IMPACT OF CARBON FARMING ON PERFORMANCE, ENVIRONMENTAL AND PROFITABILITY ASPECTS OF SHEEP AND BEEF FARMING SYSTEMS IN SOUTHLAND

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Abstract

As New Zealand's agriculture moves steadily towards implementing the Kyoto protocol, a better understanding of, and methods to reduce or offset, on-farm greenhouse gas (GHG) emissions become increasingly important. This study used the whole-farm system models FARMAX® and OVERSEER® to examine feed flow, nutrient balance, livestock emissions and profitability from sheep and beef farming scenarios in Southland. Nine farm scenarios defined by three levels of intensification across three proportions of cultivatable land to hill land were explored. In addition, within each of these simulated farms, two levels of forestry were included attempting to meet livestock emissions liability. All farms were equally sized and all feed was produced on-farm.

Increasing level of intensification resulted in greater amounts of sheep meat and beef, and to a lesser extent wool, produced per ha. This was associated with substantial increases in feed conversion efficiency (kg dry matter intake per kg animal product) and farm profit, although these results varied with land-use capability. Intensifying production was also associated with increased methane (CH_4) and nitrous oxide (N_2O) emissions at a farm level; CO_2 equivalents per stocking unit (kg CO_2-e/SU), however, was similar among all scenarios, and CO_2 equivalents per unit of production (kg CO_2-e/kg produced) decreased with intensification. Annual inventory-based emissions (CH_4 + N_2O) ranged from 2763 to 4434 kg CO_2-e/ha. Carrying capacity was minimally altered by adding forest blocks, with stocking rates being altered by less than 3%. Assuming credits from forestry accumulate at a rate of 22 tonnes CO_2-e/ha/yr, our exercise suggested that a 20-ha block of *Radiata* pines (*Pinus radiata*) planted in 2011would be able to meet liability for livestock emissions from the most intensified farming scenario until 2032. By then, additional mitigation or offsetting measures will have to be taken. Physical and financial indicators were largely in response to increased efficiency of pasture utilisation and maintenance of greater pasture quality. The achievement of high amounts of pasture production was a key driver of performance and financial efficiency, which also corresponded with an increase in GHG emissions. Reserving some area for forestry can meet liabilities for some time, but research must continue to find a secure and long-term solution.

Keywords: sheep and beef farming, intensification, forestry, livestock emissions

Introduction

In order to remain profitable and competitive in the global market, sheep and beef producers are increasingly in need of intensifying their production systems via a combination of improved efficiencies (i.e. increased animal performance from existing resources and greater use of inputs) (Mackay, 2008). To varying degrees, the diversity of landscapes and associated land-use capabilities (about half of New Zealand's agricultural land is in hill and steep lands) imposes constraints to some of these improved efficiencies. Farms with greater proportions of hill and steep lands often result in a greater proportion of spring surplus pasture growth lost to senescence, leading to greater losses of pasture quantity and quality. Strategies to improve the efficiency of nutrient utilization from temperate pastures, particularly those that lead to increases in winter carrying capacity (i.e. the timing of lambing and calving, the adjustment of stocking rates and N applications) are often essential to intensifying sheep and beef farming systems in New Zealand (White *et al*., 2010).

Intensification of these systems, however, has risen in synchrony with enhanced environmental concerns around pastoral farming. Agricultural GHG are responsible for almost half of New Zealand's total emissions, and reducing methane emissions from livestock and nitrous oxide emissions from grazed pastures are key components of any effort to reduce GHG emissions from pastoral agriculture. Recently, comprehensive reviews on mitigation strategies and technologies to reduce methane (Buddle *et al*., 2010) and nitrous oxide emissions (Luo *et al*., 2010) from grazing ruminants in New Zealand largely agree on the complex nature of these issues, the need for multiple mitigation approaches, and the lack of readily available, whole farm system strategies to be applied in the short term. These findings suggest that there is little that can be done immediately to reduce the bulk of livestock emissions without reducing stock numbers. However, reducing the number of ruminants currently being farmed in New Zealand is not a viable option given the economic importance that agriculture has to the nation (MAF, 2009), particularly as the global demands for meat are predicted to double by 2050 (FAO, 2010). Increasing soil C storage is one of the strategies that have been suggested to offset GHG emissions, but inherent difficulties in quantifying changes in soil C along with prevalent C-rich soils in New Zealand (Parsons *et al*., 2009) render this option as less viable in the short term.

Current opportunities to offset GHG emissions, therefore, rely largely on the establishment of forests, either on- or off-farm. Planting trees offers an opportunity to generate C credits via photosynthetic processes and C storage (Montagnini and Nair, 2004). Forestry C credits can then be entered into the Emissions Trading Scheme (ETS) to meet C liabilities while providing landowners with an option to combine sustainable land management and business risk management (Praat *et al*., 2010). Further, forestry was the first primary sector to enter the ETS (January 2008; MAF, 2010c) and is considered critical in meeting New Zealand's climate change goals. Under the ETS, forests planted after 1990 on land not previously in forest (i.e. Kyoto Protocol-compliant forests) are eligible to earn C credits. Given these challenges and opportunities, we examined the effects of intensification on nutritional, environmental, and financial aspects of sheep and beef farms in Southland using farm simulation models. These intensification levels were applied across different land-use capabilities, by varying the proportion of cultivatable land to hill land. In addition, within these farm scenarios, forestry was included in an attempt to meet livestock emissions liability.

Methods

Models Used

The whole-farm system models FARMAX® and OVERSEER® were used to examine the feed flow, nutrient balance, livestock emissions and profitability from sheep and beef farming scenarios in Southland. Farmax® Pro (version 6.3.74.1, www.farmax.co.nz) was used to simulate different sheep and beef Class 6 farming scenarios (Beef and Lamb New Zealand; BLNZ, 2010). Briefly, Class 6 farms (South Island Finishing-Breeding; BLNZ) comprise an extensive type of finishing operation, and frequently include some cash cropping, although not included in this exercise. Class 6 is the dominant sheep and beef farm class in the South Island (Manhire, 2010).

The biological feasibility of the stocking policies for these farms was determined using Farmax Pro; the required balance between whole-farm feed supply and feed demand was primarily obtained by adjusting the timing of lambing and calving to periods of maximum pasture growth and by using supplementary feeds (forage crops grown on farm). All farms were equally sized (effective area = 450 ha) and all feed was produced on-farm. The systems were assumed in steady state both in terms of opening and closing numbers of breeding ewes, cows and hinds, and corresponding body weights. Stocking unit (SU) was defined according to feed consumed on farm including supplemental feed [1 SU = 550 kg DM consumed, Farmax Pro; similar to the 6000 Mj ME/yr used by OVERSEER®, White *et al*., 2010).

The nutrient budget model OVERSEER® (version 5.4.9, www.overseer.co.nz) was used to examine some of the environmental impacts of intensification across the different land-use capability levels. The GHG model built within OVERSEER was developed as a decision support tool for use by pastoral farmers, and is increasingly being used as a tool to estimate on-farm GHG emissions throughout New Zealand (Wheeler *et al*., 2008). The methods used to estimate on-farm CH_4, N_2O and CO_2 emissions have been outlined elsewhere (Wheeler *et al*., 2008). Information on farm physical characteristics, stocks and management decisions from the Farmax Pro modelling exercise was exported and used to parameterize OVERSEER, including the 20-ha blocks of *Radiata* pines (J. Chrystal, personal communication). Blocks within farms included the flat to rolling and hill areas into perennial pasture, annual fodder crops, and corresponding blocks of trees.

Farming Scenarios

Nine farming scenarios were explored; these were defined by three levels of intensification (a base farm, a high intensification farm, a low intensification farm) across three land use capability levels. The levels of intensification were obtained by altering stocking rate, N application and reproductive efficiencies, and to a lesser extent, live weight (LW) gains. The land use capability was defined by varying the proportions of cultivatable land to hill land (90:10, 70:30, 50:50).

For each of the nine simulated farms, two levels of forestry (*Pinus radiata*) were included as a mean to meet livestock emissions liability. The levels were no trees and 20-ha blocks of *Radiata* pines located in the less productive hill areas. For the purpose of this modelling exercise, on-farm GHG emissions from livestock (CH_4 and N_2O) were of particular interest.

Background Information and Modelling Assumptions

Despite the substantial variation existing among sheep and beef farming systems in New Zealand, a representative farm needed to be modelled in this study. The base-farm scenario comprised a hypothetical 450-ha farm located in the Southland region representing a sheep and beef operation similar to that of BLNZ's Economic Service Survey Class 6 farm (BLNZ, 2010). Based on dry matter (DM) intake, the base farm comprised an animal species ratio of 76:20:3 (sheep:cattle:deer) including Romney ewes, Angus x Hereford cows, and Red deer. The number of animals carried through winter, supplementary feed grown, and N applied for all nine scenarios (three levels of land-use capability, three levels of intensification) are presented in Table 1.

Table 1. Key physical indicators for the nine farm scenarios tested (three land-use capabilities or rolling to hill ratios 90:10, 70:30, 50:50) and three levels of intensification (base, high, low). Output from Farmax Pro.

Rolling to hill		90:10			70:30			50:50	
Intensification	Base	High	Low	Base	High	Low	Base	High	Low
Pasture[1]	8257	8263	7089	7189	7340	6311	6166	6344	5562
Stocking, SU/ha	11.1	12.7	8.6	10.4	11.6	8.1	8.8	9.8	7.5
Sheep, wintered									
Ewes	2500	2500	2000	2300	2300	1840	1960	1960	1700
Ewe hoggets	675	650	574	643	555	565	554	465	507
MS[2] hoggets	35	35	137	33	30	158	28	25	152
Rams	40	40	35	38	37	34	32	30	31
Total sheep	3250	3225	2746	3014	2922	2597	2574	2480	2390
Cattle, wintered									
Cows	60	60	52	58	58	50	50	50	44
Calves	51	52	39	49	50	38	42	43	33
Older cattle	29	24	25	27	23	24	23	21	21
Bulls	3	3	3	3	3	3	3	2	3
Contract[3]	50	150	70	48	128	68	41	107	62
Total cattle	193	289	189	185	262	183	159	223	163
Deer, wintered									
Hinds	50	75	-	48	64	-	41	53	-
Fawns	38	60	-	36	51	-	31	42	-
Stags	2	3	-	2	3	-	2	2	-
Total deer	90	138	-	86	118	-	74	97	-
Crops									
Swedes, ha	28	28	28	22	22	22	16	16	16
Rye-corn, ha	4.0	-	-	3.0	-	-	2.0	-	-
Hay, large bales	300	300	200	300	300	200	300	300	200
N applied[4], ha	150	190	-	117	148	-	83	106	-

[1]Annual pasture production, kg DM/ha. [2]Mixed mob. [3]Contract grazing, dairy heifers. [4]N applied at an annual rate of 28 kg N/ha.

In this modelling exercise, the base and high intensification farms carried the same amount of breeding ewes and cows; however, the high intensification farms carried greater dairy heifer and deer numbers. The high intensification farm also carried a greater number of deer and cattle at the expense of ewes, with relatively more cattle finished on farm. A greater ewe lambing efficiency was reported for the high intensification farms; pregnancy and lambing efficiencies were 167 and 130%; 168 and 139%; 168 and 127% for the base, high and low intensification farms, respectively. The default Farmax hogget lambing value (74%) was used for the high intensification farm, whereas the value used for the base farm (45%) was obtained from the Farm Technical Manual, Lincoln University (2003); mid-point value used. Calving efficiency was slightly greater for the high intensification farm (87 vs. 85% and 75% for the base and low intensification farms, respectively). Fawning efficiency was also greatest for the high intensification farm (84 vs. 80%), whereas no deer were carried by the low intensification farm.

Annual pasture production was computed based on the pasture growth from the Northern Southland library of Farmax Pro (8809 kg pasture DM/ha for flat to rolling areas, 3853 kg pasture DM/ha for hill areas). Nitrogen was applied on similar proportions of the rolling areas across landscapes (~37% and 47% of the base and high intensification farms); no N was applied on the hill areas. N was applied on the base farms on 1st September, at a rate of 28 kg N/ha, with a mean response of 12 kg DM/kg N applied, whereas the application of N on the high intensification farms was partitioned into a spring (14 kg N applied, mean response 12 kg herbage DM/kg N applied) and an autumn application (1st March, 14 kg N applied, mean response 10 kg herbage DM/kg N applied) (Holmes *et al*., 2002).

For the purpose of this exercise, pasture from the flat to rolling areas was considered of medium, high and medium nutritive value for the base, high and low intensification farms, respectively, whereas all pastures from the hill areas were considered of medium nutritive value (Farmax Pro). Livestock on the high intensification farms consumed greater amounts of pasture and supplements than livestock on the other two farms, and along with a greater amounts of N applied, it allowed for greater stocking rates and achieved improved feed conversion efficiencies (Table 2).

Table 2. Performance indicators for the nine farm scenarios tested (three land-use capabilities or rolling to hill ratios 90:10, 70:30, 50:50) and three levels of intensification (base, high, low). Output from Farmax Pro.

Rolling to hill		90:10			70:30			50:50	
Intensification	Base	High	Low	Base	High	Low	Base	High	Low
Intake, t DM/ha									
Pasture	5.75	6.43	4.49	5.46	5.97	4.31	4.72	5.16	4.07
Supplements[1]	0.81	0.86	0.61	0.67	0.71	0.50	0.52	0.55	0.39
Total	6.56	7.29	5.10	6.13	6.68	4.81	5.24	5.71	4.46
FCE[2]	29.7	24.1	32.2	29.7	24.3	32.7	29.8	24.2	33.0
Species ratio									
Sheep, %	76	70	75	76	70	74	75	70	75
Beef, %	20	26	25	21	26	26	21	26	25
Deer, %	3	4	0	3	4	0	3	4	0

[1] From forage crops grown on farm and hay from excessive pasture growth. [2] Feed conversion efficiency, kg DM consumed/kg animal product.

Financial Outcomes

For each combination of land-use capability and level of intensification, financial pre-tax profit was calculated as the difference between total farm gross revenue (from Farmax Pro) and total farm expenses (from Farmax Pro and BLNZ Economic Service, Sheep and Beef Farm Survey, Forecast 2010-11). Total farm expenses included total working expenses, total standing charges, and depreciation. In order to calculate total working expenses, the sheep and beef farm survey data (BLNZ, Economic Service) provided for those items missing from Farmax Pro, on a per ha basis (i.e. wages, weed and pest control, lime, vehicle expenses, fuel, electricity, repairs and maintenance, cartage, and administration expenses). It was assumed that total labour required was 1.7 full-time employees (BLNZ, Economic Service, forecast 2010-11). Insurance was calculated as [(0.0011 x stock value) + $4000 from buildings)] (White *et al*., 2010). Rate values used (20.1 $/ha) were those of BLNZ, except for the low intensification farms (0.85 of the referred values). Similarly, corresponding depreciation values used (63.6 $/ha) were those of BLNZ, except for the low intensification farms ($20,000; White *et al*., 2010). Total working expenses plus standing charges [insurance, ACC levies and managerial salaries provided by BLNZ; plus interest on capital (livestock and feed)] accounted for total cash expenditure, according to the following:

Total cash expenditure = Total working expenses + Total standing charges

In addition, total farm expenses and farm profit before tax were calculated according to the following (BLNZ, Economic Service):

Total farm expenditure = Total cash expenditure + Depreciation

Farm profit before tax = Total gross income – Total farm expenditure

For the purpose of this modelling exercise, farm forestry costs (i.e. seedling trees, establishment, nutrition, tending, fire insurance, and logging and transportation costs) were not included.

Results and Discussion

Impact of Intensification, Land-Use Capability and Forestry on Animal and Financial Performance

Increasing level of intensification resulted in greater amounts of sheep meat and beef, and to a lesser extent wool, produced per hectare (Table 3). These findings were associated with substantial improvement in feed conversion efficiency (kg DM intake per kg animal product) and farm profit, although these results varied with land-use capability (Table 4). Caution is suggested, however, in the interpretation of the financial results; our results were obtained by assembling total gross revenue output from Farmax Pro (long-term pricing assumption) and most expense items from BLNZ Economic Service (Forecast 2010-11). Notwithstanding this limitation, the current modelling exercise provided for a measure of the change in financial variables associated with intensification and land-use capability. Further, financial pre-tax profit from BLNZ's Class 6 farm ($130.7/ha; BLNZ Economic Service, Forecast 2010-11) was similar to that of the base farm reported herein.

Table 3. Animal performance for the nine farm scenarios tested (three land-use capabilities or rolling to hill ratios 90:10, 70:30, 50:50) and three levels of intensification (base, high, low). Output from Farmax Pro.

Rolling to hill	90:10			70:30			50:50		
Intensification	Base	High	Low	Base	High	Low	Base	High	Low
Meat, kg/ha	164.2	239.9	115.5	153.3	216.9	106.5	130.2	183.8	97.6
Wool, kg/ha	41.7	49.3	32.0	38.5	45.0	29.8	32.8	38.3	27.8
Velvet, kg/ha	0.01	0.02	-	0.01	0.02	-	0.01	0.01	-

More lambs were finished and sold from the high intensification farms, with a greater proportion sold as prime (Table 4). Revenue from contract grazing was also greater for these farms, and had a considerable effect on total revenue. In addition to greater revenues, reduced expenditure associated with reduced feed costs led to greater farm profit for the high intensification farms across all land-use capability ratios. Farm pre-tax profit is essential to meet personal drawings, taxation, debt repayments, and purchase of capital items (MAF, 2010d).

Adding a block of trees to these farms had no effect on farm pre-tax profit. This was because the trees were planted in the lowest producing land, thus with minimal effects on pasture production and stock numbers. Furthermore, carrying capacity was minimally altered by adding forest blocks; stocking rates were altered by less than 3% (i.e. 7.5 to 7.3 SU/ha for the 50:50 land-use capability level).

Table 4. Financial indicators for the nine farm scenarios tested (three land-use capabilities or rolling to hill ratios 90:10, 70:30, 50:50) and three levels of intensification (base, high, low). Output from Farmax Pro and BLNZ Economic Service.

Rolling to hill		90:10			70:30			50:50	
Intensification	Base	High	Low	Base	High	Low	Base	High	Low
Gross Revenue, $/ha									
Sheep	527	743	332	481	679	297	409	580	281
Beef	130	217	127	126	195	123	106	165	109
Deer	33	53	-	31	45	-	27	37	-
Total	691	1014	459	638	919	420	542	783	390
Expenses, $/ha									
Total working expenses	355	362	272	331	339	259	302	313	245
Insurance	10	10	7	10	10	7	10	10	7
ACC Levies	6	6	6	6	6	6	6	6	6
Rates	20	20	17	20	20	17	20	20	17
Managerial Salaries	4	4	-	4	4	-	4	4	-
Interest	102	106	75	95	97	71	82	83	66
Total Standing Charges	142	146	106	136	137	102	122	123	96
Total Cash Expenses	497	508	378	466	476	360	424	436	341
Depreciation	64	64	44	64	64	44	64	64	44
Total Farm Expenses	560	572	423	530	540	405	488	499	38
Farm Profit (before tax), $/ha									
Without trees	131	441	36	109	379	15	54	283	4
With trees[1]	131	427	36	90	366	15	43	273	-5

[1]Adding 20-ha blocks of *Radiata* pines (costs associated with forestry are not included)

Improvements in production and financial indicators were largely associated with improved efficiency of pasture utilisation and maintenance of pasture quality. In agreement with previous findings (Cosgrove *et al.*, 2003; Coutinho *et al.*, 1998; Litherland *et al.*, 2002), the achievement of high amounts of pasture consumed per hectare is a key driver of performance and financial efficiency. Although annual forage production from pasture was similar for the base and high intensification farms at the 90:10 land-use capability (Table 1), it was slightly greater for the high intensification farm within the two remaining land-use capabilities. Sheep and beef farmers in New Zealand often tend to maximize pasture intake and only feed supplemental sources when pasture growth becomes insufficient to meet animal requirements (Moot *et al.*, 2007). Consequently, the grazing of swedes and consumption of supplemental hay were restricted to the cool season months (May to early October). In addition to annual pasture production, the shapes of the pasture production curves varied by level of intensification (Figures 1a and 1b). Greater pasture utilisation during the summer period was critical to increase carrying capacity. As a consequence, high intensification farms carried greater stock numbers, and were managed in a more intensive fashion than the base farm.

Figure 1a. Pasture cover (pasture herbage mass, kg DM/ha/month) for the three levels of intensification (base, high, low) and the highest level of land-use capability (90:10). Output from Farmax Pro.

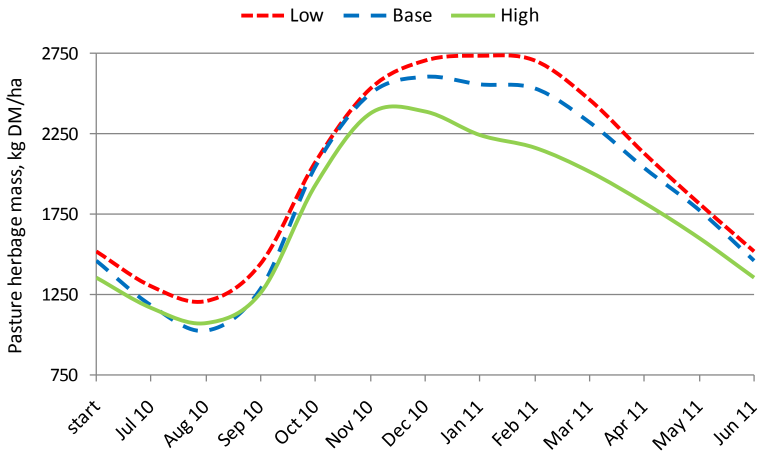
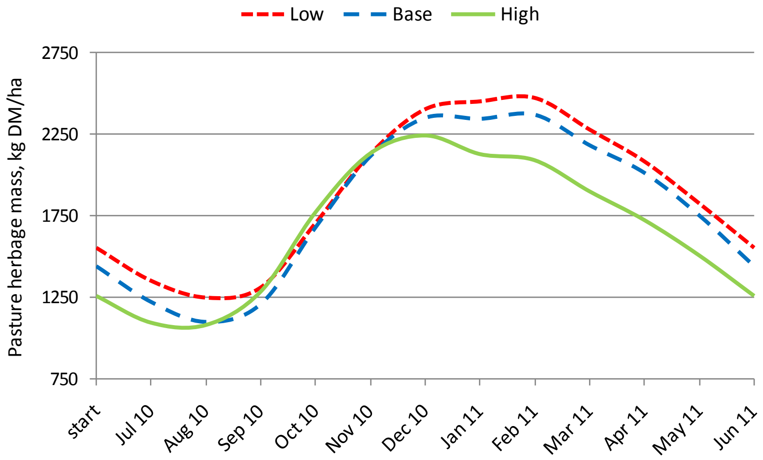


Figure 1b. Pasture cover (pasture herbage mass, kg DM/ha/month) for the three levels of intensification (base, high, low) and the lowest level of land-use capability (50:50). Output from Farmax Pro.



Impact of Intensification, Land-Use Capability and Forestry on the Environment

Intensifying production was also associated with increased methane (CH_4) and nitrous oxide (N_2O) emissions at a farm level; annual inventory-based emissions ($CH_4 + N_2O$) ranged from 2763 (low intensification, 50:50 land-use capability) to 4434 kg CO_2-e/ha (high intensification, 90:10 land-use capability) (Table 5). CO_2 equivalents per stocking unit (kg CO_2-e/SU), however, was similar among all scenarios, and CO_2 equivalents per unit of production (kg CO_2-e/kg animal product) decreased with intensification, consistent with previous findings (Aldock and Hegarty, 2006). Also in agreement with previous findings (Praat *et al*., 2010), emissions from livestock accounted for over 96% of total emissions.

Table 5. Greenhouse gas emissions for the nine farm scenarios tested (three land-use capabilities or rolling to hill ratios 90:10, 70:30, 50:50) and three levels of intensification (base, high, low). Output from OVERSEER.

Rolling to hill	90:10			70:30			50:50		
Intensification	Base	High	Low	Base	High	Low	Base	High	Low
Annual emissions from livestock, kg CO_2-e/ha									
CH_4	2789	3132	2114	2650	3009	2093	2386	2604	1982
N_2O	1146	1302	834	1080	1242	826	967	1066	781
Total	3935	4434	2948	3730	4251	2919	3353	3670	2763
Annual emissions from livestock, whole farm, t CO_2-e									
Total	1771	1995	1327	1679	1913	1314	1509	1652	1243
CH_4, % of total	71	71	72	71	71	72	71	71	72
Other annual emissions, whole farm, t CO_2-e									
CO_2 emissions	59.0	63.5	43.2	56.3	59.9	43.7	53.1	55.4	34.2
Total emissions									
kg CO_2-e/SU[1]	371	369	366	375	374	372	381	380	376
kg CO_2-e/kg AP[2]	19.7	15.8	20.6	20.1	16.7	22.1	21.3	17.1	22.6

[1]kg CO_2-e per unit of stock. [2]kg CO_2-e per kg animal product (kg carcass, net growth + kg wool, net growth).

Recently, research on the implications of intensification has shifted from a more production-based focus to a more environmental-based focus (Mackay, 2008; White *et al.*, 2010). Further, in order to address renewed international commitments and advance towards a low C economy, New Zealand has introduced several schemes under the Climate Change Response Act of 2002. Among these schemes, the moderated ETS, introduced in late September 2009, proposed a number of changes to the existing New Zealand ETS. Under the moderated ETS (and its predecessor), a price-based system for GHG emissions, agriculture will be required to purchase C credits in order to meet emissions liabilities (MAF, 2010a). Among the changes proposed, the entry date for the agricultural participants will be January 1st, 2015 (a two-year delay from its predecessor ETS), along with voluntary and mandatory reporting of emissions from January 1st 2011 and 2012, respectively (MfE, 2009).

In this study we examined the effects of adding 20-ha blocks of *Radiata* pines attempting to meet livestock emissions liability. These blocks of trees were assumed to be planted in January, 2011. Although still under scrutiny (the domestic ETS is currently being reviewed by an independent panel), for this exercise an initial liable value of 10% of livestock emissions and an incremental value of 1.3% per annum of liable livestock emissions from 2016, were assumed. Focus was placed on the most intensified farming scenario with the greatest GHG emissions at a farm level (high intensification, 90:10 land-use capability; 1995 t CO_2-e, Table 5). Carbon stock in above- and below-ground harvest residues for *Radiata* pines was estimated at 390 t CO_2-e/ha at a harvest age of 35 years (MAF, 2010b). Residual, post-harvesting C stock includes woody litter on the forest floor (i.e. branches, stumps) and in roots (MAF, 2010b).

Figure 2a. Annual carbon stocks from forestry (a 20-ha block of *Pinus radiata*) and C emissions from livestock at a farm level (high intensification, 90:10 land-use capability).

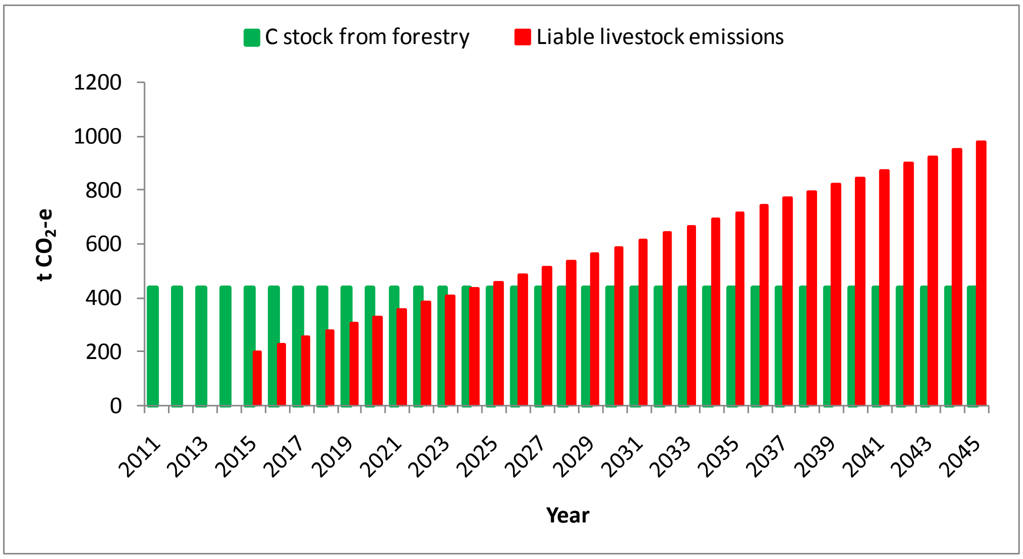
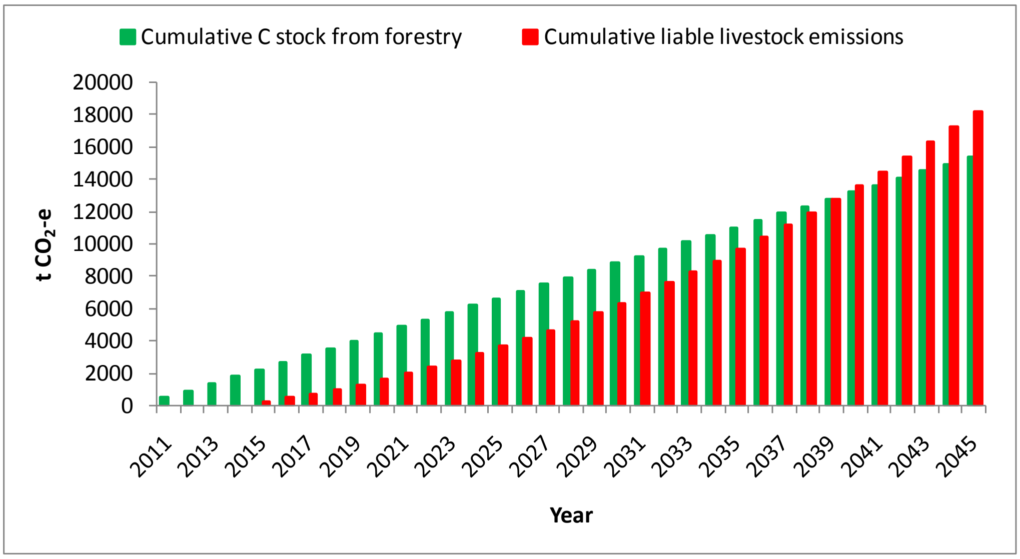


Figure 2b. Cumulative C stocks from forestry (a 20-ha block of *Pinus radiata*) and cumulative C emissions from livestock at a farm level (high intensification, 90:10 land-use capability).



Assuming credits from forestry in Southland accumulate at a rate of 22 tonnes CO_2-e/ha/yr, by 2024 annual liable livestock emissions will be almost equal to annual forest C sequestration from a 20-ha block of *Radiata* pines (Figure 2a). Within the same framework, by 2028 cumulative forest C sequestration will be equivalent to the maximum post-harvest residue (i.e. 390 t CO_2-e/ha x 20 ha = 7800 CO_2-e) (Figure 2b). A 20-ha block of *Radiata* pines planted in 2011 will be able to meet liability for livestock emissions from the most intensified farming scenario until 2032. At this point in time (a *Pinus radiata* stand 22 years old), cumulative liable livestock emissions will be almost equal to maximum risk-free forest C sequestration (i.e. 7800 CO_2-e). Beyond 2032, the balance between credits and livestock emissions continues to be positive (until 2038) but cumulative C emissions continue to be greater than the C stocked in post-harvest residues.

At harvest, a relatively large proportion (~57%) of the C credits will have to be surrendered to account for C removal from the land either as timber or as decayed forest residues. Whether or not net losses occur at the harvest stage will depend on the relative values of C and timber, as well as the C credit situation (i.e. credits sold or acquired prior to harvest) and time period, as outlined by Praat *et al*. (2010). Within the ETS framework, forestry investments have the potential to address the overall value of sheep and beef farming operations by protecting the farm business from liability costs. However, it offers an opportunity to offset livestock emissions over the medium term only. In the meantime, solutions to livestock emissions must be developed and implemented at a farm level.

Physical and financial indicators were largely in response to increased efficiency of pasture utilisation and maintenance of greater pasture quality. In our study, the achievement of high amounts of pasture production was critical in the achievement of greater carrying capacity, animal performance and financial efficiency, which also corresponded with an increase in GHG emissions. Reserving some area for forestry can meet liabilities for some time, but research must continue to find a secure and long-term solution.

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