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Some regional implications of reductions in greenhouse gas emissions from Australian broadacre agriculture

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The effect of reductions in greenhouse gas emissions on regional commodity supplies and profits in Australian broadacre agriculture is estimated using a mathematical programming model disaggregated on a state level by pastoral, wheat–sheep and high rainfall zones. The marginal cost of reductions in greenhouse gas emissions from Australian broadacre agriculture was estimated by progressively reducing the total greenhouse gas emissions from the unconstrained level. This is achieved, within the model, by altering the quantities of commodities supplied in regions without changing technologies. The marginal costs of reducing greenhouse gas emissions from agriculture as against the rest of the economy are discussed. Estimates of changes in farm cash incomes caused by an emissions tax sufficient to reduce greenhouse gas emissions by 20 per cent are presented.

An estimate of reductions achievable by means of technical options, including changes to grazing management and cultivation practices, suggests that some reduction could be achieved at a relatively low cost in this way.

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Introduction

The greenhouse effect is the natural warming of the Earth and its atmosphere which occurs through the partial entrapment of radiation reflected from the Earth's surface by greenhouse gases in the atmosphere. The extension of this effect beyond that observed naturally as a result of anthropogenic greenhouse gas emissions is referred to as the 'enhanced' greenhouse effect.

It is widely held that significant changes in climatic variables may occur within the next few decades as a result of increased anthropogenic emissions of greenhouse gases. However, the timing and nature of climatic changes is unknown at present.

Concern over such changes has provoked government action both domestically and internationally. In Australia, an interim planning target has been adopted which requires the stabilisation of greenhouse gas emissions at 1988 levels by the year 2000, plus a further 20 per cent reduction by 2005. However, meeting the target is contingent on there being no net adverse economic impacts nationally or, in the absence of similar action by other major greenhouse gas producing countries, on Australia's trade competitiveness. Internationally, 160 countries have signed the United Nations Framework Convention on Climate Change which is aimed at achieving the stabilisation of greenhouse gas emissions at a level that would prevent dangerous anthropogenic interference with the climate system.

The results of a regional analysis of the economic effects of policy actions and of different management techniques to reduce greenhouse gas emissions from Australian broadacre agriculture are presented in this paper. The research is aimed at assisting the development of greenhouse gas response strategies for the Australian agricultural sector within individual states. The analysis involves the use of individual farm data from ABARE's Australian agricultural and grazing industries survey in a mathematical programming model framework.

The mathematical programming model extends the ABARE analysis previously carried out at an aggregate level (Anandajayasekeram, Hall, MacAulay, Barry and Collmore 1992) to a detailed regional analysis for the major segment of Australian agriculture included in the broadacre industries; that is, sheep, cattle and field crops. The disaggregated model allows analysis at a regional level so that estimates are much more specific for the broadacre agricultural sectors for each state and it is possible to identify states and regions which gain or lose for each possible policy option examined.

Description of the regional greenhouse model

The regional model is based on farm level data collected in ABARE's Australian agricultural and grazing industries survey (ABARE 1993) using supply response data derived in Kokic, Beare, Topp and Tulpulé (1993). These estimates are used to derive cost functions for each product in each region. The model maximises profit derived as the difference between revenue and estimated cost subject to constraints on land area and greenhouse gas emissions.

Variables of the model are:

Z farm profit

Q_{ir} sales of commodities in regions

E_{gr} emission of greenhouse gases, by region

GW_r greenhouse gas emissions, by region

Parameters of the model are:

w_r number of farms in each region

a_r fixed cost of average farm in each region

i commodity

r region

g greenhouse gas

b_{ir} multiplicative cost coefficient, by commodity and region

μ_{ir} exponential cost coefficient, by commodity and region

s_{ir} additive cost adjustment, by commodity and region

l_r average land area per farm

c_r intercept of land use equation

h_{ir} coefficient of land use, by commodity and region

ge_{ir} greenhouse gas emissions, by commodity and region

eq_g global warming potential of greenhouse gases (CH_4, N_2O, etc).

The revenue is a simple summation of sales of commodities multiplied by price.

$$\text{Revenue} = \sum_{ir} (w_r \, P_{ir} \, Q_{ir}).$$

The cost and land area functions in Kokic et al. (1993) are estimated at an individual farm level. These are combined into regional estimates by averaging the coefficients to obtain coefficients for an average regional farm and weighting the derived costs by the number of farms in the region. The cost functions are of the following form:

$$Cost = w_r\,(a_r + \textstyle\sum_{sr} b_{ir}\, Q_{ir}^{\;\mu_{ir}}).$$

The objective is to maximise net revenue subject to the land constraint so that the cost functions, which subsume all the resource and constraint data for the individual survey farms, drive the levels of sales of each commodity by regions. Some error will be caused by the aggregation of the individual farm cost data to a regional level. This is corrected for by adding a cost component derived from the shadow price per unit of each commodity sold in each region from a model run where sales were constrained to the actual level. The modified cost function is:

$$Cost = w_r[a_r + \textstyle\sum_{ir}(bir\; Qir^{\mu} \;+ s_{ir}\, Q_{ir})].$$

The objective function of the model is thus:

max Z =

$$\max Z = \textstyle\sum_r (w_r P_i Q_{ir}) - w_r[a_r + \textstyle\sum_{ir}(bir\; Qir^{\mu_{ir}} \;+ s_{ir} Q_{ir})]$$

Total land use in each region is constrained to be less than or equal to total area available in each region:

$$(c_r + \sum_i h_{ir}\, Q_{ir}) \leq L_r.$$

Emissions of carbon dioxide, methane and nitrous oxide are defined for each commodity sold. However, wool, mutton and lamb are joint products whose greenhouse gas emissions cannot be specified on a commodity basis. The proportions of the three commodities are therefore fixed and emissions are all credited to wool:

$$E_{gr} = \sum_i ge_{ir}\, Q_{ir}$$

and

$$GW_r = \sum_g E_{gr}\, eq.$$

The effects of the different gases on global warming were standardised using the 100 year global warming potentials provided by the Intergovernmental Panel on Climate Change (1992). In addition to direct effects of greenhouse gases on global warming potential there are indirect effects caused by interaction with other gases, including water vapour, in the atmosphere. The Intergovernmental Panel on Climate Change (1992) has not yet reached a conclusion regarding the size of the indirect global warming potential of methane. Notwithstanding this, tentative estimates including the indirect effects of methane have been made here. However, the main focus of the analysis is on direct effects. This contrasts with the analysis undertaken by Anandajayasekeram et al. (1992), where estimates of 20 year global warming potentials were used and the indirect effects were included, resulting in much larger coefficients for methane (methane in Anandajayasekeram et al. 1992 has a global warming potential of 63 against 11 for direct effects and 22 for direct and indirect effects in this paper).

The set of commodities (*i*) comprises wool, lamb, mutton, beef, wheat, other crops and other enterprises. The last is an aggregation of revenue items such as sharefarming income that account for the part of broadacre farm revenues not accounted for by the individual commodities covered in this analysis.

The regions of the model (*r*) are defined by the disaggregation of ABARE farm survey zones by state. There are three zones, the pastoral zone with extensive grazing in the arid inland areas of Australia, the wheat-sheep zone where mixed cropping and grazing are possible and the high rainfall zone along the coast that is mainly a grazing area too wet for broadacre cropping (ABARE 1993). These three zones, combined with the six states and the Northern Territory, give a total of 16 regions listed below with selected data in table 1.

There is potential for further disaggregation of the regional model into smaller regions or by farm types to reduce the variation within regions. This level of aggregation was selected to provide estimates at both a state and production zone basis as well as for the individual regions.

Greenhouse gas emissions from agricultural activities are modelled as emissions per unit of commodity sold. In addition, allowance is made for the emissions from areas of improved and native pastures. The emission data per unit of sales are derived from estimates of emissions per head of livestock and per hectare of crops. These are summarised in table 2. Only anthropogenic emissions are represented in this table. For

Table 1: Model regions: selected data averages per farm, 1991-92

	Area	Sales					
		Wool	Beef	Sheep	Lamb	Wheat	Other
	ha	kg	no	no.	no	t	t
New South Wales							
Pastoral	22 409	24 423	52	962	183	101	14
Wheat–sheep	1 545	9 345	94	410	246	194	96
High rainfall	699	6 147	104	250	175	9	8
Victoria							
Wheat–sheep	799	5 570	19	221	232	267	156
High rainfall	335	5 014	69	213	99	1	12
Queensland							
Pastoral	57 982	21 589	415	703	39	0	2
Wheat–sheep	3 685	3 510	173	115	27	89	119
High rainfall	4 993	3	168	0	0	11	18
South Australia							
Pastoral	82 276	25 149	120	912	182	120	20
Whea–sheep	1 254	7 196	7	284	174	361	315
High rainfall	873	11 920	104	597	401	32	66
Western Australia							
Pastoral	227 420	24 668	336	92	0	0	0
Wheat–sheep	2 454	19 100	26	695	104	671	239
High rainfall	652	10 278	75	460	130	7	55
Tasmania							
High rainfall	887	10 641	100	431	310	2	38
Northern Territory							
Pastoral	326 617	10	1 085	0	0	0	4

the purposes of this analysis, emissions from sources such as fires and termites are assumed to be part of the natural background emissions. This assumption is satisfactory if the analysis involves marginal shifts from one form of agricultural land use to another. However, if large areas of agricultural land were to be abandoned the effect on greenhouse gas emissions may not be adequately represented by the coefficients used in this analysis. Some increase in wild and feral animals could be expected on abandoned areas even though the total population of all animals would be lower than at present if artificial watering points were also removed. The emissions from these animals and any other increased emissions from abandoned areas would reduce the benefits predicted by the model from reductions in agriculture. Hence, where large reductions in agricultural area

Table 2: Assumed greenhouse gas emissions from crops and stock

	Unit	Carbon dioxide	Nitrous oxide	Methane
Sheep	kg / head	0	0.33	7.20
Wheat	kg / ha	918	0.25	0
Cattle	kg / head	0	2.61	49.37
Other crops	kg / ha	918	0.25	0
Improved pasture	kg / ha	-993	0.33	0
Native pasture	kg / ha	0	0	0
Pastoral grazing	kg / ha	0	0	0

are predicted by the model there may be a tendency to underestimate the cost of achieving net reductions in greenhouse gas emissions.

Base run of the model

Greenhouse gas emissions are not limited in the base run of the model which should reproduce the actual situation in broadacre Australian agriculture at current prices of agricultural commodities. This is in fact the case, with the results of the base run of the model being identical for all regions and commodities to the data presented in table 1.

Simulation of regional impacts

Reductions in greenhouse gas emissions from Australian broadacre agriculture are simulated under two different policy scenarios. The first scenario involves the imposition of a tax on all greenhouse gas emissions from broadacre agriculture to achieve a specified emissions level. Emission levels derived from the model are constrained at an industry level to estimate the level of tax needed to achieve a given reduction in greenhouse gas emissions. This allows determination of the marginal cost of emissions reduction and the associated changes in production.

Given that the model is partial, the impact of tax revenue distribution throughout the economy cannot be simulated, as is possible with the ORANI model. The emphasis of this model is on its representation of regional and industry specific responses. However, it is likely that at least some proportion of the revenue would be returned to the agricultural sector. Possible further development of this model could involve the incorporation of a simple model of the Australian economy which gauges the effects of tax redistribution. No account is taken of the administrative and monitoring costs of the tax in this scenario.

The second scenario involves a policy aimed at encouraging the adoption of management techniques for crops and livestock which reduce greenhouse gas emissions. These include changes in cultivation practice to reduce the loss of soil carbon, and changes in ruminant nutrition to reduce methane emissions.

Greenhouse gas emissions from the production and use of energy are estimated to have increased by almost 8 per cent between 1987-88 and 1990-91 (Bush, Leonard, Bowen, Jones, Donaldson and Ho Trieu 1993). In contrast, the estimated emissions from Australian broadacre agriculture have been roughly constant since 1985 at about 62 million tonnes of carbon dioxide equivalent which amounted to 15 per cent of total greenhouse gas emissions from Australia in 1987-88 (Ecologically Sustainable Development Working Group Chairs 1992) (figure 1). Thus, the effective historical base for calculating emission reductions is less important for broadacre agriculture than for the energy sector.

Tax on greenhouse gas emissions from broadacre agriculture

As noted above, the tax on greenhouse gas emissions is derived through estimation of the shadow price of emissions reduction. The estimated relationship between the aggregate shadow price of emissions in Australian broadacre agriculture and the level of total emissions produced is presented in figure 2.

Figure 1: Annual greenhouse gas emissions of broadacre agriculture

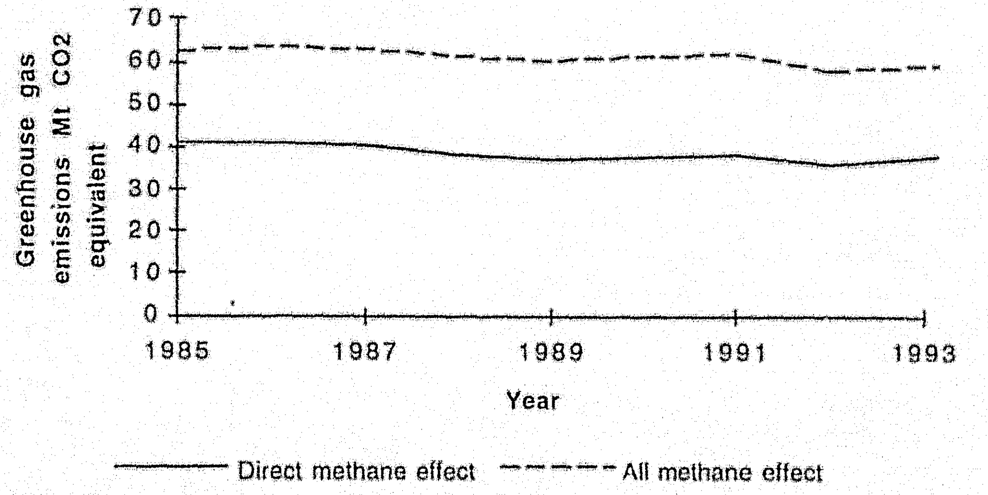
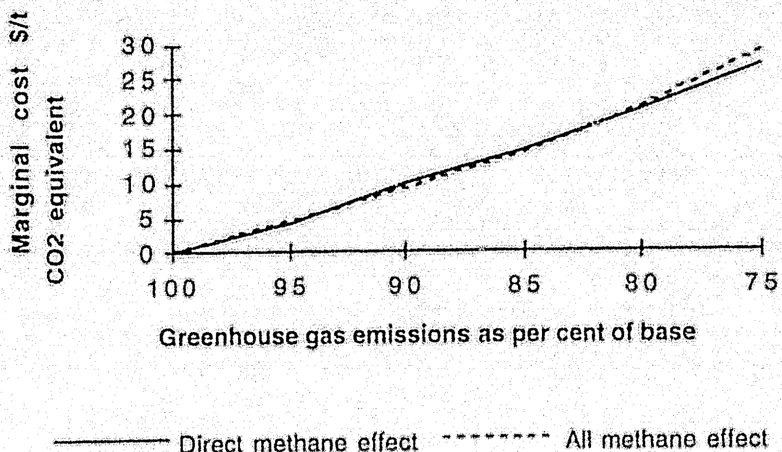


Figure 2: Marginal cost of reducing greenhouse gas emissions from broadacre agriculture



The marginal costs of a 20 per cent reduction in greenhouse gas emissions is estimated to be $20 per tonne of carbon dioxide equivalent. Thus, to reduce greenhouse gas emissions by 20 per cent, a tax rate of $20 per tonne of carbon dioxide equivalent must be applied. If the indirect effects of methane are included the marginal cost of reducing greenhouse gas emissions is estimated to be $21 per tonne. This difference reflects the differing opportunity costs of reducing numbers of methane emitting livestock rather than crops and pastures.

The estimated emissions tax required to meet the reduction target for the whole economy using the ORANI general equilibrium model (Industry Commission 1991) was $21.75 per tonne of carbon dioxide in 1988 dollars. This is equivalent to about $27 in 1991-92 dollars. It is estimated that broadacre agricultural greenhouse gas emissions would be reduced by about 30 per cent by an emissions tax at this level.

Effect on farm cash incomes

Estimates of average farm cash incomes at base, and with emissions reduced to 80 per cent of the base level through imposition of an emissions tax, are presented in table 3.

On average, the effect of reducing greenhouse gas emissions from Australian broadacre agriculture by 20 per cent, using an emissions tax based on the marginal cost derived above, is to reduce farm cash incomes by 36 per cent. There is considerable variation in the impact on regional farm incomes. The least affected region is the high rainfall zone

Table 3: Farm cash incomes at base and 80 per cent levels of emissions

	Zone	Base	Reduction in farm cash income	
		$ per farm	$ per farm	%
New South Wales	Pastoral zone	18 865	17 103	-91
	Wheat–sheep zone	24 955	10 363	-42
	High rainfall zone	12 710	5 816	-46
Victoria	Wheat–sheep zone	15 617	3 333	-21
	High rainfall zone	6 229	2 098	-34
Queensland	Pastoral zone	43 350	44 538	-103
	Wheat–sheep zone	30 519	8 783	-29
	High rainfall zone	25 992	10 930	-42
South Australia	Pastoral zone	50 053	23 939	-48
	Wheat–sheep zone	40 325	7 881	-20
	High rainfall zone	12 780	1 622	-13
Western Australia a	Pastoral zone	na	36 834	na
	Wheat–sheep zone	47 316	11 311	-24
	High rainfall zone	13 083	1 015	-8
Tasmania	High rainfall zone	11 257	4 173	-37
Northern Territory a	Pastoral zone	na	50 345	na
Australia	All zones	23 075	8 402	-36

a Northern Territory and Western Australian pastoral zone estimates of base farm cash income were not significantly different from zero in 1991-92 because of high variance and small sample size

of Western Australia. The worst affected region is the Northern Territory where the average loss of farm cash income is estimated to be $50 345 per farm. The long term impact of an emissions tax is likely to lead to major structural adjustment in the longer term as a result of the estimated short term changes in farm cash incomes.

Estimates of the aggregate effects of a 20 per cent reduction in emissions through an emissions tax at a state level are presented in table 4. The estimates are absolute changes in aggregate farm income at a state level. The hypothetical emissions tax is set at the marginal cost of a 20 per cent reduction in emissions, expressed as a carbon dioxide equivalent, as a tax on crops and livestock.

The gross cost to Australian broadacre agriculture is a decline in average income of $652 million. The tax has the most severe effect in Queensland where the pastoral beef areas have limited opportunities to diversify away from beef as a strategy to reduce greenhouse gas emissions.

Table 4: Estimated gross impacts on farm cash incomes of reducing emissions by 20 per cent with an emissions tax

	$ million	percentage
New South Wales	–236	–44
Victoria	–49	–25
Queensland	–189	–50
South Australia	–63	–21
Western Australia	–99	–27
Tasmania	–7	–37
Northern Territory	–9	na
Australia	–652	–36

Composition of production and gas emissions

Besides changes in farm incomes, another effect of reducing greenhouse gas emissions is to change the composition of production. The estimated weighted average changes in sales by commodities for all farms, expressed as percentages, are shown in figure 3.

The black bars are the estimated sales of commodities when greenhouse gas emissions are reduced to 80 per cent of base level expressed as a percentage of base sales and taking account only of the direct global warming potential of methane. The reductions in sales range from 2 per cent for mutton up to 22 per cent for crops other than wheat. Wool, beef,

Figure 3: Estimated level of sales with 20 per cent reduction in emissions

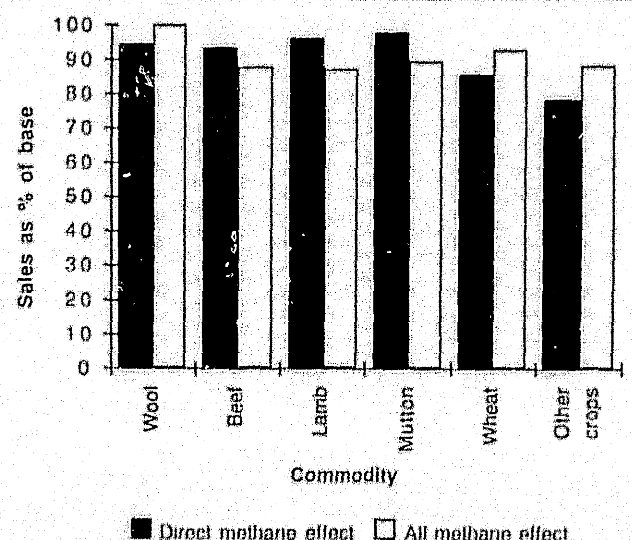
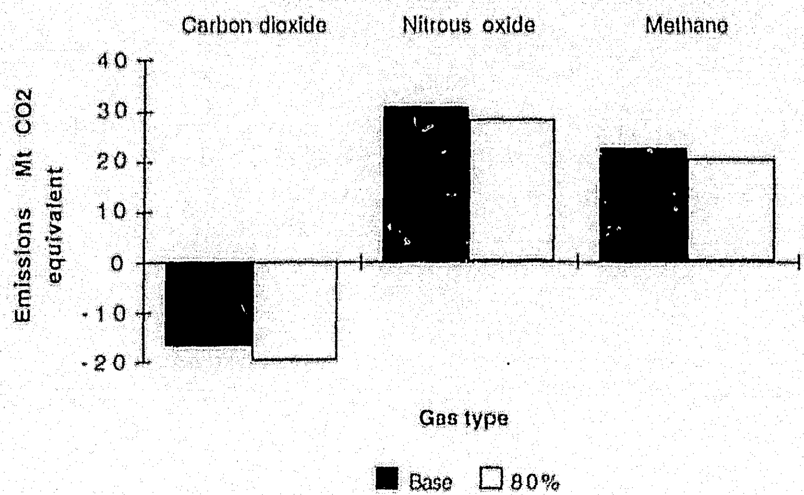


Figure 4: Composition of emissions at base and 80 per cent of base level



lamb and wheat sales fall between these limits. The second bar for each commodity, which represents the estimates where the indirect global warming potential of methane is taken into account, shows a greater effect on livestock products, with crops less affected.

In figure 4, estimates of total emissions of each gas, expressed as carbon dioxide equivalent are shown for the base and for 80 per cent of base level. The reduction in greenhouse gas emissions is estimated to be achieved by reductions in methane and nitrous oxide emissions and an increase in net absorption of carbon dioxide.

Management approaches to controlling greenhouse gas emissions

Under the second scenario, technical changes in management of crops and livestock which have the potential to reduce greenhouse gas emissions from Australian agriculture are examined. Specifically, changes in cultivation practice which can reduce the loss of soil carbon as carbon dioxide associated with cropping, and changes to ruminant nutrition and stocking rates which can reduce methane emissions are discussed.

Changes in crop management

Reducing the number of cultivations in the production cycle of crops is described as minimum tillage. Generally, cultivation exposes soil carbon to oxidation with resultant carbon dioxide emissions to the atmosphere. In contrast, continuous and healthy pasture builds up soil carbon and so acts as a carbon dioxide sink. Thus, a shift from a rotation of traditionally cultivated crops to one with longer pasture breaks and reduced cultivation can be expected to lead to reduced losses of soil carbon and even to carbon buildup in the soil. The extent of carbon buildup is limited as cultivated soils eventually reach an equilibrium organic carbon content that depends on their location and structure. Once this level is reached, no additional carbon can be saved or fixed. There is also some limit to carbon depletion, even long cultivated soils retain some carbon content so that further cultivation of such soils may not lead to any significant further net release. These equilibrium levels of soil carbon depend on constant management and the level of carbon dioxide in the atmosphere. If the latter is changing the equilibrium level of soil carbon will also change.

Another management approach to reducing greenhouse gas emissions is the use of waxed calcium carbide in conjunction with nitrogen fertiliser applications for crops. Waxed calcium carbide acts as a nitrification inhibitor and has been shown to be a cost-effective means of reducing nitrous oxide emissions under certain conditions (Magalhaes, Chalk, and Schmel 1984).

Reduced cultivation has been used, to some extent, on about 70 per cent of all cropping farms in Australia (ABARE farm survey estimates) which implies that reductions in greenhouse gas emissions may already have been achieved by this means. Hence, the scope for further reductions from this approach may be limited.

A simulation of reduced cultivation was carried out by reducing the levels of emissions of carbon dioxide from wheat and other crops by 33 per cent (Hamblin 1991). The coefficients were changed on the assumption that reduced cultivation techniques could be applied to an additional 10 per cent of the cropped area over all of southern Australia (New South Wales, Victoria, Western Australia and South Australia). These assumptions are very crude but broadly in line with the actual feasibility of reduced cultivation which is easier on lighter soils and winter rainfall areas. Summer rainfall promotes more vigorous weed growth and hence increases the costs of control by herbicides. Additional costs are incurred for herbicides in reducing cultivations but these are offset by reduced fuel use and machinery costs. These changes in costs were incorporated in the simulation, the effect being a small overall decrease in costs and a negligible increase in farm revenue.

It is estimated that reduced cultivation could reduce greenhouse gas emissions by 385 000 tonnes or 1 per cent if it were able to be applied to 10 per cent of all cropping in New South Wales, Victoria, South Australia, Western Australia and Tasmania.

Changes in livestock management

A further approach would be to reduce methane emissions from ruminant livestock. Increasing production of meat or wool per unit of feed reduces the greenhouse gas emissions per unit of product (Department of the Arts, Sport, the Environment and Territories 1992). Leng (1989) has suggested that methane emissions from ruminants could be substantially reduced by improving feed quality and digestibility of forage.

Alternatively, Howden, McKeon, Scanlan, Carter and White (1994) have indicated that significant reductions in greenhouse gas emissions from grazing lands could be achieved through adjustments in stocking rates. Howden, McKeon and Galbally (1991) modified an agricultural systems model (GRASSMAN) to identify management options which reduce greenhouse gas emissions in the woodland grazing system of Queensland, whilst maintaining the productivity and viability of a complex tropical grazing system. It was estimated that a 20 per cent reduction in methane emissions could be achieved by a reduction in stocking rates of 24 per cent from those used by large numbers of graziers in the region. As a result, the gross margin of cattle production in the region is estimated to fall by only 5 per cent.

If it were possible to extrapolate this result to all grazing areas in the pastoral zones of Queensland, Northern Territory and Western Australia, it was estimated that a reduction of 605 000 tonnes in carbon dioxide equivalent, which represents a 2 per cent reduction on the base level of greenhouse gas emissions from Australian broadacre agriculture, might be achieved. Further experimentation would be needed to validate the assumption that a similar reduction in methane emissions would be possible in the other pastoral grazing zones.

For the southern Australia region, Howden, White and Bowman (1993) have adapted the DYNAMOF (Dynamic Management Of Feed) model to compare management options to reduce greenhouse gas emissions from flocks grazing annual or perennial pastures in south eastern Australia. They ran the model for a pasture–sheep grazing system where two key management decision variables are the choice of stocking rate and the time of lambing. Examining these two variables concurrently, it was found that in order to achieve a 20 per cent reduction in greenhouse gas emissions (methane and nitrous oxide) from the region, about an 18 per cent reduction in sheep stocking rates was required. Simple changes in stocking rates would therefore be a costly way of reducing greenhouse gas emissions in southern Australia. However, Howden et al. (1993) suggest that more complex rearrangements of farming systems such as those discussed by White, Bowman, Morley, McManus and Filan (1983), which incorporate changes to pasture management and lambing times could allow reductions in greenhouse gas emissions at lower cost.

Changes in crops and livestock management, such as these, are unlikely to produce very large individual reductions in greenhouse gas emissions but there may be the potential for a useful cumulative reduction if greenhouse gas emissions are taken into account in planning for research and extension in livestock and cropping industries.

Conclusions

The broadacre industries are a major source of greenhouse gases and make a substantial contribution to national greenhouse gas emissions. They can also be significant fixers of carbon with the potential to fix large amounts of carbon in the soil and in biomass.

Carbon dioxide is far less important as a source of emissions in Australian agriculture than in the energy sector, the major source being the breakdown of soil carbon under cropping which is countered by the fixing of carbon in the soil under pastures in other areas. Nitrous oxide is a large source of agricultural emissions from fertilisers and legumes, from animal urine and from fires, particularly in the pastoral zone of northern Australia. However, it is particularly hard to reduce nitrous oxide emissions by adjusting enterprise patterns because they are associated with both crops and livestock. The third component of national emissions examined in this study is methane. The importance of methane depends on the global warming potential attributed to it. Although methane has a lower global warming potential than in earlier work, it is still a large source of emissions from broadacre agriculture. Methane is largely derived from ruminant livestock and fires. The soil, however, has a substantial capacity to break down methane into the less active carbon dioxide. The study focused on anthropogenic emissions associated with Australian broadacre agriculture but, particularly in pastoral areas, the boundary between natural processes and human management is unclear.

Using a mathematical programming model, the estimated marginal cost of reducing emissions from Australian broadacre agriculture was shown to increase with increasing reductions in emissions.

The impact of reducing greenhouse gas emissions on regional farm incomes by imposing an emissions tax was also estimated. On average, a 20 per cent reduction in net emissions from Australian broadacre agriculture was associated with a gross fall in farm cash income of 36 per cent. Reductions in greenhouse gas emissions were also associated with changes in commodity production at national and regional levels.

It can be inferred from the simulations presented that substantially reducing greenhouse gas emissions from Australian broadacre agriculture by an emissions tax would be costly although some reduction could be achieved at a relatively low cost by adjusting farm management practices. On this basis, an emissions reduction policy for Australian broadacre agriculture would be best directed toward research and extension to encourage the adoption of low emission practices and to build up carbon sinks rather than be directed at industry specific emission taxes.

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