were dried at 60 ºC, then analysed for dry matter digestibility (DMD) and crude protein (CP) using near infrared (NIR) reflectance analysis at the Hamilton FEEDTEST laboratory.

Animal and pasture data were analysed using the restricted maximum likelihood (REML) and linear regression procedures in Genstat 7.2. (Genstat Committe 2003).

3.3 Soil sampling

In November 2004, soil cores (40 mm diameter, in depth layers 0-10, 10-20, 20-30, 30-50 and 50-80 cm) were taken at 5 positions in each of the 18 paddocks. One sampling position (Position 1) was in the sheep camp area at the top (upslope) part of the paddock, and the other 4 positions (Positions 2-5) were in the non-camp area of the paddock (Figure 4). At each position, 4 cores were taken in a transect across the paddock and combined to make a composite sample. The soil sampling conformed to standards established in the National Carbon Accounting System (McKenzie *et al*. 2000). Soil samples were dried at 40ºC and weighed in order to estimate bulk density. Soil samples were then ground and sieved to <2 mm, which removed most of the ironstone gravel.

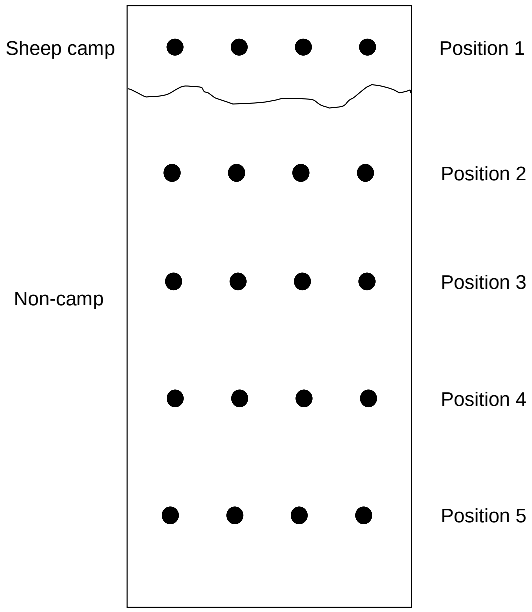


Figure 4. Soil sampling positions used for each paddock.

3.4 Soil organic C_{WB}

The <2mm soil samples were further ground to <0.5 mm and analysed for soil organic C using a modified Walkley-Black method (Rayment and Higginson 1992, method 6A1), hereafter referred to as organic C_{WB}. The organic C_{WB} analyses were performed at the Department of Primary Industries Laboratory, Werribee.
Soil bulk density was not significantly related to the experimental treatments. McCaskill and Cayley (2000) found that, at this site, most of the variation in bulk density below 10 cm could be accounted for by variation in the gravel content of the soil. After allowing for the volume occupied by gravel, the bulk density of the fine earth component averaged 1.24 g/cm^3 and was virtually constant at all depths to 80 cm. Because gravel had been removed from the samples before analysis, organic C_{WB} (mass/ha) was calculated assuming a bulk density of gravel-free soil of 1.24 g/cm^3 below 10 cm depth.

The organic C_{WB} data were analysed using the restricted maximum likelihood (REML) and linear regression procedures in Genstat 7.2 (Genstat Committe 2003). Unless otherwise stated, the statistical significance of effects was judged at the 95% level (P<0.05).

3.5 Soil carbon fractions and modelling

3.5.1 Samples

Analyses of soil C fractions for the modelling study were done (at CSIRO laboratories, Adelaide) on soils from the 0-10, 10-20 and 20-30 cm depths from the non-camp areas of the paddocks. Four sampling positions were analysed for each paddock, except for paddock 6 where only 2 positions were analysed (total 210 samples). Archival soil samples taken in 1994 at different depth intervals (Appendix 2) were also analysed from 2 non-camp positions of paddocks 6-18 (total 51 samples). The <2 mm soil samples were sub-sampled (approximately10 g) and further ground in a ring mill.

3.5.2 Chemical Analyses

All samples were analysed for total organic carbon (TOC) by Leco furnace (Merry and Spouncer 1988) and by mid-infrared (MIR) with partial least square (PLS) analysis to predict a range of soil properties (Janik *et al.* 1995, 1998; Janik and Skjemstad 1995). Data for the 2004 and 1994 samples are presented in Appendices 1 and 2 respectively.

The MIR/PLS method provides data at a number of levels in that some predictions are very accurate, some poor and some in between. For charcoal-C (char-C), prediction is reasonable (R^2 = 0.86) and robust but for particulate organic C (POC), prediction can be variable with an average R^2 = 0.71. The latter analysis is much more robust if a local calibration using soils from the study area are used. For this study, 49 samples were analysed for POC directly (Skjemstad *et al..* 1999) and these used to predict the entire set of soils. Using this smaller local set, R^2 for POC prediction was improved from 0.71 to 0.87.

3.5.3 Modelling

For soil organic carbon modelling, RothC (ver. 26.3) in Excel format was used (Skjemstad *et al*. 2004). The model has 5 pools: easily decomposable plant material (DPM); resistant plant material (RPM); microbial biomass (BIO); humic material (HUM); and inert organic matter (IOM) (Skjemstad *et al*. 2004). Details of the requirements for the modelling are given in Table 2. As well, each soil sample must have TOC, POC and Char-C data to initialise the model. Data from TOC, POC and Char-C were converted to t C/ha using the measured bulk density data. Since bulk density varied from paddock to paddock and between the 2 different times of sampling, it was necessary to adjust the t C/ha for each core to ensure that each core represented exactly the same amount of soil by weight. After examining the bulk density to 30 cm for each core, it was decided that a total of 4,000 t soil/ha was representative of the cores across space and time. The absolute amount of soil used is not critical, provided that it is representative of the 0-30 cm layer required for modelling and that the same value is used throughout. The 4 soil cores sampled from each paddock in 2004 were averaged for modelling. Archival samples were not available from paddocks 1-5.

Long term pasture data were only available for a limited number of paddocks (6, 7, 10, 11, 12, 14, 15, 16, 18) and not for the entire period. Using the climate data (Appendix 3) the initial soil OC and pool structure data (Appendix 4) along with the pasture data (Appendix 5), the RothC model was initialised and run for each of the 9 paddocks for the period 1994 to 2004. The modelled data were then compared with the measured TOC, POC, HUM and Char data for the soils sampled in 2004. Initial modelling demonstrated that the estimated pasture input data was too high. In a series of subsequent model runs, the pasture input was systematically reduced until a reasonable fit was obtained for the majority of the paddocks not only for TOC but also for the pools. Reducing the value by 30% above ground resulted in a good fit. This seemed a reasonable approach since there is some uncertainty in the dry matter produced across the entire modelling period as well as uncertainty in the amount of pasture consumed and returned to the paddocks.

Table 2. Data and other requirements for running of the RothC model.

Data and other requirements	Comments
Soil samples	Representative soil samples from the beginning and end of a period of interest to a depth of 30 cm.
Soil bulk density	Measured at the time of sampling using core weight/volume
Above-ground biomass	Biomass for each of the years to be modelled
Management	Details of the amount of pasture consumed and returned to the soil as dung
Climate	Details of average monthly temperature, rainfall and pan evaporation

4 Results and Discussion

4.1 Animal measurements

4.1.1 Liveweight change

The wethers on all treatments gained weight over the duration of the project, with those on the lowest level of fertiliser gaining significantly less (4.4 kg) than those on the other fertiliser levels (11.3, 11.3, 12.3, 15.0 and 12.4 kg for P rates of 4, 8, 15, 23 and 33 kg/ha, respectvely; P<0.001;standard error = 1.6 kg). The wethers at 23 kg P/ha gained significantly (P<0.001) more weight (15.0 kg) than those at the other fertiliser levels. Monthly mean liveweight of the treatments are shown in Figures 5 and 6.

The stocking rates at each of the fertiliser levels were chosen to reflect the pasture productivity at that fertiliser level, so it is not surprising that there were not substantial differences in liveweight change between fertiliser levels. The P level of 23 kg P/ha could possibly be stocked at a slightly higher rate.

The wethers stocked at 28.5 DSE/ha gained significantly less (P< 0.001) liveweight (6.0 kg) than those at other stocking rates (13.8, 13.9, and 10.8 kg for those stocked at 9, 16.5 and 22.5 DSE/ha, respectively). There were no significant differences among the other stocking rates.

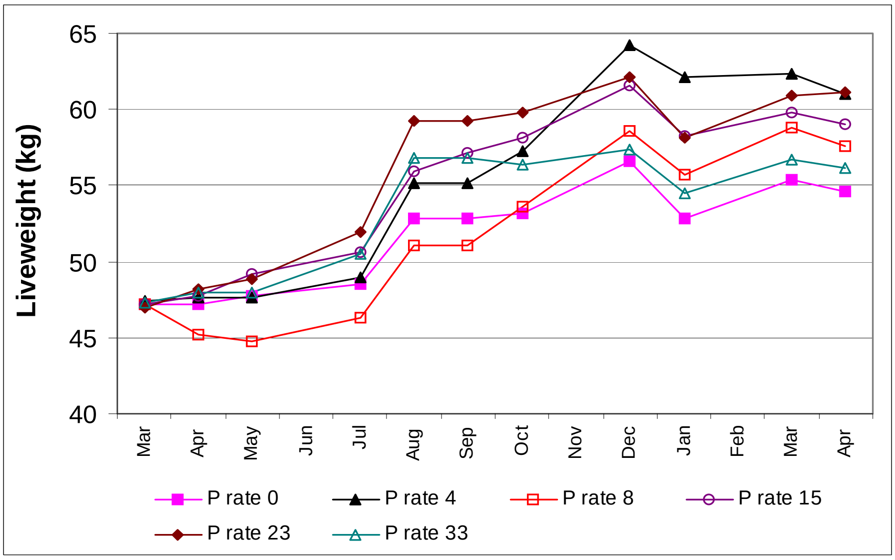


Figure 5. Mean monthly liveweight and P application rate (kg P/ha).
Standard error = 1.6 kg.

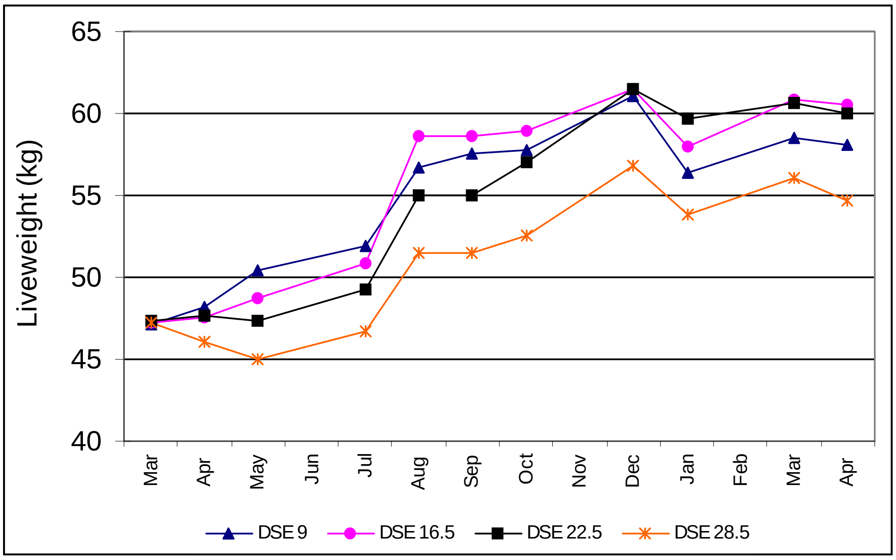


Figure 6. Mean monthly liveweight and stocking rate (DSE/ha).
Standard error = 1.4 kg.

4.1.2 Wool production

Figures 7 and 8 and Table 3 show the relationships between fleece weight, P application, and stocking rate. Wool production generally reflected the differences in liveweight change due to differences in P rate and stocking rate. The wethers at the P rate of 23 kg P/ha produced the highest greasy fleece weight (5.9 kg/head; $P<0.001$), with the lowest fertiliser treatment producing significantly less wool than the other fertiliser treatments (4.4 kg/head; $P<0.001$).

The highest stocking rate produced significantly less wool per head at 4.6 kg/head (*P*<0.001) compared to the other stocking rates, again reflecting the differences in liveweight change. Those stocked at 22.5 DSE produced significantly less wool (5.1 kg/head; *P*<0.001) than those stocked at 9 and 16.5 DSE/ha, there being no difference between those two levels.

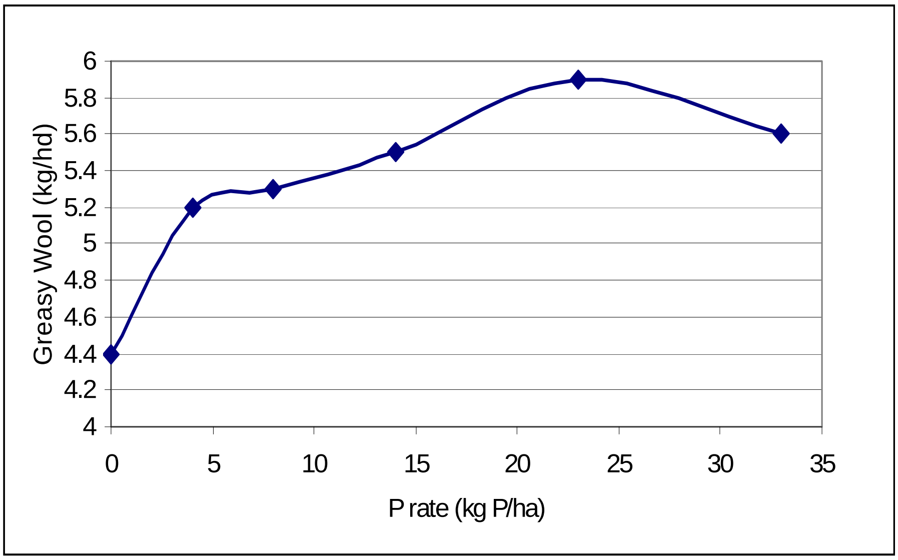


Figure 7. Greasy fleece weight (kg/head) and P application rate.
Standard error = 0.24 kg/head.

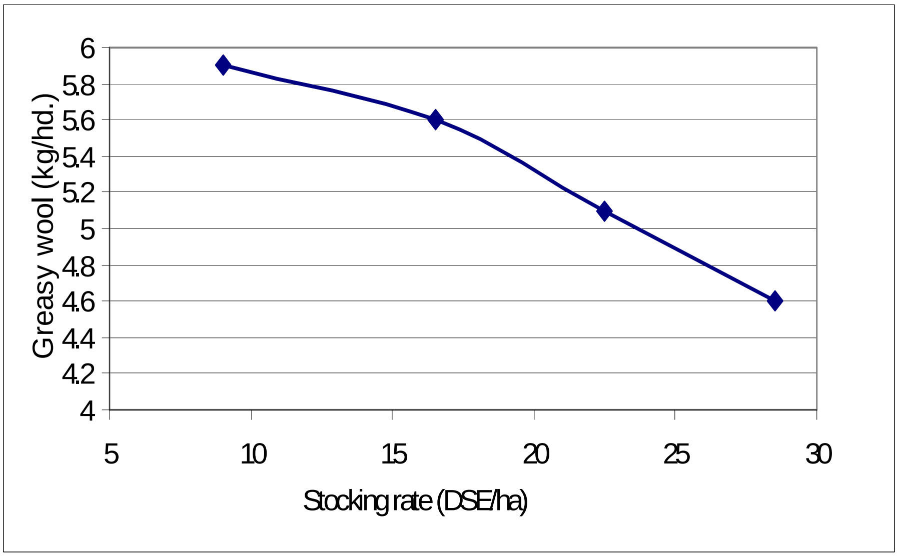


Figure 8. Greasy fleece weight (kg/head) and stocking rate.
Standard error = 0.21 kg/head.

Table 3. Effect of stocking rate and P application on wool production per hectare (kg greasy wool/ha). s.e. = standard error.

Stocking rate (DSE/ha)	**9**	**16.5**	**22.5**	**28.5**	**s.e.**		
Wool production (kg/ha)	55.8	91.9	117.2	133.7	4.8		
P application (kg P/ha)	**0**	**4**	**8**	**15**	**23**	**33**	**s.e.**
Wool production (kg/ha)	87.1	94.2	97.4	102.4	111.5	105.4	5.4

Stocking rate differences in terms of wool produced per hectare are shown in Table 3. Although there was a reduction in wool produced per head with increased stocking rates, there was a large increase in wool production per hectare achieved through increasing both stocking rate and fertiliser application, whilst maintaining satisfactory liveweight change. Whilst stocking rate influences wool production per hectare, it is the increased P application rate allowing a much higher carrying capacity that has the largest influence. At the lowest P application rate where the stocking rates of 9 and 16.5 DSE/ha were appropriate, 45.4 and 75 kg of wool per hectare was produced respecively, whilst the wool production of the two stocking rates of 22.5 and 28.5DSE/ha which were possible at the the higest P application rate, 121 and 140 kg of wool was produced, respectively.

4.2 Pasture measurements

4.2.1 Pasture availability

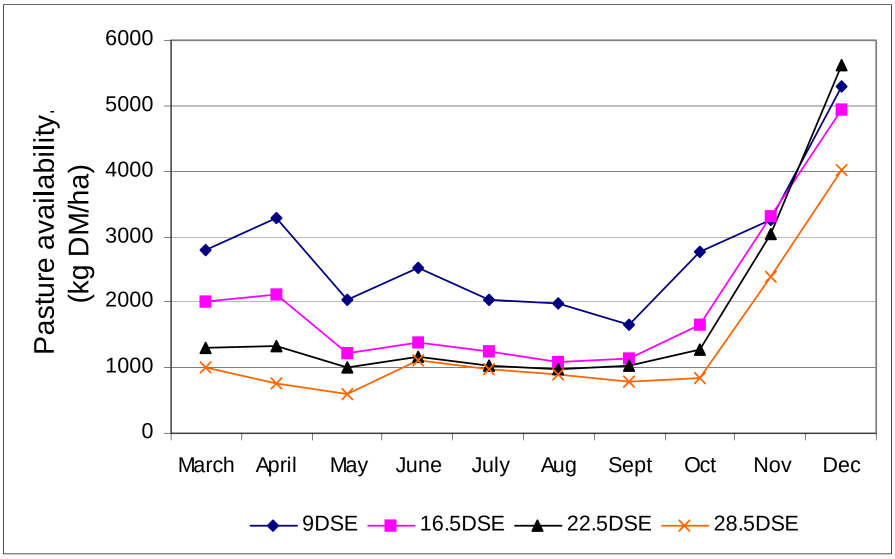


Figure 9. Pasture availability and stocking rate (DSE/ha).

Figures 9 and 10 show monthly measurements of pasture availability and, not surprisingly, indicate that there is more available pasture at the lower stocking rates compared to the higher stocking rates, particularly earlier in the season, with differences decreasing from mid year. Larger differences between fertiliser rates occur in spring when pasture growth is at its maximum. The mean annual pasture availability at P levels of 0, 4, 8, 15, 23 and 33 kg P/ha was 1037, 1322, 1711, 2377, 2675 and 2821 kg DM/ha, respectively (standard error = 208 kg DM/ha). The mean availability at 9, 16.5, 22.5 and 28.5 DSE was 3306, 2176, 1634 and 846 kg DM/ha, respectively (standard error = 1810 kg DM/ha). The level of pasture availability was generally a reflection of fertiliser application. The available pasture at 33 kg P/ha was significantly higher (*P*<0.001) than at 0, 4, 8 and 15 kg P/ha. There were significant differences in mean pasture availability between all stocking rates. These differences would be due to a combination of pasture utilization and pasture quality. The spring increase in pasture availability at the three highest fertiliser rates suggest that the spring stocking rate could be increased during that period to increase utilization.

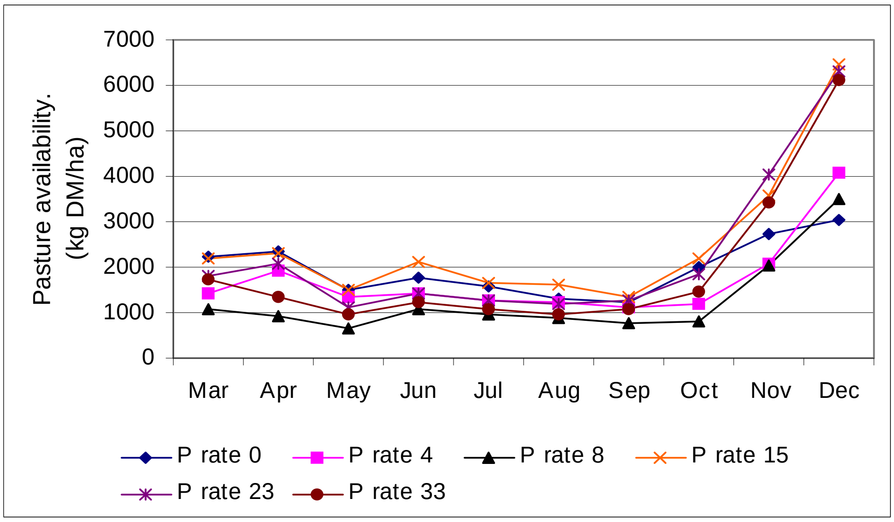


Figure 10. Pasture availability and P application rate (kg P/ha).

Differences in spring pasture availability due to fertiliser rate can be clearly seen in Figure 11, which shows pasture availability (kg DM/ha) for the extremes in fertiliser rate of 0 and 33 kg P/ha for their respective highest and lowest stocking rates.

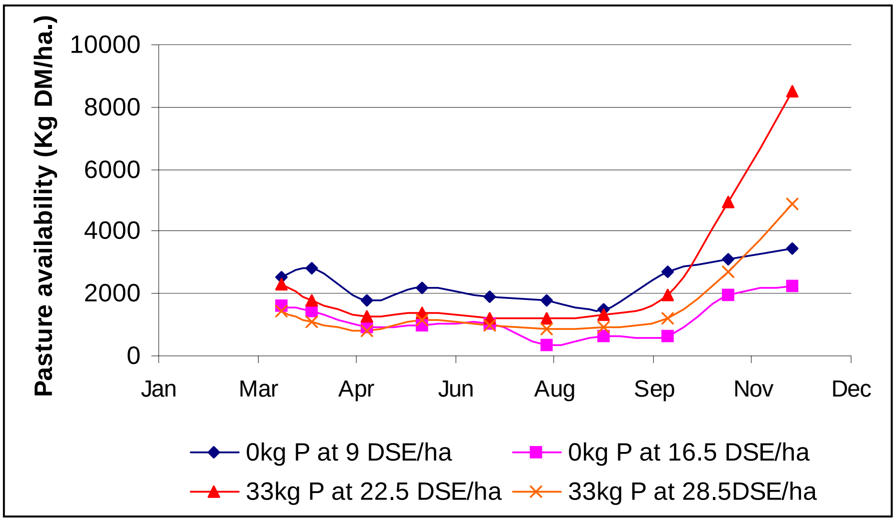


Figure 11. Pasture availability at the extreme P application rates, at their highest and lowest stocking rates.

4.2.2 Pasture growth

Pasture growth estimates are shown in Figures 12 -14, and the estimated yearly-accumulated pasture growth is shown in Table 4

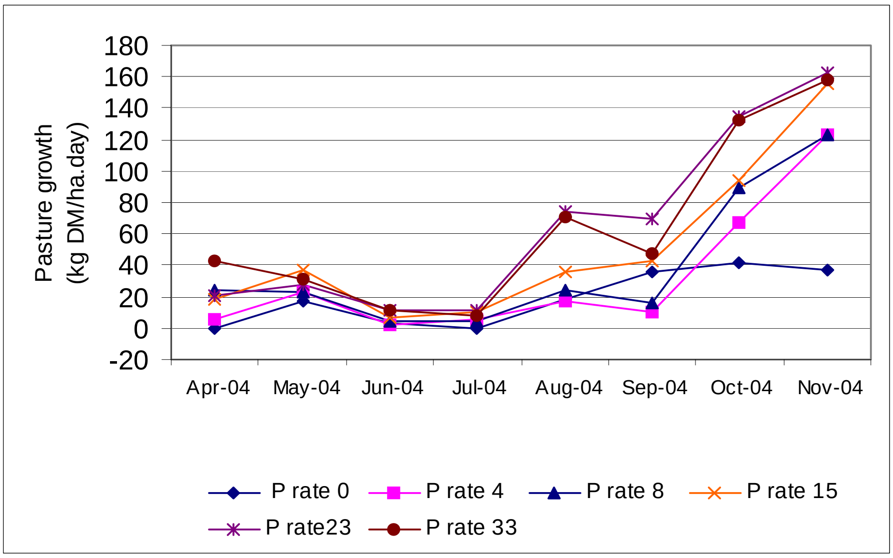


Figure 12. Pasture growth and P application rate (kg P/ha).

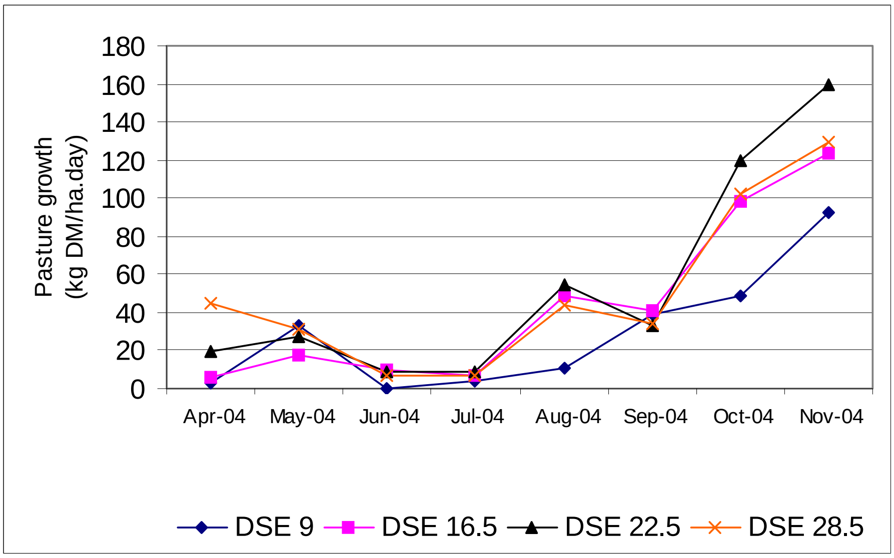


Figure 13. Pasture growth and stocking rate (DSE/ha).

The increases in pasture dry matter production due to increased fertiliser application indicate why higher stocking rates can be utilized. The relative failure of the lowest fertiliser level to respond to more favourable seasonal conditions in spring explains why this treatment can only carry low stocking rates. Table 4 shows both the average growth rate and accumulated yearly pasture production due to treatment. There was no significant effect of stocking rate on mean pasture growth (*P*>0.05). As would be expected, P level significantly (*P*<0.001) influenced pasture growth, particularly P levels above 15 kg P/ha. Table 4 also shows the accumulated yearly pasture production, and the large accumulated effect of fertiliser rate. There was over a three-fold difference in total pasture production between the lowest and highest fertiliser rates, with significant increases at every level of P increase except between 23 and 33 kg P/ha. For the nil fertiliser rate, the highest and lowest stocking rates of 9 and 16.5 DSE/ha gave accumulated pasture production of 4713 and 5018 kg DM/ha/year, respectively. At the highest P application rate (33 kg P/ha), the yearly accumulated pasture production at the highest and lowest stocking rates was 18,878 and 13,665 kg DM/ha/year, respectively. Pasture growth at the extreme fertiliser and stocking rate treatments is shown in Figure 14.

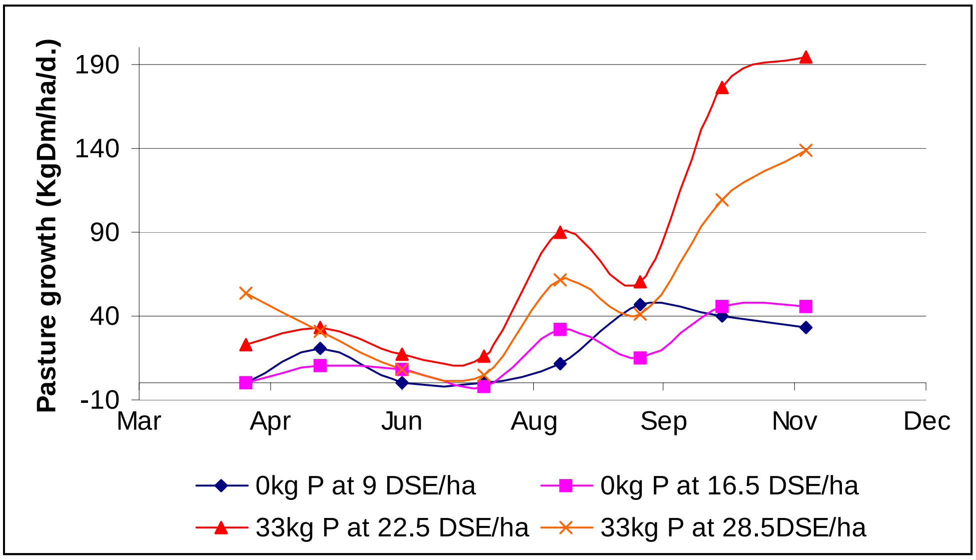


Figure 14. Pasture growth (kg DM/ha.day) at the extreme fertiliser rates (0 and 33 kg P/ha) and the associated extreme stocking rates.

Table 4. Mean pasture growth rate for each month, and total yearly accumulated pasture growth as affected by fertiliser P rate (kg P/ha) and stocking rate (DSE/ha). s.e. = standard error.

Pasture growth rate (kg DM/ha)									**s.e.**
Month	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	
	18	27	6	7	40	37	93	128	5.9
P rate (kg P/ha)	**0**	**4**	**8**	**15**	**23**	**33**			
	18.2	29.3	38.5	51.5	63.8	66.2			5.6
Stocking rate (DSE/ha)	**9**	**16.5**	**22.5**	**28.5**					
	44.1	48.1	48.8	37.2					*ns*
Total pasture accumulation (kg DM/ha.yr)									
P rate (kg P/ha)	**0**	**4**	**8**	**15**	**23**	**33**			
	4580	7247	9482	12724	15759	16316			1907
Stocking rate (DSE/ha)	**9**	**16.5**	**22.5**	**28.5**					
	10888	11984	12085	9115					*ns*

4.2.3 Pasture quality

4.2.3.1 Dry matter digestibility

Figures 15 and 16 and Table 5 show treatment differences in dry matter digestibility (DMD%). Date of sampling significantly influenced pasture digestibility, with samples collected in early autumn having significantly lower ($P<0.001$) digestibility than at other periods. This would be due to the pasture having a higher percentage of dead material present. There were significant differences ($P<0.001$) between other times of sampling, with the highest digestibility occurring with the newly grown autumn pasture in April. After April, the next highest period of digestibility occurred in September, with the new spring growth.

There was a significant effect of fertiliser rate on digestibility, with the lowest fertiliser rate having lower digestibility at all times of the year. Pasture at the lowest two fertiliser levels was significantly lower in digestibility than at the other levels ($P<0.001$). Saul *et al.*. (1999) showed that an average application of 33 kg P/ha as single superphosphate over 18 years increased the digestible dry matter of subterranean clover herbage by up to 10 units compared with an application of only 1 kg P/ha. They also found that crude protein increased in all pasture species with higher P application. Although there was a trend for the pasture at the lowest stocking rate to have lower digestibility (Figure 16), there was no significant effect of stocking rate.

The mean digestibility and yearly pasture accumulation rates were used in the RothC model.

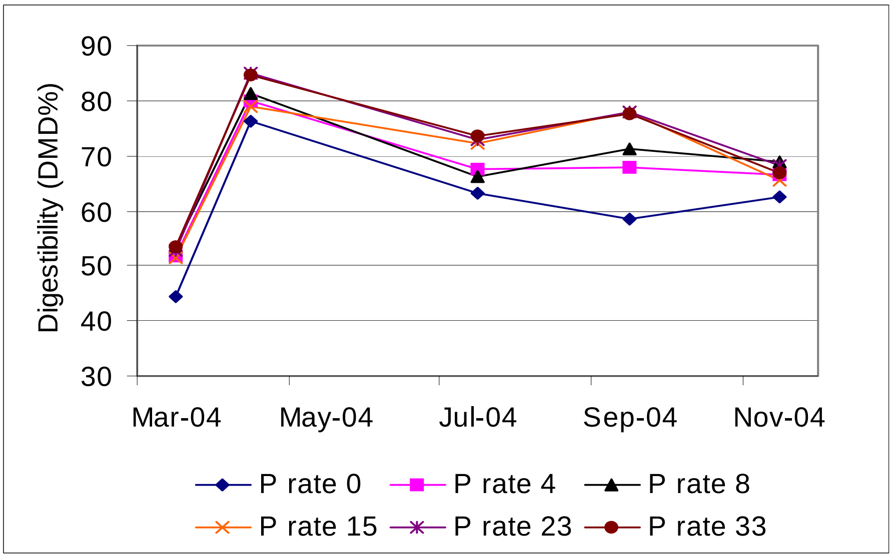


Figure 15. Digestible dry matter percentage (DMD%) and fertiliser P application rate (kg P/ha).

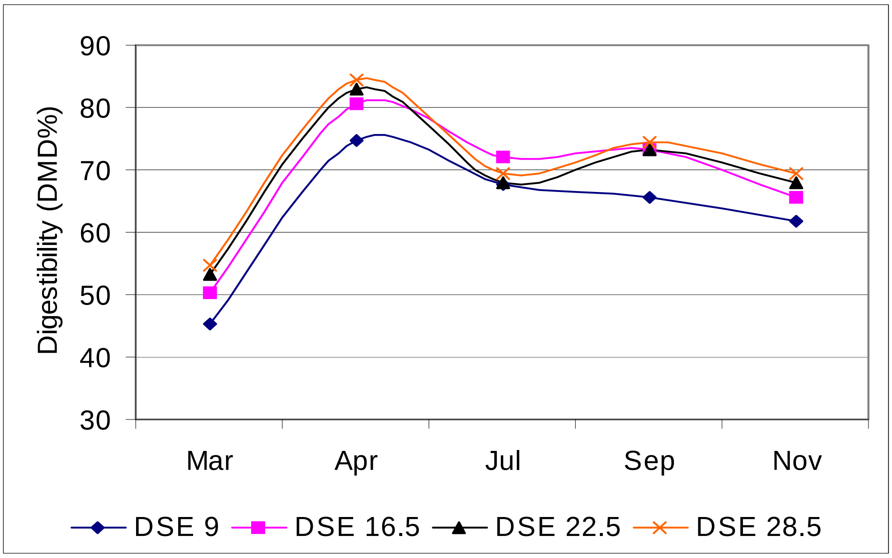


Figure 16. Digestible dry matter percentage (DMD%) and stocking rate (DSE/ha).

Table 5. Effects of stocking rate, fertiliser application and month on pasture dry matter digestibility.
s.e. = standard error.

Pasture dry matter digestibility							**s.e.**
Month	**Mar**	**Apr**	**Jul**	**Sep**	**Nov**		
	51.2	80.9	69.2	71.8	66.4		1.4
P application (kg P/ha)	**0**	**4**	**8**	**15**	**23**	**33**	
	62.1	67.2	67.5	69.4	70.6	70.5	1.7
Stocking rate (DSE/ha)	**9**	**16.5**	**22.5**	**28.5**			
	65.7	68.8	68.3	68.7			ns

4.2.3.2 Crude protein percentage

Figures 17 and 18 and Table 6 show changes in crude protein percentage (CP%), of the pastures, as affected by stocking rate and fertiliser rate. Following a similar trend to digestibility, there was a large influence of month of sampling on CP%, with the samples taken in April having the lowest CP%. There was a month by P rate interaction, with the lowest levels of P application generally having lower levels of CP% in July and September (*P*<0.001), with differences decreasing by late spring. This would be due to differences in dry feed carry over and pasture species. The higher stocking rates resulted in significantly (*P*<0.001) higher protein content at all P levels (Table 6)

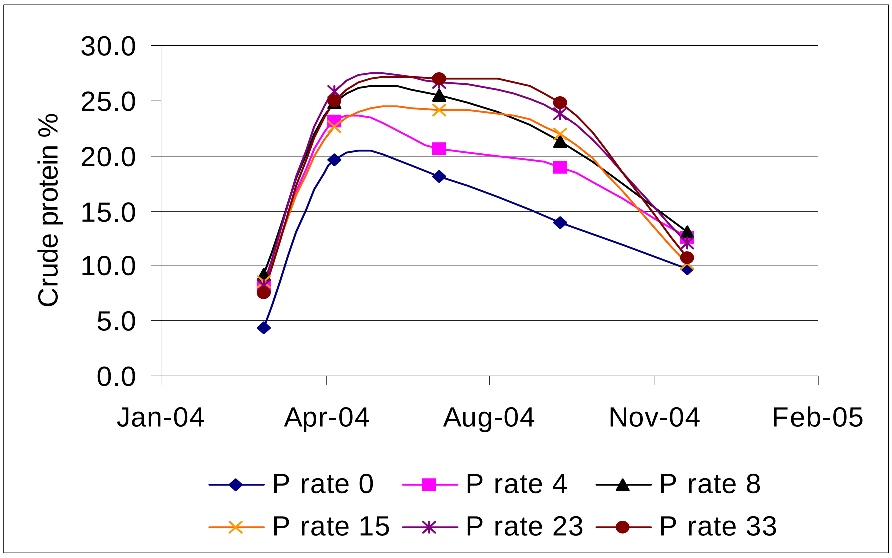


Figure 17. Crude protein percentage and fertiliser P application rate (kg P/ha).

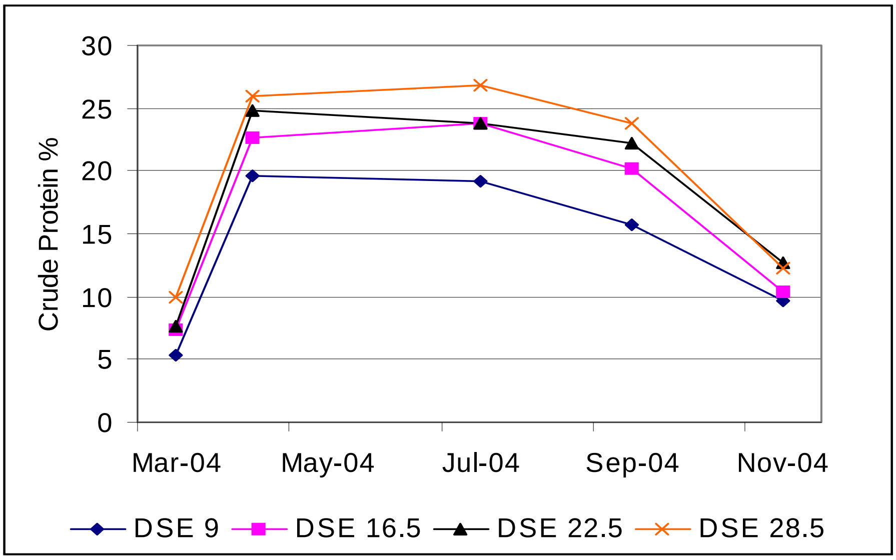


Figure 18. Crude protein percentage and stocking rate (DSE/ha).

Table 6. Effect of stocking rate and fertiliser application on crude protein percentage of pasture.
s.e. = standard error.

P application (kg P/ha)	Month					
	Mar	**Apr**	**Jul**	**Sep**	**Nov**	**se**
0	6.0	21.2	19.7	15.4	11.3	1.4
4	8.5	23.5	20.9	19.2	12.9	
8	8.5	24.0	24.7	20.5	12.3	
15	8.8	22.8	24.3	22.1	10.5	
23	7.5	25.1	26.0	23.1	11.3	
33	6.1	23.5	25.4	23.3	9.3	
Stocking rate (DSE/ha)	**9**	**16.5**	**22.5**	**28.5**		
	15.1	16.9	17.9	19.2		0.6

4.3 Organic C_{WB}

The REML analysis indicated that soil organic C_{WB} was not significantly affected by P fertilisation rate (*P*>0.10, Figure 19) or stocking rate (*P*>0.10, data not shown). However, linear regression analysis indicated a trend of gradually increasing soil organic C_{WB} with increasing P application, in the non-camp areas only (Figure 19). Over the 25 years of this experiment, organic C_{WB} in the 0-30 cm depth increased by 216 kg C per kg P applied annually (the slope of the line in Figure 19b). Field variability in soil organic C_{WB} was such that an increase of around 9 t C/ha would be required to be detectable at the commonly accepted 5% level of significance (*P*<0.05). At a P application rate of 13 kg P/ha/year (average for western Victoria; Luke Fitzpatrick, *personal communication*) this would take about 80 years, and with a P application rate of 33 kg P/ha/year, it would take about 30 years (assuming the response remained linear). Soil organic C_{WB} levels in this study were moderately high (generally 5-6% C in 0-10 cm depth), and it is probable that P application would have a greater effect on soils of lower initial organic C content.

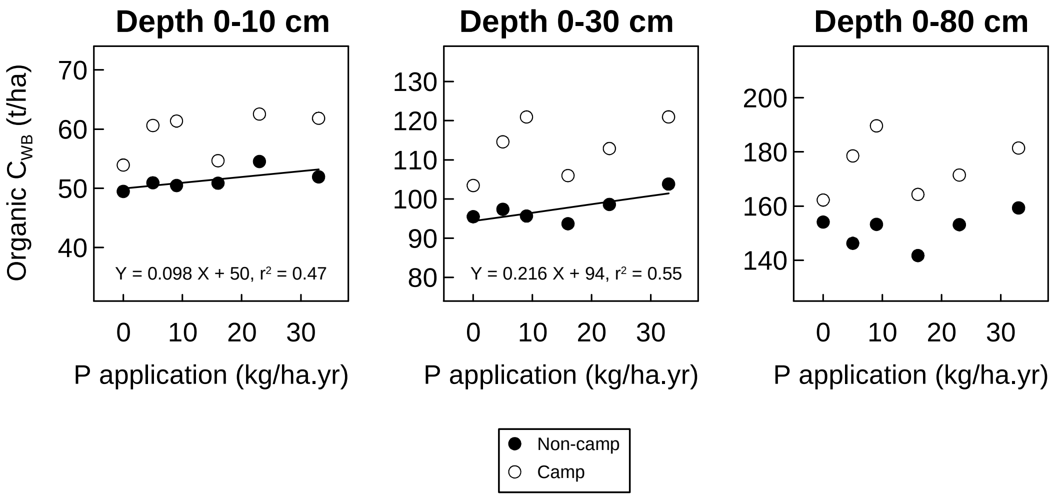


Figure 19. Soil organic C_{WB} and P application, in the upper 10, 30, and 80 cm depths.

The weak response of C_{WB} to P application may seem surprising, given the strong response in pasture growth to P application at this site (this report, and Cayley *et al*. 1998). However, organic C accumulation would also be influenced by pasture utilisation by the grazing animals, by pasture root growth, and by the rate of decomposition of pasture residues. In this experiment, the concentrations of P and N in pasture increased linearly with increasing P application, thus pasture residue decomposition was probably more rapid at higher P applications. Only around half of the variation in organic C_{WB} could be explained by P application, as seen by the coefficient of determination (r^2) of the regression equations shown in Figure 19.

Our results are consistent with findings from New Zealand where superphosphate application to pastures greatly increased pasture (ryegrass-clover) and animal production but did not increase soil C accumulation over 20 years (Saggar *et al*. 1997; Stewart and Metherell 1999; Metherell 2003). In their study, superphosphate resulted in less proportional allocation of C to plant roots, faster root turnover (decomposition), and lower root mass. The authors considered that these responses to superphosphate application reflected changes in both pasture species composition and physiology of individual species. It is highly likely that similar processes operated in the Hamilton experiment.

Grazing management has been suggested as a potential means of promoting C sequestration in some situations (Conant *et al*. 2001). In New Zealand, increasing the stocking rate of sheep on a fertilised tussock grassland was found to increase allocation of C to plant roots, but to reduce C sequestration because of increased pasture utilization and reduced return of litter (Stewart and Metherell 1999). Similarly, studies in North America have found less soil C sequestration under grasslands with heavy grazing than with light or moderate grazing (Dormaar and Willms 1998; Wright *et al*. 2004). The lack of response to stocking rate in the current experiment may reflect the large spatial variation in C_{WB} and interactions between C sequestration and C loss processes. Also, there is a degree of confounding in the experimental design i.e. low stocking rates occur at low fertiliser rates and *vice versa*, which would make treatment differences more difficult to detect. This experiment was managed under set-stocking, and it is possible that rotational grazing may have given different results. Conant and Paustian (2001), in Virginia, USA, found that intensive grazing management (rotational grazing) increased soil C compared to extensive grazing, due to either greater aboveground inputs (greater plant productivity or manure inputs), increased root turnover, or a combination of the two.

Organic C_{WB} was significantly greater in the stock camping areas than in the rest of the paddock, to 80 cm depth (Figures 19 and 20). Thus, total C sequestration over the whole paddock would have been slightly greater than suggested by the regression equations presented above (Figure 19). However, it was not possible to include the camp effects in a meaningful way because of the extreme variability within the camps and the difficulty in defining the exact extent of the camps.

Organic C_{WB} declined sharply with depth, reflecting the concentration of plant roots in the top 10 cm of soil, and deposition of plant residues and dung at the soil surface. Accumulation of C in the camp relative to the non-camp areas would have occurred primarily through direct deposition of dung and urine in the camp. That the camp effect was measurable as deep as 50-80 cm suggested that soluble C had leached from the surface soil, probably through macropores (e.g. root or worm channels, soils cracks and large pores, White 1985).

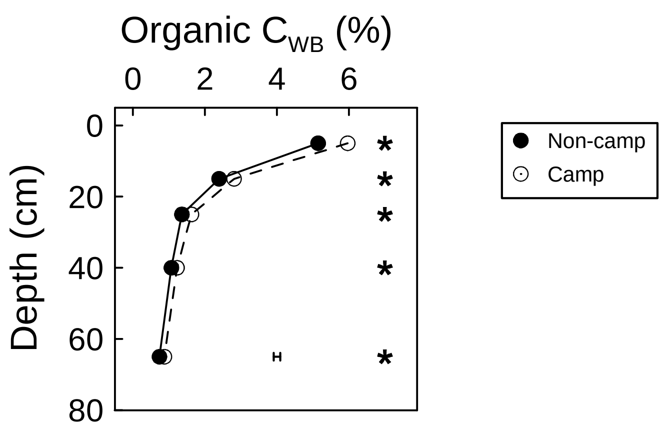


Figure 20. Soil organic C_{WB} in camp and non-camp areas to 80 cm depth. Asterisks indicate a significant difference between camp and non-camp. Horizontal bars indicate least significant difference for comparing depths.

4.4 Modelling of soil C dynamics

Table 7 shows the soil C in t C/ha for paddocks 6-18 in 1994 and 2004 along with the standard deviation (St Dev) between the 4 cores for the 2004 sampling event. In all cases except for paddocks 8, 9 and 10, the 2004 data are higher than that from 1994. In a few cases e.g paddocks 17 and 18, the differences are large. In terms of soil C change, the time span of 10 years is not long and so large changes in TOC without significant changes in inputs would not be expected. A major issue with any soil C accounting process is spatial variation in C across paddocks. Table 7 also gives the St Dev for the 4 cores taken in 2004. The spatial St Dev is often much larger than the temporal differences creating considerable uncertainty in these temporal changes.

Table 7. Soil TOC data in t C/ha for paddocks 6-18.
Paddocks highlighted in grey were also modelled.

Paddock	P rate (kg P/ha)	Stocking rate (DSE/ha)	Positon (1994)	TOC 1994	TOC 2004 Mean	TOC 2004 St Dev	TOC 2004 similar site as 1994
6	33	22.5	3	94.8	102.7	nd	92.9
7	8	28.5	3	85.9	90.3	8.4	90.7
8	15	16.7	3	116.0	100.2	10.1	89.1
9	23	28.5	3	107.2	96.2	12.4	84.4
10	0	9.2	1	107.8	103.4	7.3	103.0
11	15	28.5	3	104.3	122.2	12.3	111.0
12	33	28.5	3	101.3	107.5	7.7	98.8
13	23	16.7	3	114.4	117.7	2.6	121.0
14	0	16.7	3	106.6	107.5	13.3	116.4
15	33	28.5	3	116.6	126.0	16.4	112.1
16	0	9.2	3	104.0	121.0	2.4	124.1
17	4	22.5	3	94.2	131.9	9.3	119.0
18	8	16.7	3	96.8	122.8	5.7	115.7

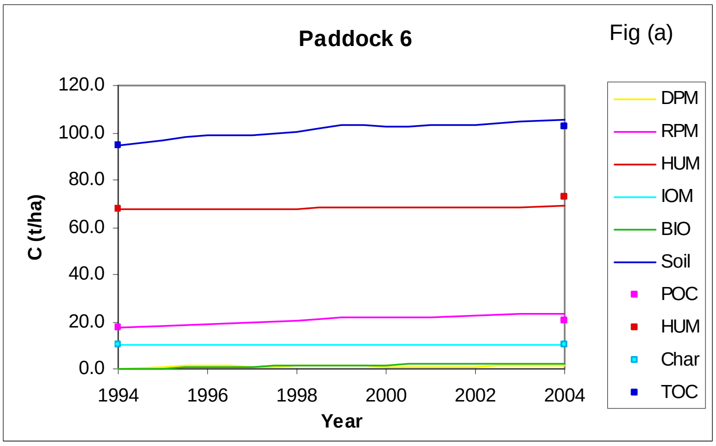
The model outputs also showing the measured data for 2004 (means) are presented in Figures 21 a-i for paddocks 6, 7, 10, 11, 12, 14, 15, 16 and 18, respectively. Paddocks 6, 7, 10, 12, 14 and 15 show good agreement between the modelled and measured data. Paddocks 11, 16 and 18 showed poor agreement, where in each case the modelled output is considerably lower that the measured data. For paddock 16, a small increase in pasture input would improve the fit considerably, but for paddocks 11 and 18 no reasonable amount of input could build soil C to the extent suggested by the measured data. In particular, the HUM pool which, has a turnover time around 50 years, could not be increased to such an extent without a complimentary very large increase in the more labile POC pool which is not evident. The lack of agreement in some paddocks therefore probably reflects spatial variability rather than some basic flaw in the model. Four sets of cores were sampled outside the camp area in 2004 and only three in 1994. Positions where cores were taken on the two occasions therefore do not correspond, but Table 7 shows data for the position nearest the camp in 2004 that corresponds most closely with the 1994 sampling. In some cases there are very large differences between the mean for 2004 and position 2 from that same year. This may explain why the measured and modelled data do not agree well for some soils. Considering the good agreement for most paddocks however, our conclusion is that the model performs well for TOC and each of the pools for this system in this environment and should be transferable across most of the grazing systems in SE Australia.

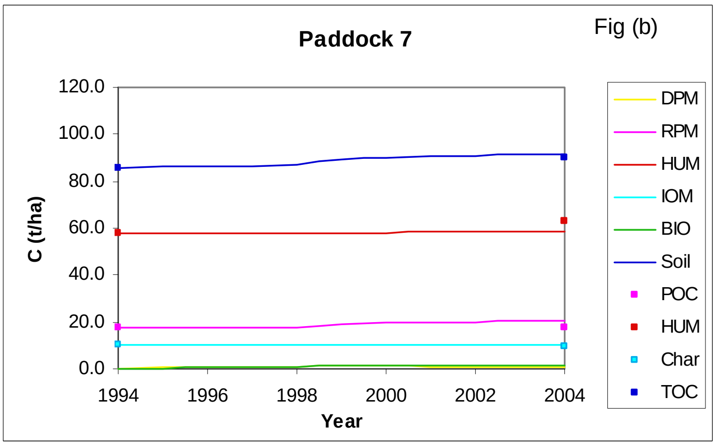
To determine what the long term impact of increasing and decreasing inputs to these systems may be, some long-term predictions using the model were run over a number of scenarios. Because the chemistry of the soils across the paddocks were very similar (Appendix 1), only one soil type was used. Previous work has demonstrated that clay content can have a significant influence on soil C dynamics but this is only significant at the sandy (<15% clay) end. Two paddocks were chosen, to represent soils low in TOC (paddock 7; fertiliser rate 8 kg P/ha.year and stocking rate 28.5 DSE/ha), and soils with a higher TOC level (paddock 15; fertiliser rate 33 kg P/ha.year and stocking rate 28.5 DSE/ha). On each of these, a low (4.4 t DM with 0.5 retention) and a high (8.5 t DM with 0.5 retention) input level was imposed. These values seemed reasonable to represent a long-term poor pasture input and a pasture input at the higher end. The runs were projected out for 300 years assuming a constant climate and input. Such long runs using average data are not realistic but do give valuable information on the ability of the soil to continue to sequester or lose soil C.

The impact of the low and high input scenarios on paddock 7 are given in Figure 22a and b respectively. From a starting point of 85.9 t C/ha in the top 30 cm, low input would result in a slow decline to a new equilibrium below 80 t C/ha (Figure 22a). This is such a small and slow change that it would not be measurable and would be highly susceptible to small changes in climate and input. High input to this soil, on the other hand, has a large impact on soil C and over 300 years, where soil C might be expected to increase to near 140 t C/ha, an increase of 63% of the original soil C level (Figure 22b). Half of this increase occurs within the first 50 years. Over this period an average of just over 0.5 t C/ha.year of soil C could be sequestered.

The impact of the low and high input scenarios on paddock 15 are given in Figure 22c and d, respectively. From a starting point of 116.6 t C/ha in the top 30 cm, low input would result in a more rapid decline than in paddock 7 to a new equilibrium below 89 t C/ha (Figure 22c). High input to this soil has a smaller impact on soil C and over 300 years, where soil C might be expected to increase to near 150 t C/ha, an increase of 18% of the original soil C level (Figure 22d) but still equivalent to 0.4 t C/ha.year of soil C that could be sequestered over the initial 50 years.

Normally, most of the C that can be sequestered as soil C occurs within the first 30-50 years. At Hamilton, the relatively cold climate slows this process down so that soil C sequestration has the potential to be significant over much longer periods. It also appears that under the climatic conditions, the soils are far from saturated in soil C and much higher soil C levels are possible. Clearly, if lower or higher inputs than those used in the modelling presented here were maintained, then losses and gains of soil C could be larger.





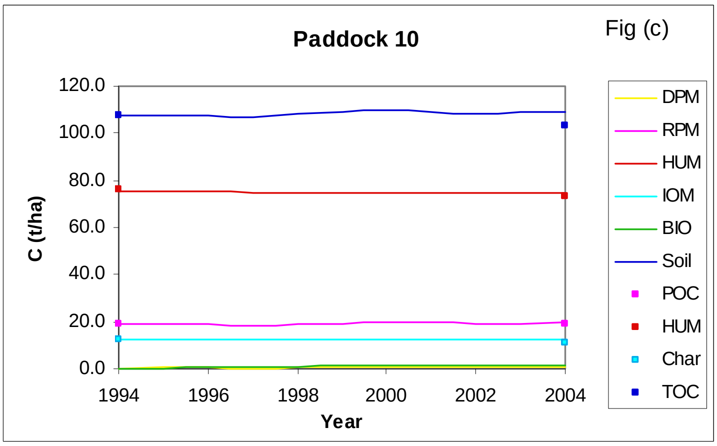
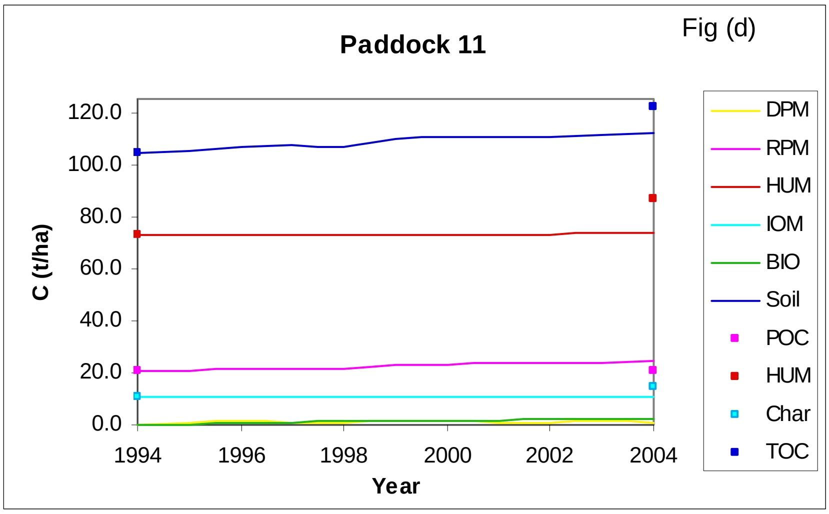
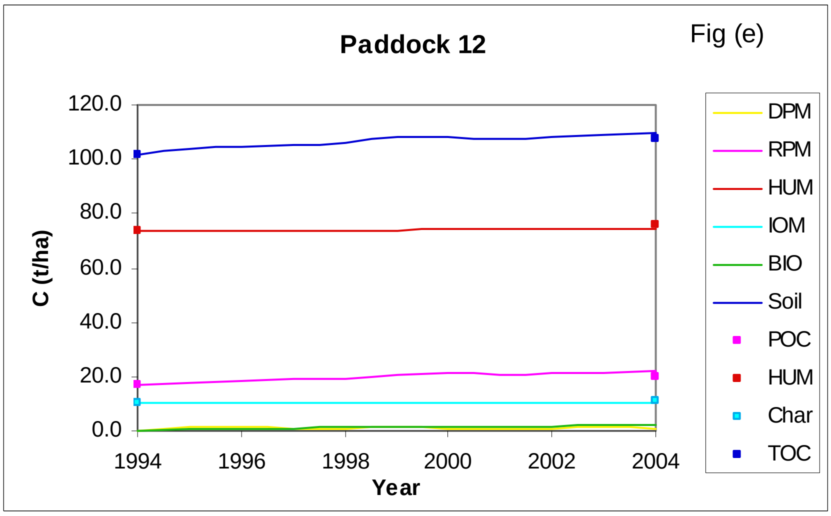
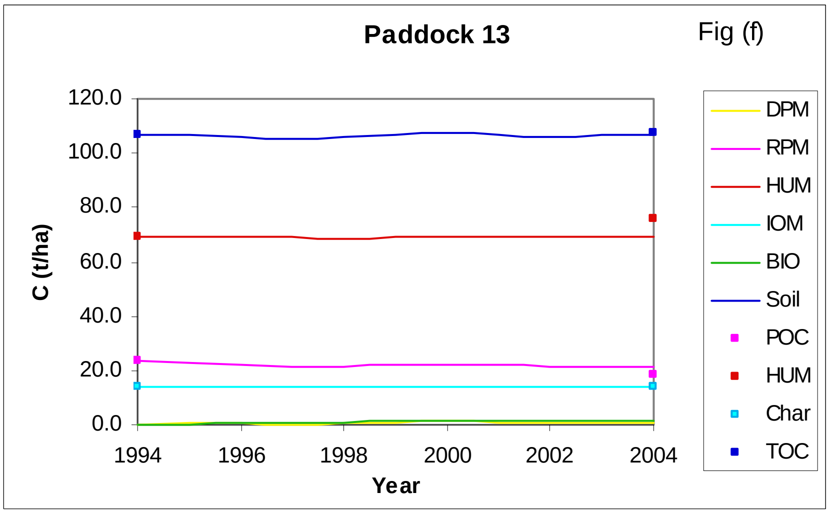


Figure 21. Modelled total organic C (TOC) and C pools (lines) for paddocks 6 (a), 7 (b), 10 (c), 11 (d), 12 (e), 14 (f), 15 (g), 16 (h) and 18 (i).
Points are measured data. Pools are: easily decomposable plant material (DPM); resistant plant material (RPM); humic material (HUM); inert organic matter (IOM); and microbial biomass (BIO).







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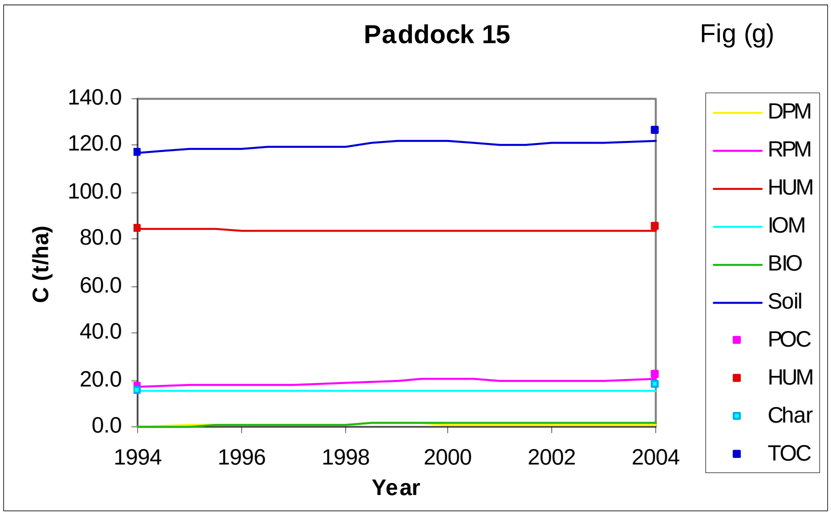

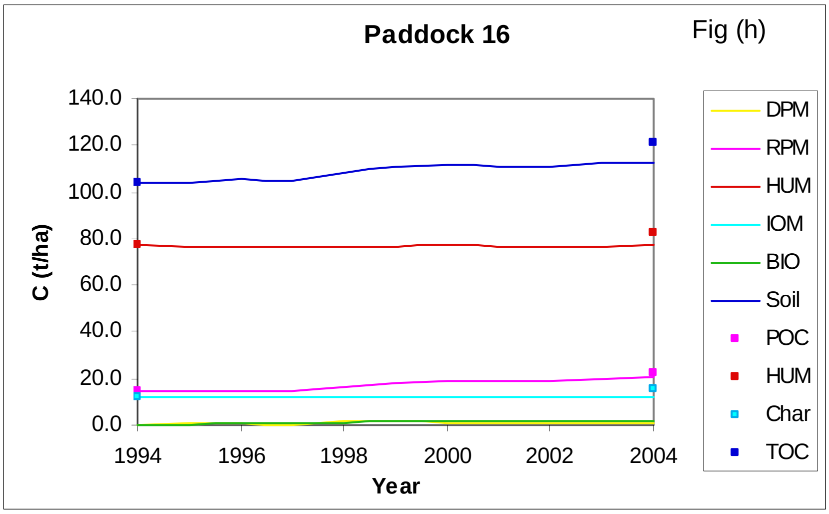

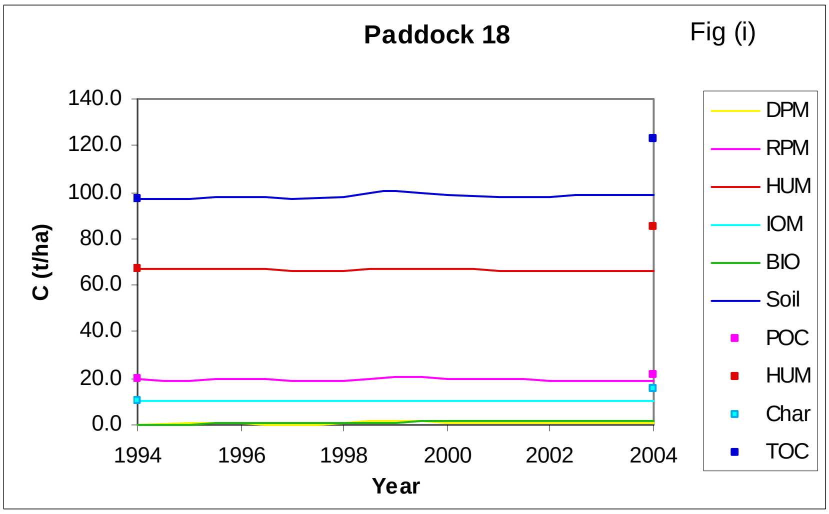

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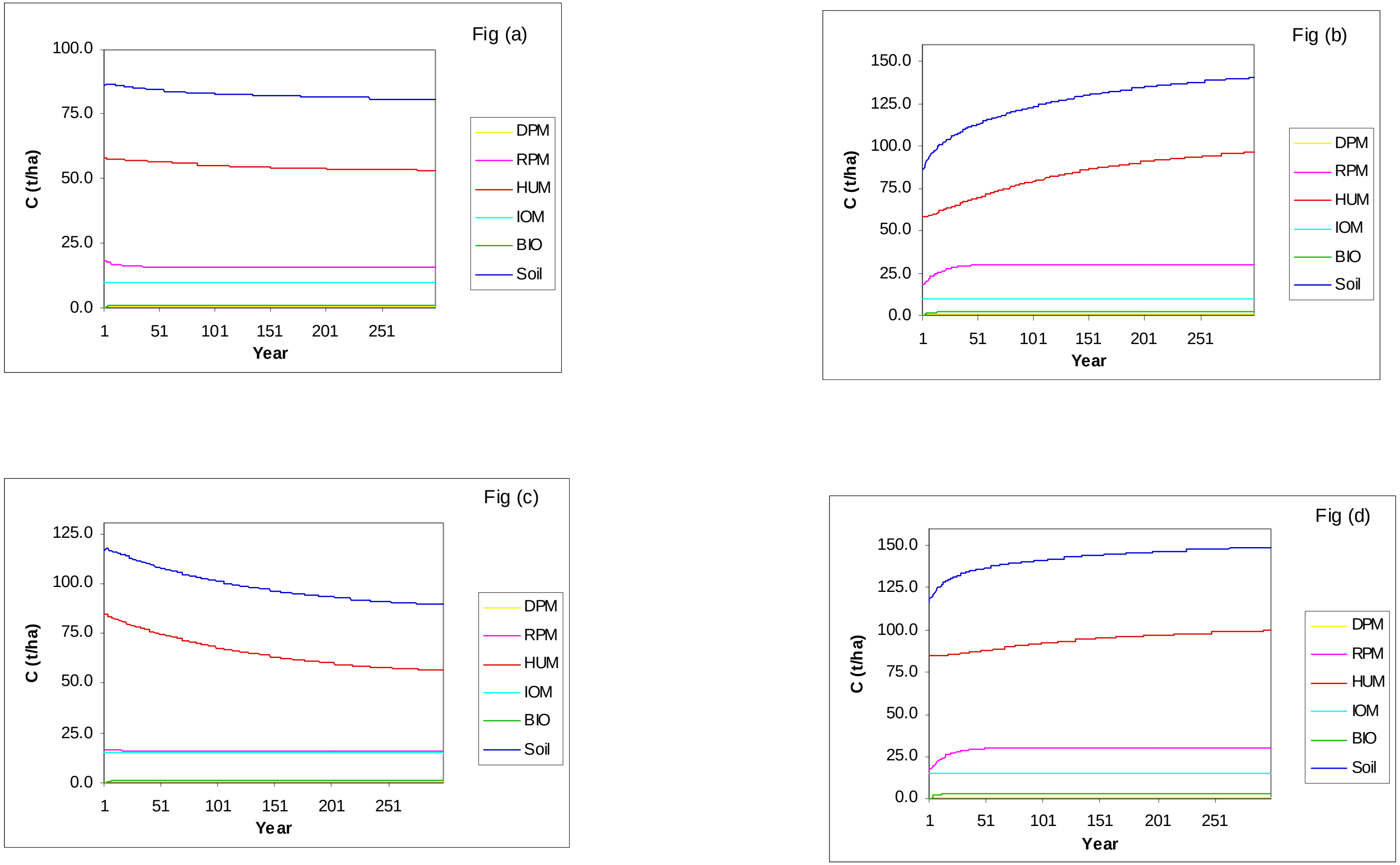

Figure 22. The impact of low inputs to paddocks 7 (a) and 15 (c) and high inputs to paddocks 7 (c) and 15 (d).
Pools are: easily decomposable plant material (DPM); resistant plant material (RPM); humic material (HUM); inert organic matter (IOM); and microbial biomass (BIO).

4.5 Concluding discussion

The animal and pasture productivity measurements in this study corroborate the trends observed in the experiment over the previous 25 years (Cayley *et al*. 1998; Saul *et al*. 1999). In general, fertiliser P application increased pasture growth and quality, allowing increased stocking rates, and resulting in greater animal productivity.

Systems with high plant productivity often show high rates of C sequestration (Lal 2004). There is a common perception that high animal productivity, because it depends on high plant productivity, will also promote C sequestration. With grazed pastures, however, the relationship between plant productivity and soil C is more complex. Fertilisation of pasture to increase plant production and quality tends to promote growth of tops at the expense of roots (increase shoot: root ratio), and produces higher quality plant residues (above- and below-ground) which decompose more quickly (Power 1977; Milchunas and Lauenroth 1992; Stewart and Metherell 1999; Wang *et al*. 2004). Also, high animal productivity usually depends on a high degree of pasture utilisation by the animals. This reduces the return of pasture residue and increases the proportion of residue returned as dung. At very high levels of pasture utilisation, poor ground cover may promote C loss through wind or water erosion.

Measurements made in this study represent effects accumulated over 25 years. Spatial variation of soil C was large and generally greater than variation due to the fertiliser and stocking rate treatments. After this time, stocking rate had no detectable effect on C sequestration. Increasing rates of P application contributed to a very slow increase in C sequestration, that would only be detectable at the 95% level if the higher application rates were sustained for more than 30 years.

The RothC model gave good prediction of soil C change over the previous 10 years of the experiment. The long-term modelling scenarios indicated that management resulting in low pasture production would lead to slow C loss, particularly in soils of initially high C content, but that it would be difficult to measure over periods of less than 50 years. Management resulting in high pasture production, on the other hand, would lead to long-term C gains. Under high productivity, C sequestration would increase by 0.4-0.5 t C/ha.year during the first 50 years, eventually leading to an increase of 18-63% in the top 30 cm, depending on the starting level of soil C. Such increases are significant when compared with C sequestration achieved by various management improvements to grasslands across the world. e.g. rates of C sequestration reported by Conant *et al*. 2001, who reviewed 115 studies examining the effects of improved grassland management on C sequestration potential, were between 0.1 and 3.0 t C/ha.year, with a mean of 0.5 t C/ha.year.

Farmers could contribute to increased soil C sequestration by maintaining high pasture productivity through using medium-high P applications and medium stocking rates. However, in the sheep-grazing systems and soil type used in this study, C sequestration in even the most productive systems is so slow that increases would not be detectable for 30-50 years. This long time-scale makes it difficult for individual farmers to influence soil C levels on their farms.

The grazing system in this study, using set-stocking, resulted in very high pasture utilisation for about 6 months of the year (around 1000 t DM/ha left standing) in all but the lowest rate of stocking. This level of utilisation, which is common in western Victoria between May and October, would strongly limit the ability of the pasture to fix atmospheric CO_2 through photosynthesis (Troughton 1977), and so would also limit the ability of the soil to sequester C. It may be hypothesised that less intense grazing during this period of slow pasture growth will result in faster soil C sequestration than was found in this study.

The effect of grazing management on soil C sequestration is likely to vary with seasonal conditions. In grasslands in the western United States, Schuman *et al*. 2005 found that, in years of normal rainfall, there was no difference in soil C sequestration under pastures managed under light and heavy grazing intensities; but when drought conditons prevailed for several years, heavy grazing resulted in large losses of soil C whereas light grazing did not. The heavy grazing in drought years had reduced CO_2 assimillation (photosynthesis), changed botanical composition, and reduced pasture biomass.

Carbon sequestered under pasture can be lost relatively rapidly when the soil is brought under cultivation (Combardella and Elliot 1994; Chan *et al*. 1995). At Hamilton, two long-established pastures (ryegrass-subterranean clover), on a similar soil type as used in this study, had total organic C contents of 3.9 and 5.0% in the top 10 cm. After 5 years of cultivation and cropping, organic C had decreased to 2.5 and 3.6%, respectively (P. Riffkin and P. Evans, unpublished data). Whilst part of this decrease in C concentration may have been due to redistribution of C with depth, these results suggest that substantial reductions in organic C would occur if the soils in this study were cultivated.

Although increased plant production may promote soil C sequestration, it is not possible to say whether this will result in a net reduction in CO_2 emissions until all C fluxes in the farming system are taken into account.

5 Success in Achieving Objectives

Objective (1), to determine the effects of P application and stocking rate on soil C sequestration in the high-rainfall zone of western Victoria, was achieved. After 25 years of treatment, neither stocking rate nor P application had a detectable effect on C sequestration. However, there was evidence that continued application of P at the higher rates would increase soil C sequestration in the long-term (more than 30 years).

Objective (2), to compare long-term trends in soil C in the different pasture systems using the RothC model, was achieved. The model gave good prediction of soil C change over the previous 10 years. The model predicted that management resulting in low pasture production would lead to very slow C loss that would be difficult to measure over periods of less than 50 years. Management resulting in high pasture production was predicted to increase C sequestration by 0.4-0.5 t C/ha.year during the first 50 years, eventually leading to an increase of 18-63% in the top 30 cm. It would, however, take around 30 years before this increased C sequestration could be detected.

Objective (3), to identify management practices that landholders may use to promote soil C sequestration, was partially achieved. This study demonstrated that maintaining a high level of plant productivity, through moderate-high P application and moderate grazing, is likely to increase soil C sequestration in the long-term. However, the slow rate of C sequestration means that individual farmers will have only limited ability to increase soil C. Apart from a general recommendation to maintain high pasture productivity, it is not possible to provide benchmarks in terms of using grazing management to change soil C content.

6 Impact on Meat and Livestock Industry – now & in five years time

The impact of increasing fertiliser levels and using appropriate stocking rates to increase per hectare productivity has been demonstrated both in this and past projects. Data presented in this project showed total yearly pasture production ranging from 4 t/ha at nil fertiliser up to 16 t/ha at the highest P application level of 33 kg P/ha. This increase in pasture production allowed a three-fold increase in stocking rate from 9 to 28.5 DSE/ha, associated with an increase in wool production from 55 to 133 kg wool/ha. The potential to increase pasture production and animal productivity through strategic fertiliser use and appropriate stocking rates is now well recognised by sheep and cattle producers in south-western Victoria (Saul *et al*. 2005). These authors estimated that the increased productivity was worth around $A85M/year to the high rainfall zone of southern Australia.

This study showed that the increased plant and animal production through P fertiliser use is generally consistent with a very gradual increase in soil C sequestration which, if maintained in the long-term (~50 years), would result in significant increases in soil organic C. The main effect on the meat and livestock industry within the next 5 years may be to give producers confidence that increasing plant and animal production in these grazing systems is not likely to be detrimental to soil C sequestration. Maintenance, and eventual improvement, of soil C levels can provide direct benefits to farmers in terms of soil structure and fertility, water retention, and reduced erosion. In order to realise the potential gains in C sequestration, however, land managers would need to take a long-term view.

7 Conclusions and Recommendations

This study confirmed that increasing fertiliser P application (0-33 kg P/ha.year) resulted in increased pasture growth and quality, allowed stocking rates to be increased (9-28.5 DSE/ha), and resulted in greater animal (wool) production.

Soil C sequestration was not affected by either P application or stocking rate, after more than 20 years of treatment. Simulations using the RothC model predicted that management resulting in low pasture production would eventually reduce C sequestration, and that management resulting in high pasture production would substantially increase C sequestration. Rates of C sequestration were so slow, however, that differences would not be measurable for 30-50 years.

In order to promote soil C sequestration in grazed pasture systems, our recommendation is to maintain a high level of plant productivity for as long as possible. Plant production can be maximised through appropriately matched P application and grazing regimes.

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9 Appendices

9.1 Appendix 1 - 2004 Soils

Soil	Depth (cm)	Paddock	P application (kg/ha.year)	Position	%OC as TOC	%OC as Char	%OC as POC	%Clay
SA-6	0-10	1	15	2	4.68	0.30	1.20	19
SA-7	10-20	1	15	2	2.13	0.34	0.44	16
SA-8	20-30	1	15	2	1.20	0.19	0.18	19
SA-11	0-10	1	15	3	5.01	0.25	0.97	17
SA-12	10-20	1	15	3	2.19	0.22	0.45	14
SA-13	20-30	1	15	3	2.18	0.16	0.21	13
SA-16	0-10	1	15	4	4.54	0.29	0.83	20
SA-17	10-20	1	15	4	2.12	0.26	0.36	18
SA-18	20-30	1	15	4	1.06	0.15	0.13	14
SA-21	0-10	1	15	5	4.55	0.29	0.96	20
SA-22	10-20	1	15	5	1.99	0.28	0.37	19
SA-23	20-30	1	15	5	1.05	0.12	0.13	16
SA-31	0-10	2	4	2	5.11	0.27	1.04	19
SA-32	10-20	2	4	2	2.02	0.26	0.35	16
SA-33	20-30	2	4	2	0.90	0.15	0.33	10
SA-36	0-10	2	4	3	5.17	0.36	1.14	22
SA-37	10-20	2	4	3	1.94	0.29	0.35	17
SA-38	20-30	2	4	3	0.79	0.10	0.16	10
SA-41	0-10	2	4	4	4.97	0.27	1.11	20
SA-42	10-20	2	4	4	1.61	0.18	0.30	16
SA-43	20-30	2	4	4	0.80	0.12	0.09	15
SA-46	0-10	2	4	5	4.72	0.30	1.02	18
SA-47	10-20	2	4	5	2.33	0.31	0.36	15
SA-48	20-30	2	4	5	1.04	0.16	0.15	12

9.1 Appendix 1 - 2004 Soils (cont)

Soil	Depth (cm)	Paddock	P application (kg/ha.year)	Position	%OC as TOC	%OC as Char	%OC as POC	%Clay
SA-56	0-10	3	23	2	5.61	0.33	1.06	23
SA-57	10-20	3	23	2	2.21	0.28	0.27	22
SA-58	20-30	3	23	2	1.14	0.20	0.16	19
SA-61	0-10	3	23	3	5.33	0.34	1.06	25
SA-62	10-20	3	23	3	2.29	0.29	0.28	22
SA-63	20-30	3	23	3	1.41	0.13	0.05	22
SA-66	0-10	3	23	4	4.50	0.27	0.97	18
SA-67	10-20	3	23	4	1.64	0.17	0.30	15
SA-68	20-30	3	23	4	0.72	0.09	0.22	9
SA-71	0-10	3	23	5	4.84	0.23	1.08	19
SA-72	10-20	3	23	5	2.37	0.26	0.43	17
SA-73	20-30	3	23	5	1.06	0.15	0.29	11
SA-81	0-10	4	4	2	5.57	0.39	1.06	25
SA-82	10-20	4	4	2	2.08	0.29	0.28	21
SA-83	20-30	4	4	2	1.21	0.19	0.18	20
SA-86	0-10	4	4	3	4.67	0.23	1.07	21
SA-87	10-20	4	4	3	1.93	0.16	0.34	18
SA-88	20-30	4	4	3	0.99	0.11	0.10	17
SA-91	0-10	4	4	4	4.23	0.25	0.98	20
SA-92	10-20	4	4	4	2.17	0.29	0.35	18
SA-93	20-30	4	4	4	1.08	0.20	0.20	16
SA-96	0-10	4	4	5	4.97	0.39	1.07	21
SA-97	10-20	4	4	5	2.55	0.34	0.39	18
SA-98	20-30	4	4	5	1.26	0.24	0.21	18

9.1 Appendix 1 - 2004 Soils (cont)

Soil	Depth (cm)	Paddock	P application (kg/ha.year)	Position	%OC as TOC	%OC as Char	%OC as POC	%Clay
SA-106	0-10	5	8	2	4.72	0.33	1.08	19
SA-107	10-20	5	8	2	2.13	0.24	0.34	16
SA-108	20-30	5	8	2	1.03	0.15	0.17	10
SA-111	0-10	5	8	3	5.10	0.25	1.20	20
SA-112	10-20	5	8	3	2.18	0.26	0.44	17
SA-113	20-30	5	8	3	0.93	0.17	0.23	13
SA-116	0-10	5	8	4	5.17	0.39	1.21	24
SA-117	10-20	5	8	4	2.62	0.35	0.46	23
SA-118	20-30	5	8	4	1.74	0.26	0.29	17
SA-121	0-10	5	8	5	5.17	0.38	0.99	26
SA-122	10-20	5	8	5	2.53	0.35	0.40	23
SA-123	20-30	5	8	5	1.41	0.23	0.19	22
SA-131	0-10	6	33	2	4.53	0.33	1.19	18
SA-132	10-20	6	33	2	2.25	0.27	0.40	16
SA-133	20-30	6	33	2	0.97	0.16	0.19	13
SA-136	0-10	6	33	3	5.22	0.34	1.11	20
SA-137	10-20	6	33	3	2.37	0.27	0.36	19
SA-138	20-30	6	33	3	1.45	0.18	0.22	32
SA-156	0-10	7	8	2	4.20	0.34	1.00	25
SA-157	10-20	7	8	2	1.83	0.29	0.32	22
SA-158	20-30	7	8	2	1.00	0.13	0.21	22
SA-161	0-10	7	8	3	4.17	0.27	0.94	18
SA-162	10-20	7	8	3	1.65	0.17	0.36	15
SA-163	20-30	7	8	3	0.84	0.09	0.16	9
SA-166	0-10	7	8	4	4.78	0.23	0.94	19
SA-167	10-20	7	8	4	2.01	0.26	0.31	17
SA-168	20-30	7	8	4	1.21	0.15	0.21	11
SA-171	0-10	7	8	5	3.77	0.39	0.65	25
SA-172	10-20	7	8	5	1.56	0.29	0.22	21

9.1 Appendix 1 - 2004 Soils (cont)

Soil	Depth (cm)	Paddock	P application (kg/ha.year)	Position	%OC as TOC	%OC as Char	%OC as POC	%Clay
SA-181	0-10	8	15	2	4.92	0.23	1.10	21
SA-182	10-20	8	15	2	1.78	0.16	0.38	18
SA-183	20-30	8	15	2	0.86	0.11	0.16	17
SA-186	0-10	8	15	3	4.74	0.25	1.07	20
SA-187	10-20	8	15	3	1.98	0.29	0.34	18
SA-188	20-30	8	15	3	1.32	0.20	0.20	16
SA-191	0-10	8	15	4	5.04	0.39	1.07	21
SA-192	10-20	8	15	4	2.52	0.34	0.43	18
SA-193	20-30	8	15	4	1.79	0.24	0.25	18
SA-196	0-10	8	15	5	5.11	0.33	0.96	19
SA-197	10-20	8	15	5	2.42	0.24	0.36	16
SA-198	20-30	8	15	5	1.22	0.15	0.18	10
SA-206	0-10	9	23	2	4.00	0.25	0.88	20
SA-207	10-20	9	23	2	1.81	0.26	0.33	17
SA-208	20-30	9	23	2	0.76	0.17	0.14	13
SA-211	0-10	9	23	3	4.56	0.39	1.07	24
SA-212	10-20	9	23	3	1.58	0.35	0.33	23
SA-213	20-30	9	23	3	0.97	0.26	0.17	17
SA-216	0-10	9	23	4	4.69	0.38	0.83	26
SA-217	10-20	9	23	4	2.31	0.35	0.31	23
SA-218	20-30	9	23	4	1.37	0.23	0.20	22
SA-221	0-10	9	23	5	4.68	0.33	0.95	18
SA-222	10-20	9	23	5	2.50	0.27	0.38	16
SA-223	20-30	9	23	5	1.42	0.16	0.21	13

9.1 Appendix 1 - 2004 Soils (cont)

Soil	Depth (cm)	Paddock	P application (kg/ha.year)	Position	%OC as TOC	%OC as Char	%OC as POC	%Clay
SA-231	0-10	10	0	2	5.16	0.34	1.16	20
SA-232	10-20	10	0	2	2.42	0.27	0.27	19
SA-233	20-30	10	0	2	1.07	0.18	0.21	32
SA-236	0-10	10	0	3	5.00	0.39	1.07	22
SA-237	10-20	10	0	3	2.20	0.30	0.28	21
SA-238	20-30	10	0	3	1.17	0.21	0.22	20
SA-241	0-10	10	0	4	5.41	0.35	1.08	25
SA-242	10-20	10	0	4	3.07	0.50	0.40	24
SA-243	20-30	10	0	4	1.41	0.20	0.27	29
SA-246	0-10	10	0	5	5.22	0.36	1.05	23
SA-247	10-20	10	0	5	2.54	0.28	0.45	20
SA-248	20-30	10	0	5	1.30	0.21	0.22	16
SA-256	0-10	11	15	2	5.12	0.45	0.85	28
SA-257	10-20	11	15	2	2.48	0.37	0.29	25
SA-258	20-30	11	15	2	1.50	0.25	0.31	23
SA-261	0-10	11	15	3	5.36	0.42	1.01	30
SA-262	10-20	11	15	3	2.55	0.36	0.40	28
SA-263	20-30	11	15	3	1.44	0.20	0.35	27
SA-266	0-10	11	15	4	5.20	0.33	1.00	24
SA-267	10-20	11	15	4	2.87	0.40	0.46	22
SA-268	20-30	11	15	4	2.76	0.53	0.32	22
SA-271	0-10	11	15	5	5.79	0.47	1.14	25
SA-272	10-20	11	15	5	2.95	0.41	0.46	24
SA-273	20-30	11	15	5	1.61	0.36	0.25	20

9.1 Appendix 1 - 2004 Soils (cont)

Soil	Depth (cm)	Paddock	P application (kg/ha.year)	Position	%OC as TOC	%OC as Char	%OC as POC	%Clay
SA-281	0-10	12	33	2	5.53	0.40	1.09	21
SA-282	10-20	12	33	2	2.34	0.37	0.41	16
SA-283	20-30	12	33	2	1.01	0.22	0.26	14
SA-286	0-10	12	33	3	6.09	0.40	1.22	27
SA-287	10-20	12	33	3	2.66	0.36	0.43	25
SA-288	20-30	12	33	3	1.50	0.20	0.20	22
SA-291	0-10	12	33	4	4.96	0.28	1.16	21
SA-292	10-20	12	33	4	2.41	0.26	0.50	18
SA-293	20-30	12	33	4	1.38	0.18	0.17	15
SA-296	0-10	12	33	5	5.56	0.43	1.16	23
SA-297	10-20	12	33	5	2.78	0.35	0.41	21
SA-298	20-30	12	33	5	1.49	0.23	0.21	20
SA-306	0-10	13	23	2	6.30	0.38	1.26	21
SA-307	10-20	13	23	2	2.60	0.41	0.46	17
SA-308	20-30	13	23	2	1.47	0.28	0.33	14
SA-311	0-10	13	23	3	5.85	0.44	1.02	26
SA-312	10-20	13	23	3	2.47	0.36	0.38	24
SA-313	20-30	13	23	3	1.72	0.28	0.20	23
SA-316	0-10	13	23	4	5.60	0.27	0.90	22
SA-317	10-20	13	23	4	2.50	0.34	0.40	21
SA-318	20-30	13	23	4	1.85	0.30	0.29	16
SA-321	0-10	13	23	5	5.30	0.44	1.25	24
SA-322	10-20	13	23	5	2.89	0.43	0.41	22
SA-323	20-30	13	23	5	1.58	0.33	0.23	19

9.1 Appendix 1 - 2004 Soils (cont)

Soil	Depth (cm)	Paddock	P application (kg/ha.year)	Position	%OC as TOC	%OC as Char	%OC as POC	%Clay

SA-331	0-10	14	0	2	5.24	0.45	0.96	25
SA-332	10-20	14	0	2	2.75	0.45	0.39	19
SA-333	20-30	14	0	2	1.56	0.32	0.39	17
SA-336	0-10	14	0	3	4.87	0.40	0.71	20
SA-337	10-20	14	0	3	1.94	0.27	0.26	18
SA-338	20-30	14	0	3	1.00	0.17	0.22	15
SA-341	0-10	14	0	4	5.05	0.50	1.01	26
SA-342	10-20	14	0	4	2.70	0.43	0.46	23
SA-343	20-30	14	0	4	1.89	0.33	0.26	36
SA-346	0-10	14	0	5	4.67	0.38	1.01	21
SA-347	10-20	14	0	5	2.23	0.35	0.40	15
SA-348	20-30	14	0	5	1.14	0.23	0.16	15
SA-356	0-10	15	33	2	5.69	0.49	1.12	23
SA-357	10-20	15	33	2	2.35	0.42	0.38	17
SA-358	20-30	15	33	2	1.27	0.30	0.44	17
SA-361	0-10	15	33	3	5.87	0.59	0.91	27
SA-362	10-20	15	33	3	3.26	0.50	0.43	25
SA-363	20-30	15	33	3	1.91	0.30	0.23	21
SA-366	0-10	15	33	4	6.01	0.63	1.15	26
SA-367	10-20	15	33	4	2.30	0.46	0.37	18
SA-368	20-30	15	33	4	1.09	0.26	0.27	15
SA-371	0-10	15	33	5	6.15	0.74	1.11	22
SA-372	10-20	15	33	5	3.58	0.72	0.40	19
SA-373	20-30	15	33	5	1.94	0.31	0.28	13

9.1 Appendix 1 - 2004 Soils (cont)

Soil	Depth (cm)	Paddock	P application (kg/ha.year)	Position	%OC as TOC	%OC as Char	%OC as POC	%Clay
SA-381	0-10	16	0	2	6.09	0.46	0.92	28

SA-382	10-20	16	0	2	2.98	0.38	0.36	25
SA-383	20-30	16	0	2	1.66	0.28	0.22	26
SA-386	0-10	16	0	3	5.34	0.44	0.93	23
SA-387	10-20	16	0	3	2.90	0.40	0.35	21
SA-388	20-30	16	0	3	1.67	0.31	0.29	14
SA-391	0-10	16	0	4	5.37	0.62	1.42	26
SA-392	10-20	16	0	4	2.82	0.49	0.49	24
SA-393	20-30	16	0	4	1.46	0.28	0.19	21
SA-396	0-10	16	0	5	5.29	0.51	1.21	26
SA-397	10-20	16	0	5	3.02	0.47	0.37	22
SA-398	20-30	16	0	5	1.39	0.32	0.26	17
SA-406	0-10	17	4	2	6.25	0.36	1.12	23
SA-407	10-20	17	4	2	2.75	0.36	0.35	23
SA-408	20-30	17	4	2	1.48	0.16	0.32	34
SA-411	0-10	17	4	3	6.56	0.53	1.10	27
SA-412	10-20	17	4	3	3.39	0.53	0.55	25
SA-413	20-30	17	4	3	1.70	0.25	0.27	25
SA-416	0-10	17	4	4	6.63	0.61	1.05	27
SA-417	10-20	17	4	4	3.18	0.60	0.53	29
SA-418	20-30	17	4	4	1.71	0.30	0.35	34
SA-421	0-10	17	4	5	6.36	0.55	1.00	23
SA-422	10-20	17	4	5	1.80	0.34	0.42	19
SA-423	20-30	17	4	5	2.28	0.40	0.35	19

9.1 Appendix 1 - 2004 Soils (cont)

Soil	**Depth (cm)**	**Paddock**	**P application (kg/ha.year)**	**Position**	**%OC as TOC**	**%OC as Char**	**%OC as POC**	**%Clay**
SA-431	0-10	18	8	2	5.14	0.37	1.08	23
SA-432	10-20	18	8	2	3.04	0.43	0.41	19

SA-433	20-30	18	8	2	1.70	0.31	0.22	21
SA-436	0-10	18	8	3	5.49	0.45	1.33	22
SA-437	10-20	18	8	3	2.88	0.50	0.43	21
SA-438	20-30	18	8	3	1.87	0.34	0.37	21
SA-441	0-10	18	8	4	6.15	0.55	1.21	24
SA-442	10-20	18	8	4	3.04	0.49	0.37	20
SA-443	20-30	18	8	4	1.29	0.29	0.14	14
SA-446	0-10	18	8	5	5.75	0.46	1.12	24
SA-447	10-20	18	8	5	2.71	0.44	0.42	20
SA-448	20-30	18	8	5	1.57	0.28	0.22	17

9.2 Appendix 2 - 1994 Soils

Soil (PVI-)	Depth (cm)	Paddock	P application (kg/ha.year)	Position	%OC as TOC	%OC as Char	%OC as POC	%Clay
1017	0-5	6	33	3	6.36	0.33	1.35	19
1018	5-10	6	33	3	4.30	0.34	0.65	19
810	10-22	6	33	3	1.80	0.27	0.23	15
840	22-43	6	33	3	0.84	0.15	0.11	15
1025	0-5	7	8	3	5.49	0.26	1.06	21
1024	5-10	7	8	3	3.69	0.30	0.63	19
820	10-19	7	8	3	2.05	0.30	0.25	17
842	19-48.75	7	8	3	0.86	0.20	0.22	12
1029	0-5	8	15	3	6.40	0.31	1.47	20
1030	5-10	8	15	3	3.76	0.31	0.81	20
834	10-28.5	8	15	3	2.48	0.42	0.37	24
838	28.5-51.75	8	15	3	1.00	0.16	0.13	17
1037	0-5	9	23	3	6.76	0.39	1.45	21
1038	5-10	9	23	3	4.80	0.47	0.77	22
850	10-18.75	9	23	3	1.33	0.25	0.22	24
851	18.75-53	9	23	3	1.66	0.23	0.13	26
1043	0-5	10	0	1	5.50	0.35	1.29	21
1044	5-10	10	0	1	4.01	0.41	0.71	22
862	10-17.25	10	0	1	2.20	0.36	0.28	21
863	17.25-37.5	10	0	1	1.35	0.19	0.24	20
1056	0-5	11	15	3	7.42	0.42	1.43	25
1057	5-10	11	15	3	4.25	0.41	0.76	23
874	10-11.25	11	15	3	3.07	0.40	0.42	24
875	11.25-44.75	11	15	3	1.27	0.20	0.29	24

9.2 Appendix 2 - 1994 Soils (cont)

Soil (PVI-)	Depth (cm)	Paddock	P application (kg/ha.year)	Position	%OC as TOC	%OC as Char	%OC as POC	%Clay
1068	0-5	12	33	3	7.35	0.37	1.42	24
1069	5-10	12	33	3	4.19	0.36	0.63	22
890	10-14	12	33	3	2.32	0.32	0.29	20
891	14-41.5	12	33	3	1.21	0.20	0.21	17
1076	0-5	13	23	3	7.14	0.39	1.63	22
1077	5-10	13	23	3	4.69	0.46	0.75	22
902	10-15.23	13	23	3	2.97	0.38	0.48	21
903	15.23-33.25	13	23	3	1.66	0.29	0.23	22
1082	0-5	14	0	3	6.23	0.42	1.28	21
1083	5-10	14	0	3	4.18	0.43	0.70	20
913	10-15.25	14	0	3	2.93	0.47	0.37	20
914	15.25-41.75	14	0	3	1.44	0.28	0.15	21
1091	0-5	15	33	3	6.50	0.51	1.15	22
1092	5-10	15	33	3	5.05	0.54	0.75	22
925	10-16.25	15	33	3	3.44	0.53	0.40	22
926	16.25-50.75	15	33	3	1.14	0.25	0.17	25
1100	0-5	16	0	3	6.09	0.46	1.23	26
1101	5-10	16	0	3	4.22	0.45	0.71	25
937	10-17.75	16	0	3	2.23	0.35	0.24	22
938	17.75-43.5	16	0	3	1.29	0.20	0.11	20
1106	0-5	17	4	3	5.17	0.55	0.72	25
1107	5-10	17	4	3	4.27	0.41	0.74	21
953	10-17.25	17	4	3	1.74	0.23	0.23	18
954	17.25-47	17	4	3	1.30	0.19	0.20	17
1114	0-5	18	8	3	7.25	0.51	1.44	24
1115	5-10	18	8	3	4.79	0.46	0.74	24
965	10-17.5	18	8	3	2.13	0.29	0.46	17
966	17.5-36.75	18	8	3	0.78	0.14	0.21	14

9.3 Appendix 3 - Climate data

9.3.1 Average Temperature (ºC)

Year	January	February	March	April	May	June	July	August	September	October	November	December
1994	15.7	18.5	16.2	13.7	10.8	8.8	8.9	7.9	9.1	11.8	12.3	17.5
1995	18.6	18.7	15.4	11.3	10.5	8.8	7.8	9.6	9.6	10.8	13.5	13.9
1996	17.4	17.0	16.4	12.2	11.3	8.8	8.5	9.1	9.9	11.9	12.3	14.1
1997	19.1	21.4	15.5	13.3	10.8	9.3	7.1	8.2	9.9	11.9	14.3	15.9
1998	18.5	17.8	16.6	11.9	10.3	7.8	7.1	9.3	11.3	11.1	12.5	16.5
1999	19.7	19.6	14.8	11.5	11.6	8.8	8.9	9.4	10.9	12.3	12.9	15.7
2000	17.4	21.1	17.0	13.7	10.6	8.7	8.9	9.0	11.0	12.0	16.7	17.0
2001	21.2	21.7	16.8	13.4	10.9	10.6	9.1	10.0	12.2	11.6	13.1	13.5
2002	16.4	17.4	17.0	15.3	11.8	9.6	9.1	9.2	10.7	12.4	14.7	17.0
2003	19.0	18.6	15.9	14.2	11.5	9.8	8.7	8.6	9.9	10.6	14.5	18.1
2004	15.7	18.4	15.8	14.0	10.8	9.6	8.5	9.7	10.8	13.0	14.2	17.3

9.3.2 Rainfall (mm)

Year	January	February	March	April	May	June	July	August	September	October	November	December
1994	41	28.6	1.8	55.2	62	68.6	60.6	52.2	64.2	64.8	58.4	25.8
1995	28	30.2	40	94	54.6	81.4	110.6	67.4	56.4	26.2	42	38.4
1996	43	21.4	32.6	47.2	8	94.6	125.8	114.8	113.8	46	22.6	25.6
1997	37.6	15.7	23.6	12.8	88	28.1	40.9	60.2	68	40.8	76.6	6.6
1998	19.8	30.2	12.2	77	38.8	104	72.8	34.9	89.7	65.5	47.1	29.3
1999	29.7	28.5	60.1	17.1	56.2	42	35.2	67.6	52.5	48.7	55.9	57.5
2000	17.7	12.6	11.6	69.7	93.8	48.5	68.1	59.2	105.1	92.3	23.1	25.9
2001	23.9	19.5	57.3	63.7	33.4	44.8	29	154.6	74.4	124.5	88.9	48.4
2002	29.1	29.1	20.8	28.2	45.4	74.3	95.5	50.6	64.6	52.7	48.4	47.3
2003	43.3	59.5	73	31.3	26.3	121.7	73.9	96.5	78.6	80.4	33.5	41.5
2004	45.4	30.2	64.5	37.4	43.1	126.2	75.6	95.8	47.7	31.6	54.4	44

9.3.3 Pan Evaporation (mm)

Year	January	February	March	April	May	June	July	August	September	October	November	December
1994	188.4	167.8	152.6	95.4	64.6	44.6	48	57.4	71	115.2	121.6	215.2
1995	200.2	200.8	148.6	72.4	43.8	34.2	39.8	69.3	65.6	96.6	135.6	158
1996	192.6	181.6	153.6	75.6	49.8	39.2	44.8	58.8	92.8	117	134.6	173.1
1997	247.4	205.6	145.2	89.8	43.9	38.9	40.6	54.6	70.2	115.6	139.1	188.9
1998	215.2	210.6	185	77.6	44	41.2	39.2	54	81.4	111.9	128.7	178.2
1999	229	185.7	144.2	75	64.6	40.3	57.3	56	87.4	117.6	140	199.6
2000	206.4	210.4	162	88	52	35.4	41.8	52	77.6	108	165	221.8
2001	263	200.6	153.6	90.2	44.4	36.2	27	63	82	109.2	134	163.4
2002	186.2	160.2	145.8	84	61	46	57.6	67.2	115.2	145.6	178.6	226.2
2003	254	168.4	142	88.4	49	44.4	43.6	59.4	86.2	104	174.2	208
2004	202.2	189	158.2	97.4	54.6	48	45.2	67.6	73.2	145.8	162.8	187.6

9.4 Appendix 4 - Initial Soil Carbon Pools

Paddock	Year	Site	POC	HUM	Char	TOC
6	1994	3	17.32	67.62	9.82	94.77
7	1994	3	17.89	58.03	9.97	85.89
8	1994	3	21.13	80.68	14.21	116.03
9	1994	3	16.65	78.85	11.67	107.18
10	1994	1	19.31	75.76	12.70	107.77
11	1994	3	20.70	72.79	10.77	104.26
12	1994	3	17.06	73.84	10.36	101.26
13	1994	3	19.49	81.38	13.56	114.43
14	1994	3	23.35	69.38	13.87	106.60
15	1994	3	16.85	84.42	15.34	116.61
16	1994	3	14.50	77.12	12.36	103.98
17	1994	3	14.47	68.64	11.06	94.16

9.5 Appendix 5 - Total Dry Matter and Stubble Retained (estimated)

	Paddock 6		Paddock 7		Paddock 10		Paddock 11		Paddock 12	
Year	TDM (t/ha)	Stubble Retained (t/ha)	TDM (t/ha)	Stubble Retained (t/ha)	TDM (t/ha)	Stubble Retained (t/ha)	TDM (t/ha)	Stubble Retained (t/ha)	TDM (t/ha)	Stubble Retained (t/ha)
1994	6.80	3.72	5.01	1.32	3.72	2.19	6.39	2.01	8.67	4.47
1995	9.65	6.24	5.44	1.39	4.25	2.39	9.27	4.39	8.30	3.60
1996	6.41	3.00	4.90	1.16	2.33	0.77	6.84	2.69	6.94	2.76
1997	8.18	4.87	5.35	1.28	6.23	4.51	5.87	1.20	7.52	2.96
1998	11.64	8.72	10.07	6.60	7.06	5.46	11.21	7.47	11.41	7.31
1999	5.65	2.51	7.12	3.39	5.28	3.72	7.82	3.46	6.34	1.95
2000	7.38	3.98	7.44	3.73	4.61	2.60	8.92	4.14	6.64	1.77
2001	7.96	4.72	7.32	3.43	4.78	3.09	8.04	3.62	7.97	3.55
2002	8.12	4.86	6.58	2.79	4.93	3.22	8.28	3.85	7.87	3.41
2003	7.91	4.67	6.78	2.97	5.03	3.34	8.14	3.78	7.81	3.39
2004	13.21	8.58	7.01	1.04	3.69	1.76	7.89	1.95	11.19	5.14

	Paddock 14		Paddock15		Paddock 16		Paddock 18	
Year	TDM (t/ha)	Stubble Retained (t/ha)	TDM (t/ha)	Stubble Retained (t/ha)	TDM (t/ha)	Stubble Retained (t/ha)	TDM (t/ha)	Stubble Retained (t/ha)
1994	5.03	2.23	10.24	4.32	3.57	2.02	4.12	2.26
1995	6.27	3.18	8.43	1.47	5.87	3.94	5.80	3.75
1996	3.92	1.09	9.07	3.85	2.74	0.88	1.80	0.84
1997	7.34	4.25	8.32	1.49	10.45	8.67	5.96	3.55
1998	9.89	6.91	13.59	7.91	10.29	8.57	9.68	7.26
1999	8.62	5.58	8.53	2.04	6.47	4.78	2.53	1.12
2000	7.95	4.41	7.15	0.03	5.23	3.24	4.31	2.32
2001	7.00	3.95	9.33	3.02	6.37	4.59	4.89	2.90
2002	7.28	4.20	9.20	2.83	6.77	4.95	4.99	2.99
2003	7.43	4.34	9.32	3.03	6.90	5.10	4.88	2.88
2004	5.02	5.02	9.65	2.40	4.15	1.41	3.36	2.18