AARES 52nd Annual Conference
5 - 8 February 2008
Rydges Lakeside, Canberra, ACT

Biophysical Modelling and Performance Measurement

Mary Graham
School of Accounting, Economics and Finance,
Deakin University
Victoria

Abstract

Agricultural production, by its nature, impacts both positively and negatively on the environment. Impacts can be point source or diffuse; however all should be considered in performance measurement.

To estimate potential environmental impacts from the use of nitrogen fertilizer, a biophysical model of dairy grazing systems, DairyMod, is used to simulate individual farming practices and determine the likely extent of leaching and run-off from each farm. Although not the only environmental impacts of farming, leaching and run-off are two variables that can be measured and combined with other marketed inputs to determine farm performance.

1. Introduction

Efficiency and productivity growth estimates are common measures of farm performance. The estimates are generally developed using marketed output and purchased inputs. However, the nature of agriculture is such that the production process interacts with, and impacts on, the environment. Performance measures should reflect the full impact of a production activity and to acquire a more complete representation of the production process, this paper explores an alternative approach to the measurement and analysis of farm performance.

Farmers in all regions of Australia have generally been willing to adopt new or improved technologies, such as improved breeding, pasture production and feed supplementation. In particular, dairy farms generally have high stocking rates and use intensive management techniques. This has allowed them to maintain or increase the efficiency and profitability of farm management practices and remain competitive. However, from society's perspective, where there is much greater environmental awareness today than in the past, farming practices need to deal effectively with the environment to create an environmentally friendly agricultural sector. In all Australian dairy regions, farmers are encouraged by their industry body to consider the environment and integrate environmental management into profitable dairy farming systems (WestVic Dairy 2004).

In recognition of the emphasis given to the environment today, this paper develops a measure of farm performance that considers the environment. Environmental impacts are important from the wider social perspective. The focus of this paper is to use a biophysical model developed specifically for Australian dairy production systems to develop a social performance measure.

This paper begins with an overview of the Australian dairy industry. The overview is followed with an examination of production theory, in particular the concepts of efficiency and productivity and their relevance to agricultural performance measurement. The relationship between agricultural activities and environmental impacts is examined in section 4. The production system at the farm level is linked with offsite impacts, particularly those arising from nitrogen in an attempt to examine the relationship between land use and the environment. Section 5 outlines how a conceptual system can be developed from an economic perspective. Simulation models can be used to model joint production and in section 6 the biophysical dairy pasture model, DairyMod, is examined. The need to consider both biophysical and economic factors in a performance measure is emphasised. Environmental and production performance are often seen as being in conflict but if all inputs are considered and used efficiently, economic and environmental objectives may both be achieved. Limitations of the model and the role of farm level modelling is examined in section 7 before concluding comments, focussing on the need to integrate biophysical and economic factors when measuring performance, are presented in section 8.

2. The Australian Dairy Industry

The dairy industry is Australia's third largest rural industry in terms of the value of production and employment and is an important source of exports, particularly processed milk and manufactured dairy products (Dairy Australia 2006). The industry is one which has undergone considerable restructuring over the last few decades in response to changes in the international market for dairy products, volatile market returns, government regulation and increases in the volume of milk produced.

Following market deregulation in 2000, significant structural change has occurred. Over the last 30 years the number of dairy farms has fallen 70%, but average farm and herd sizes have increased, with the national average currently 224 cows per farm (Dairy Australia 2006). Average milk produced per cow has almost doubled over the period (Edwards 2003). These changes follow earlier and significant deregulation to the dairy processing industry that lead to dairy farms being exposed directly to world market forces (Doucouliagos and Hone 2000). As a consequence, farm size and intensity of operations has increased in an attempt to increase, or at least maintain, profitability.

Kompas and Che (2006) report on the pressure the industry has been under with not just the removal of price subsidies for 'market milk' following deregulation, but also the ongoing drought in many dairy regions which has resulted in large falls in income. The Australian Bureau of Agricultural and Resource Economics, (ABARE) report the drought over the 2002–3 period generated a fall in average cash income of over 75% in Victoria (ABARE 2004). Production for the 2006–7 year decreased by 507m.litres (5.1%) to 9.05m. litres (Dairy Australia 2007), with a further 3% decline forecasted for 2007-8 (Hogan and Berry 2007).

Farmers also face volatile market returns. Being dependent largely on world markets, they are essentially "price takers" with prices varying from one year to another. The opening price for the 2006–7 season was 5% lower than the previous season; this was in response to a weaker international market and fluctuations in the Australian dollar. For the 2007–8 year, price increases have occurred as milk companies compete for limited supplies from drought-stricken farmers amid strong global demand. In Victoria for example, a 35% increase in the opening price for the 2007–8 season was announced by Murray Goulburn Co-operative Co. Ltd. (Sim 2007). Increased output prices are needed to balance the increase in costs, particularly fodder costs.

Productivity is central to the performance and international competitiveness of Australia's dairy sector. New technologies, including the use of more purchased inputs, are important to improving a farmer's productivity. Invariably though increased intensification impacts on the environment.

In Australia, a Dairy Australia project, 'Sustaining Our Natural Resources—Dairying for Tomorrow', (DFT), outlines a national strategy which involves a vision and goal for the industry to:

> 'manage natural resources in a way that sustains industry viability, maintains the resource intact for long-term use, and protects and enhances the wider environment'   (Dairy Australia 2003).

In recognition of the impact agriculture has on the environment, key management issues identified in the DFT program are the impact of nutrients from fertilisers, and nutrients and microbial pathogens from effluent on water, land, soil, and biodiversity (Dairy Australia 2003). Fertilisers are applied to pastures to increase production and maximise the benefit from rainfall or irrigation. Nitrogen (N) and phosphorous (P) are the two most critical nutrients applied by dairy farmers that impact on the environment.

Price fluctuations and variable climatic patterns are part of this industry. To survive farmers need to operate in a productive and efficient way. Farmers need to be able to apply marketable inputs as efficiently as possible to be competitive, whilst also trying to achieve the DFT objectives of 'protecting the environment' and 'making efficient use of natural resources' (Dairy Australia 2003). In the Netherlands large increases in nutrient surpluses—a result of the rapid intensification of livestock production—has contributed to negative consequences on the environment (Ondersteijn et al. 2001). Legislation limits specific activities such as fertiliser application rates. The industry in Australia, through DFT, is working to prevent the same outcome.

The Department of Sustainability and Environment (DSE), along with the Department of Primary Industry (DPI), collaborate with industry, farmers and local communities to develop and implement sustainable production systems, aimed at the long-term viability of the industry. The Regional Natural Resource Action Plan (2001) for WestVic Dairy, one of Australia's dairy regions, argues that the drive for increased productivity needs to be harnessed and natural resource management improved by using resources more effectively and in innovative ways (WestVic Dairy 2001).

3.   Introduction to Performance Measurement

Efficiency and productivity, although referring to distinct concepts, are interrelated and are common performance measures by which agricultural units are evaluated. Both are derived from the production function and this section focuses on the basic concepts underlying these estimates

The everyday meaning of the term 'efficiency' refers to a situation where resources are used to their capacity so that no resources are wasted. The operational concept of efficiency, widely used in economic literature today, can be traced back to the work of Farrell (1957) where a simple measure of efficiency accounting for a single output and multiple inputs is defined. The efficiency of an economic unit is a 'holistic measure', in that it takes account of all resources used and all outputs produced in determining 'how well' or 'how effectively' the decision making unit combines inputs to produce output.

Technical efficiency (TE) involves a comparison between observed and optimal values of outputs and inputs. Using an input orientation to compare the actual or observed input level to the optimal input level with the corresponding output, the level of technical efficiency can be determined. A technically efficient farm will operate on the isoquant representing the efficient quantity. Adopting an output orientation, technical efficiency occurs when the maximum output is obtained from the given inputs. A technically efficient farm will be located on the production frontier.

If information on relevant market prices is available and an economic objective, such as revenue or cost efficiency is assumed, allocative efficency can be determined. Allocative efficiency (AE) reflects the ability of the farmer to use inputs, or produce output, in the most profitable manner, given their respective prices and the production technology (Coelli et al. 2005). Combining allocative efficiency with technical efficiency gives a measure of overall economic efficiency. Productive efficiency essentially measures the extent to which production at a particular time reflects the best possible practice. Economic efficiency provides a measure for whole farm comparison independent of the level of inputs used, or output produced, and can be used as a benchmark to make comparisons across many producers. Relative efficiencies can be determined as well as the identification of the factors that are responsible for variations between units.

Productivity is a measure of the efficiency with which inputs are used to produce output. It is a ratio of output to input(s). It can be measured in relation to one single input, such as labour or capital, to yield a partial productivity measure, or to multiple inputs to provide a wider total factor productivity measure. Reasons why productivity may vary between productive units over time include differences in the technology used by the productive units, or differences in the efficiency of the production processes in the use of inputs to produce output, or variations in the environment in which production takes place (Lovell 2004). Technical progress, efficiency and scale can all impact on performance.

Agricultural output requires the use of both private and environmental or public inputs. To cut back on using a public input would result in a lower level of output, and/or require a higher level of private inputs to produce the same output. To the extent that production activity can have impacts beyond the production process, the wider implications need to be considered when measuring performance. The traditional performance measures using financial inputs and marketed output need to be extended to include environmental inputs if farm performance is to reflect the full impact of the economic activity. The environment needs to be treated as an integral part of the economic process and not treated as a free good. A "whole farm system" approach integrating natural resource use and management with production and profit is required. Good economic management requires all environmental inputs and outputs to be fully valued and allocated among competing goals to maximize welfare.

Measures of a farm's performance inclusive of environmental impacts reported in the literature, are limited to studies undertaken of American (see Ball et al. 2001, Ball et al. 2002, Ball et al. 2004) and European dairy and pig farms (see Reinhard et al. 1999, Reinhard and Thijssen 2000, Reinhard et al. 2000, Fernandez et al. 2002 Oude Lansink and Reinhard 2004, Ondersteijn et al. 2005 and Coelli et al. 2007). Analysis of Australian farm performance has not previously been approached from the wider social perspective. A review of the literature shows Australian dairy farm performance analysis to be limited to measures of private productivity and efficiency (see for example, Fraser and Cordina 1999, Kompas and Che 2002, Fraser and Graham 2005 and Kompas and Che 2006).

The measurement of the environmental impact, particularly with regard to fertiliser application rates and timing and the use of dairy effluent, have been undertaken by the DPI, formerly the Department of Natural Resources and Environment (DNRE), as well as by dairy research centres, such as Ellinbank Research Centre in Gippsland,

Victoria. Dairy Australia (2003), as part of the DFT initiative, has produced a Dairy Self Assessment Tool, DairySAT, to assist farmers assess environmental issues on their farms and promote 'environmentally sensitive dairying practices'. More recently, in June 2007, Dairy Australia launched a four year project for the industry to develop a method of nutrient accounting on dairy farms (McKenzie 2007, Parry 2007). The project aims to involve farmers in identifying the risk of nutrients leaving the farm. Farmers are today being made aware of the importance of environmental impacts. Performance measures need to be extended to reflect this trend.

Hence a more holistic approach to performance measurement is required and the following section outlines an approach where biophysical processes are integrated with the economic principles of agricultural production. The efficiency measures, technical, allocative and scale efficiency, need to be constructed to take account of all resources used and outputs produced.

4. Developing a systems approach to analysis

Agriculture draws on the environment both as a source of inputs, such as water and soil, and as a sink for disposal of wastes, such as nutrients from fertiliser application. It is in competition with other industries and households for such resources. If the resources are reduced due to either poor management or use by other industries, agricultural production, in the absence of technical progress, will be less (Tisdell 1999). The interdependence and interaction between the environment and agriculture, as an example of one economic activity, is illustrated in Figure1 below.

Figure 1: Environment and economy: interdependence between the natural resource base and economic activity
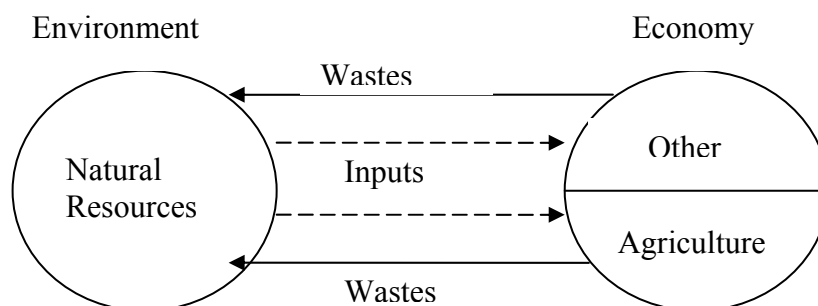

Source: Tisdell 1999, p. 39.

Modern agriculture has been successful in increasing output over many decades. However, this output has been produced at a cost to many natural resources, particularly soil and water (see, among others, Carpenter et al. 1998, Jarvis 1999, Pimentel 1999, Powlson 1999, Pretty 1999, Parker 2005, Tisdell 1999, Williams 2005). In essence, agricultural products and environmental services are produced jointly and reflect the input and output decisions of farmers (Fraser and Hone 2001).

Joint production refers to the situation where an action producing an economic benefit will also produce an environmental good (Nowicki 2004). The relationship can become increasingly competitive as agricultural production is increased and additional

output can only be obtained at the expense of the environment (Fraser and Hone 2001). In Figure 2 below, jointness of production is shown by the production possibility frontier (PPF), RST. Initially, at low levels of output, both agricultural production and the environment complement one another, but as agricultural production increases and moves beyond point S, there is competition for resources and any increase in agricultural output occurs at the expense of the environment. The goods are jointly produced over the restricted range, RS. The relationship is, however, not always fixed. Over some range of production, a reduction of agricultural production intensity can produce an increase in environmental quality, while over other ranges, the opposite may apply (Hodge 2004). The challenge is to find ways of delivering increased output without exceeding the optimal rate of use of the capital base which includes social, environmental and economic assets.

Figure 2: The agricultural-environment relationship

Environmental
Goods

S

R

T

Agricultural
Output
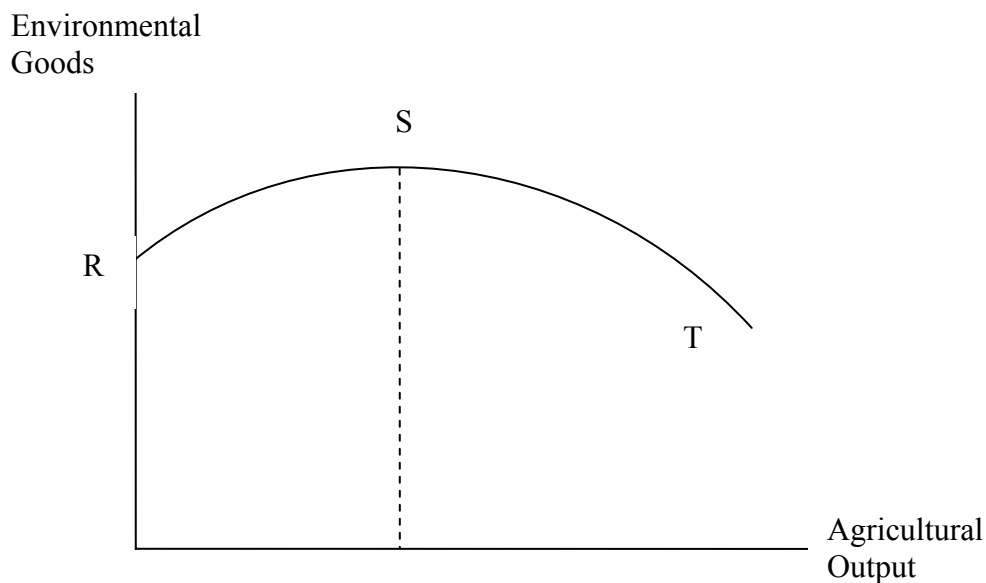
Being highly dependent on the biosphere and living resources, a wider measure of agricultural performance requires all resources, i.e. natural or biophysical, social, economic and institutional, as illustrated in Figure 3 below, to be considered and integrated with production and profit (Tisdell 1999, Ewert et al. 2006).

Figure 3: Relationships within an integrated system
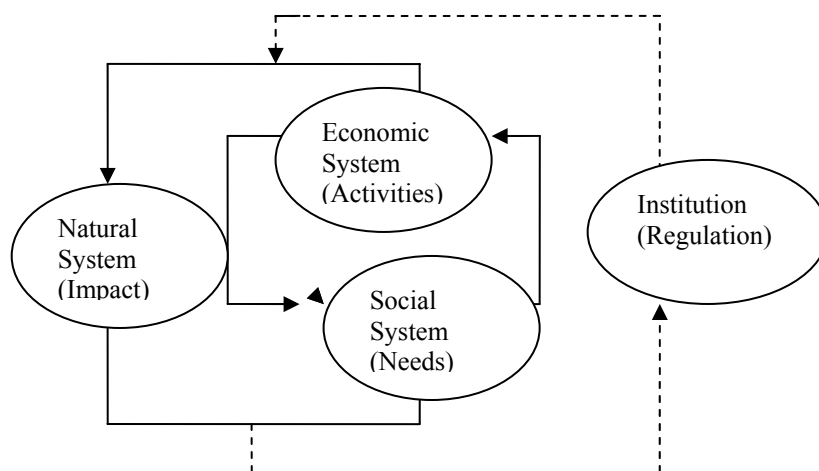
Source: Ewart et al. 2006, p. 12 of 50.

Agricultural production takes place over time and with many interacting sub-systems adding to the complexity of the production process. Within any particular production season, a farmer has a sequence of decisions to make relating to, among others, the quantity and timing of the fertiliser applications, and the cutting of pasture for silage or leaving it for hay. In addition, the agricultural system interacts dynamically with the environment. Each component of the system may be dynamic but if the properties are not integrated dynamically, then the relationship could be described as 'loose coupling' (Antle et al. 2005). Productivity is then determined by exogenous biophysical conditions and economic decisions, such as land use and management. Economic decisions affect environmental outcomes, but environmental changes do not feed back to the economic outcomes. If however, close coupling characterises the system, the biophysical and economic components of the model interact dynamically. Hence, management decisions impact soil productivity and soil productivity in turn affects management decisions. The challenge is to capture these dynamics in a model of an agricultural system so that the system can be judged in terms of economic and environmental performance (Antle et al. 2005). The approach used in this paper attempts to capture these dynamics.

5.   The conceptual system from an economic perspective

The interdependence that exists between the agricultural sector and the environment requires a framework that recognises this two-way interaction. Private economic choices relating to inputs and outputs, as well as the effect of these private choices on the biophysical processes, need to be considered.

An evaluation of the sector's performance from a systems perspective requires the production of a private goods output, with the inputs to include environmental, private, public or semi-public goods (Weaver et al 1996). When applying general systems modelling principles to dairy farms, the level of private output (milk and stock sales) will be partly dependent on a vector of traditional inputs, such as labour,

feed, fertiliser; plus public or quasi-public unpaid environmental inputs, such as nutrient flows in surface and ground water, as well as other environmental inputs including rainfall and slope of land. An integrated model, composed of an economic model involving the private good production process, and a biophysical model describing the biophysical processes, can be developed. Using the notation of Weaver et al. (1996) the model can be expressed as:

$$G(Y^i, Q^i, X^i, E^i, Z, \theta^i) = 0 \qquad\qquad (1.1)$$

where the superscript i, indicates the variable is associated with the ith farmer. The output (Y^i) is private goods produced and inputs, Q^i, X^i, Z, E^i, θ^i, include environmental, private, and public or semi-public good inputs. In particular,

- Y^i is a M * 1 vector of private good outputs, (e.g. milk, animal sales)

- Q^i is a J * 1 vector of environmental inputs, (e.g. leaching, run-off)

- X^i is a vector of private good variable inputs, (e.g. labour, fertiliser, feed)

- E^i is a L * 1 vector of environmental effort, defined in relation to the extent of adoption of environmental practices or specific input embodied effort that contributes to the production of the environmental effects, (e.g. the use of effluent ponds, feeding pads, where such practices contribute to the production of environmental effects)

- Z is a K * 1 vector of public or semi-public good input flows, or environmental conditions, not depleted by contributing to the productivity of output, (e.g. rainfall, slope of the land, etc)

- θ^i is a J * 1 vector of flows from quasi fixed private factors of production, (e.g. dairy shed, land, etc.).

Because Q^i and Z are public or semi public inputs, the production function involves the direct interaction of private and public goods and, hence, represents a mixed good production function. Private output and inputs can be measured in dollar values (quantity * price) since they are traded on the market, and to measure environmental effects, taking consideration of public or semi public good input flows, a biophysical simulation model of the dairy pasture system can be used (Weaver et al. 1996).

If the public good interaction is ignored, the joint production function takes the form:

$$F(Y^i, X^i, \theta^i) = 0 \qquad\qquad (1.2)$$

The incorporation of θ^i gives a joint production function but it has no public good interaction, Z or Q, as is implicit in equation 1.1. To model environmental effects, the private production function can be combined with an additional process that reflects the biophysical process:

$$H(Q^i, X^i, E^i, Z, \theta^i) = 0 \qquad\qquad (1.3)$$

However, combining equations 1.1 and 1.3 to evaluate a farm's performance gives a non-jointness or 'environmental independence' to the analysis (Weaver et al. 1996, p.

176). Prices on private inputs are treated independently, as are the combination of private and public inputs.

In contrast, modelling agriculture production as being produced jointly with environmental services brings a 'holistic approach to the study of farming systems by focusing on the interactions between system components' (Weatherley et al. 2003, p. 2). If environmentally interactive technologies are being considered, public and quasi-public goods used in the production process need to be considered (Weaver 1998). The environmental effects result from the integration of private good production with biophysical processes (Weaver et al. 1996). Complexity and uncertainty are inherent to the interaction of the environment and the economic system. Using an integrated model allows the behaviour of a complex system to be explained in a more reliable way (van den Bergh et al. 2006).

6. A Simulation Model: DairyMod

A Victorian-wide project, Best Management Practices for Nitrogen in Intensive Dairy Production Systems, reported in Eckard et al. (2001), aimed to produce guidelines to 'minimise' nitrogen (N) losses while maintaining dairy pasture productivity, and to evaluate different N cycling models. DairyMod, developed specifically for Australian dairy farming systems, provides the level of detail required to predict the N cycle. The model, produced through a DRDC (now Dairy Australia[1]) funded research project, commenced in 1998 and has been developed and refined using peer review processes, including the National Dairy Farming Systems Team (NDFS) and workshops with NDFS scientists. In the model, the interaction between management inputs and resource dynamics (water and nutrients) is investigated with a view to identifying efficient, sustainable management strategies (Johnson et al. 2003). Weaver et al. (1996) claims the scale of focus for any model needs to be narrowly defined as the farm field and this can be implemented in DairyMod.

DairyMod provides researchers with a tool to investigate farm management systems operating under different environmental conditions. Rotational grazing management, where the N is supplied either through N fixation by a legume, or as fertiliser, is the main focus of the model. Current knowledge of surface and ground transport of agricultural chemicals indicates the importance of farm site characteristics and the production practices of individual farmers, such as application rates and the timing of applications, in determining the possible environmental impacts. The ability to input information on such farm specific practices, along with local soil and climate data, gives the model the desired flexibility and relevance for application to any dairy pasture located in Australia. The heterogeneity that exists between farms in any one region is recognised (Wossink et al. 2001).

DairyMod has been developed so that it can be applied to existing farms or used to create virtual experimental farmlets located in the milk producing states of Australia, namely South Australia, Western Australia, Queensland, Tasmania and Victoria. An overview of the structure of the model is provided in Figure 4 below and highlights the interrelationships that exist between the components.

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[1] Dairy Australia was formed in 2000 from a merger of the Dairy Research and Development Corporation, (DRDC), and the Dairy Industry Association, (DIA).

Figure 4: Overview of the structure of the dairy pasture system model 'DairyMod'
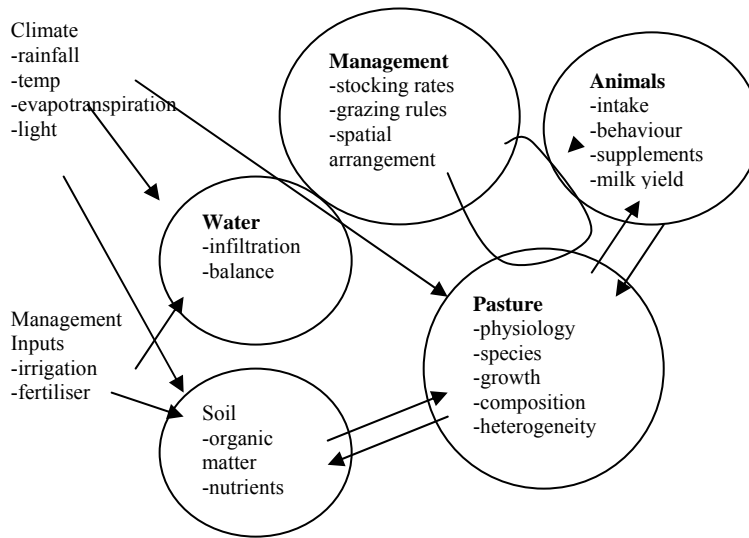
Source: Weatherley et al. 2003.

Figure 5 below shows the main DairyMod window. Across the top of the window are the main modules which are discussed further below. Down the left hand side of the window are the simulation controls where the period over which the simulation exercise is run is selected. The twenty paddock grid into which a farm is hypothetically divided, along with selected graphs showing daily milk production, rainfall, soil water etc. are displayed in the middle of the window.

## Figure 5: The main DairyMod window
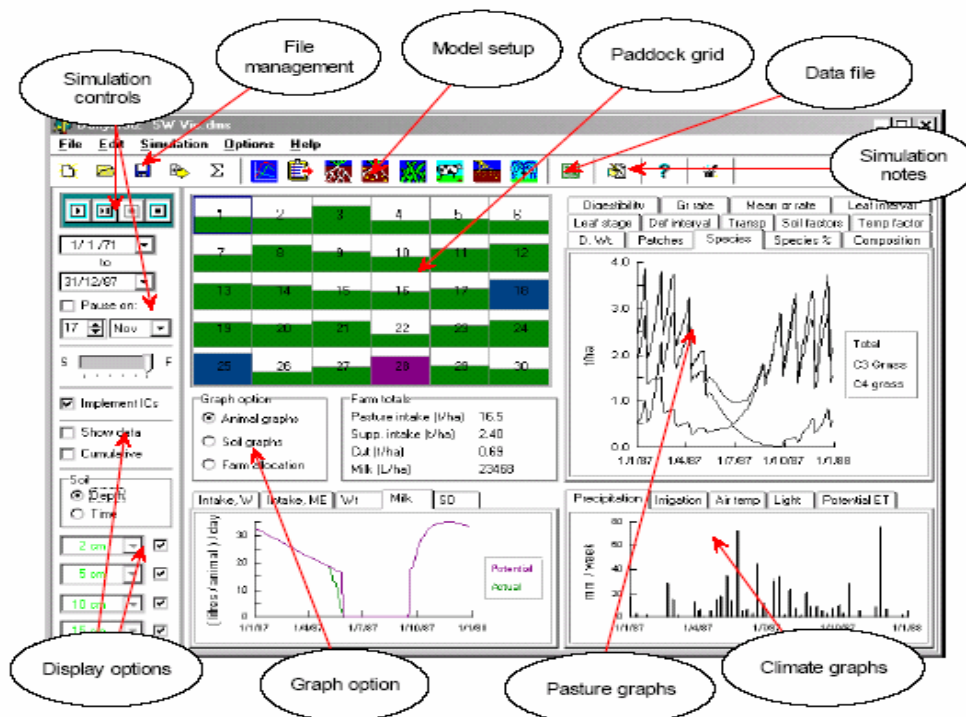
(Source: Johnson et al. 2003)

The model combines various inputs including available land, stock, pasture type, supplementary feed in the form of forage and concentrates, fertiliser and climatic information, to produce output in the form of pasture and litres of milk per hectare. The model simulates production in terms of what is technically feasible assuming the farm operates efficiently.

The simulated or modelled pasture growth, as shown in Figure 6, corresponds closely to the growth experienced on field sites from research undertaken at Ellinbank Dairy Research Centre in Gippsland, Victoria. Both modelled and actual pasture growth is most rapid in the spring season when rainfall and temperatures are favourable.

Figure 6: Modelled average monthly pasture growth rates
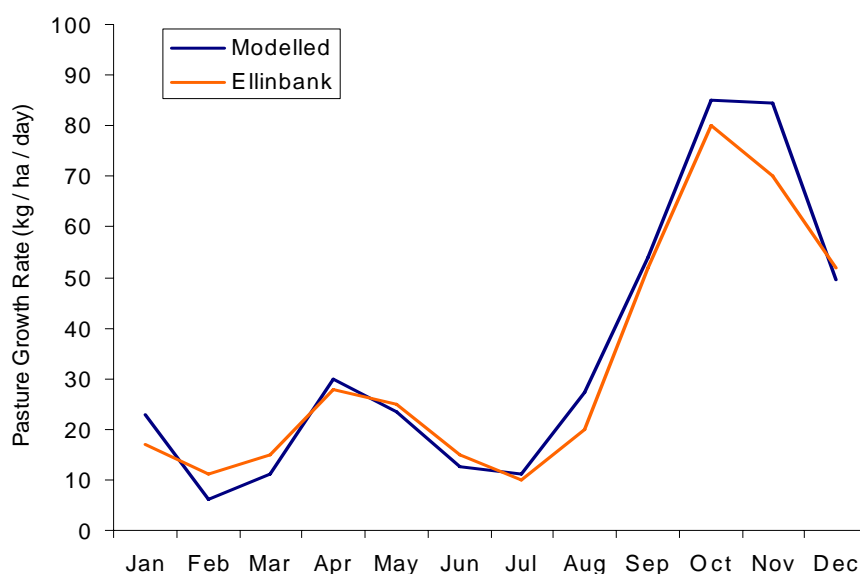
(Source: Eckard et al. 2005)

Pasture also responds to fertiliser but experiences diminishing returns. As more fertiliser is applied and holding other inputs constant, pasture growth occurs at a decreasing rate. As illustrated in Figure 7, with application rates up to 400kgN/ha per year, pasture is simulated to increase from 7 tonnes of dry matter weight (tDM/ha) to between 10.5 and 12.5tDM/ha depending on the N form (urea or nitrate). Increasing the rate of application beyond 400kgN/ha per year will produce much smaller increases. An additional 100knN/ha per year will only produce an additional 1tDM/ha/year of pasture.

Figure 7: Modelled annual yield response
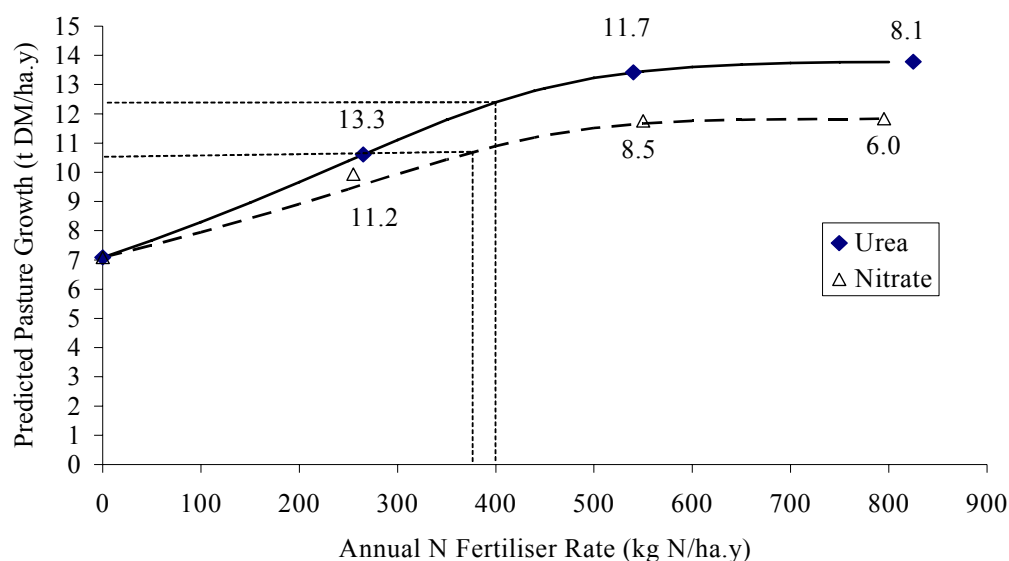
(*Source: Eckard et al. 2005.)*

The second output from the model, milk production, reflects stocking rates and herd management in terms of pasture rotation and the use of supplementary fodder. DairyMod calculates the intake from both pasture and supplementary feeding and uses this intake for the metabolic processes of growth, maintenance, lactation and pregnancy (Johnson et al. 2003). Input substitution in terms of pasture, concentrates and forage by individual farms is possible in DairyMod.

Milk output, Y_M, reflects the stocking rate, S_R, fertiliser application rate, F_R, climate, in particular rainfall, R, and temperature, T, soil temperature, S_T, and pasture and feed management, P_M, F_M. Thus the milk production function in the model can be expressed as:

$$Y_M = F(S_R, F_R, T, R, S_T, P_M, F_M) \qquad (1.4)$$

The reliance of milk production on many factors is illustrated in Figure 8 below where milk production is simulated under different fertiliser application rates and periods of increased rainfall. Milk output increased in year four compared to year one but the reduced output in years two and three highlight the fact that milk output is a reflection of many inputs, not just fertiliser and rain.

Figure 8: Simulated milk production function
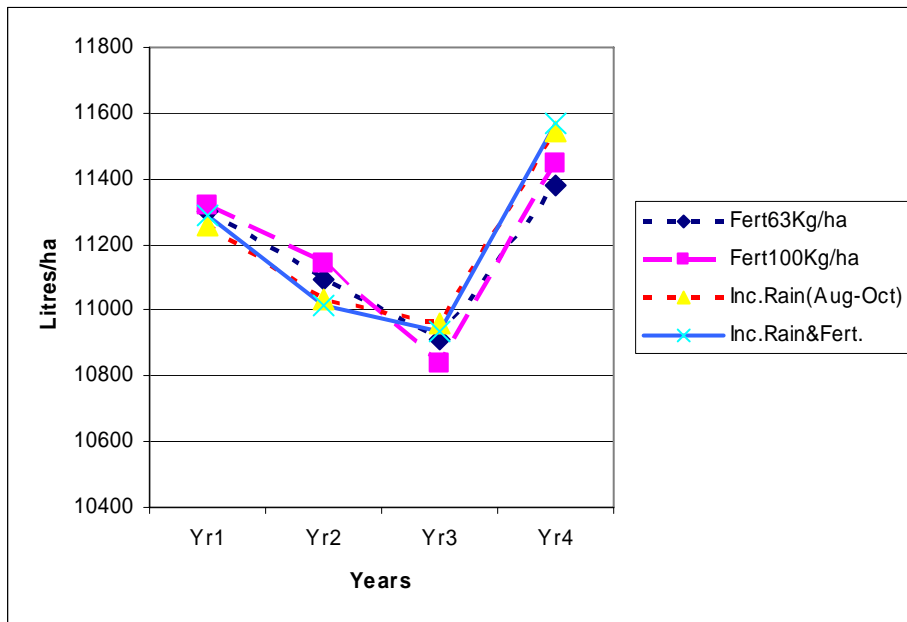
DairyMod also simulates water and nutrient flows. Nitrate losses vary with rainfall, the level and source of N inputs, soil characteristics and hence soil N transformation rates, stocking rates, pasture species and growth rate. For example, changing climatic patterns, such as increasing the rainfall received in late winter and early spring, results in the simulated levels of leaching increasing, as illustrated in Figure 9 below.

Figure 9: The impact of increased rainfall on leaching
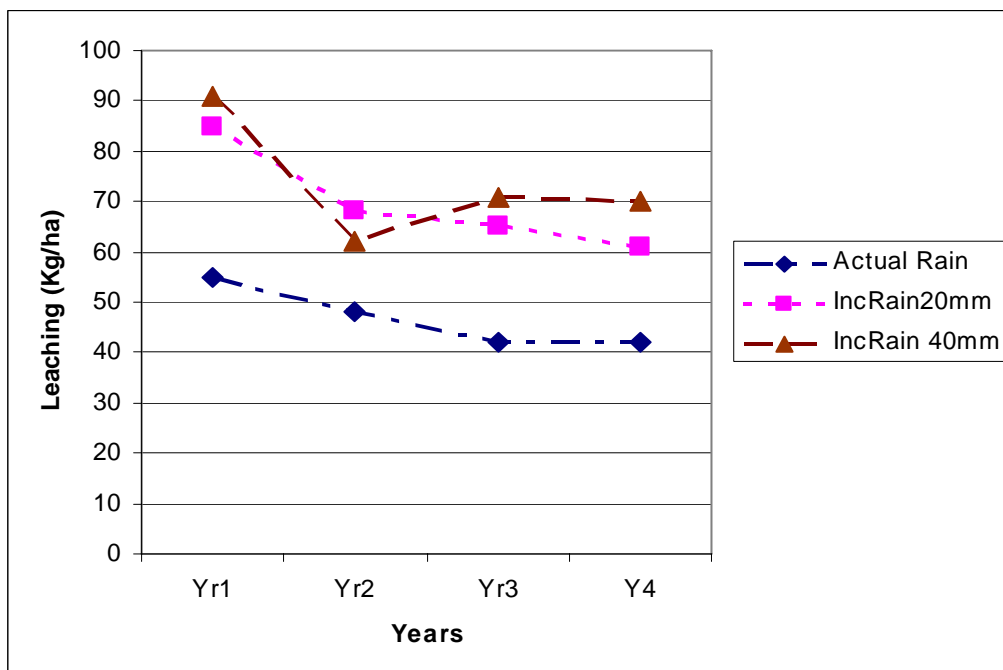
Water and nutrient flows are also governed by the application rate of N. Research conducted by DPI shows that higher application rates run the risk of increasing leakage of N to groundwater. If the fertiliser application rate is increased from 63 to 80 kgN/ha and then to 100 kg and 200 kgN/ha, making the yearly application of N fertiliser increase from 160 kgN/ha to 800 kgN/ha, the model simulates leaching to increase from 56 kgN/ha to 61 and then 70 kgN/ha, as illustrated in Figure 10 below.

Figure 10: The impact of increasing the rate of fertiliser application
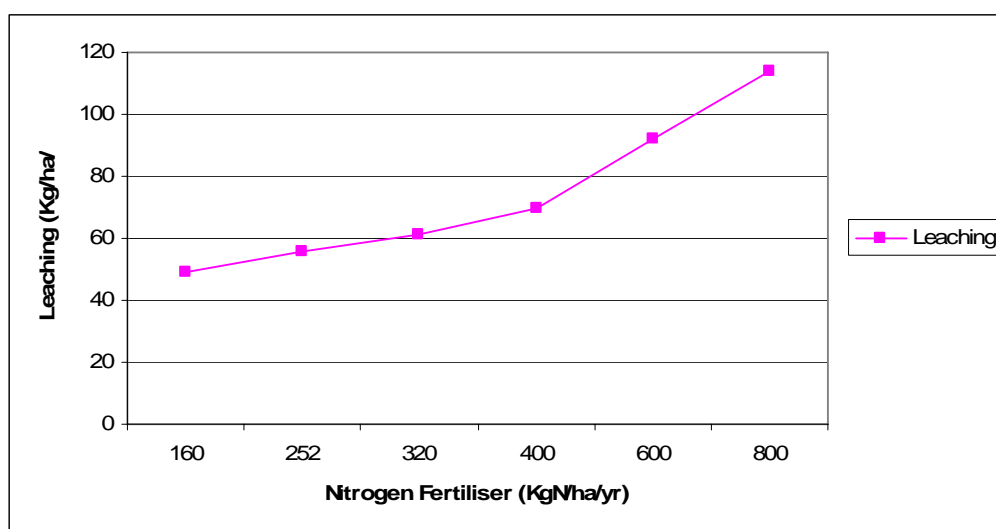
In recent years, farmers have been encouraged by DPI field officers to use the rich N resource available from dairy effluent to fertilise summer crops and boost silage regrowth yields. DPI (2006) recommends that fertiliser can be cut back or left off land that has been spread with effluent. In terms of potential environmental impact, the total N application, rather than the particular form the application takes, is important. Hence, effluent can be assumed to replace a fertiliser application in the model.

Soil type impacts greatly on the level of leaching and run-off. Clay loams result in much less leaching than sandy loams. However, run-off is zero in sandy soils. If rainfall or fertiliser is increased on a sandy loam soil, the amount of leaching is more than double that resulting from a clay loam soil. Increasing late autumn rainfall by 10mm on a sandy soil, while producing zero run-off, results in leaching of 171 kgN/hectare, compared to 54 kgN/hectare on clay loam soil. Rainfall, fertiliser application rates and soil type all impact on the extent of sandy soil leaching and run-off.

Other factors that influence the extent of leaching include the use of supplementary feed and concentrates, soil temperature, and stocking rates and stocking intensity. Individual farm data for each of these factors can be included in the model.

The above factors collectively determine the level of leaching and run-off that could result on any one farm and can be expressed as a damage function, D, where the damage is expressed as a function of fertiliser application, F_R, rainfall, R, soil type, S_T, the use of supplementary feed, F_C, and stocking rate, S_R.

$$D = F(F_{R}, R, S_{T}, F_{C}, S_{R}). \qquad\qquad (1.5)$$

The data discussed above, are accommodated in one of DairyMod's eight modules. Each is discussed briefly below.

6.1 The management module requires information on the size of a farm's grazing area, in hectares, and the management of the pasture in terms of grazing and cutting. If the minimum residual grazing conditions are reached, supplementary feeding is implemented.

6.2 The soil water module involves the interaction between rainfall, evapotranspiration, run-off and infiltration. Individual farm data on soil type and depth of each layer, along with the inclination of the land, are required in this module. Soil type and slope both impact greatly on the level of leaching and run-off. Clay loams result in much less leaching than sandy loams. However, run-off is zero in sandy soils.

Soil layers and their depths are also recorded in the model. The movement of nutrients occurs with the movement of water. Nutrients move through the soil with water above a critical soil water content, defined as a percentage of field capacity. The smaller the percentage, the greater is the potential for leaching. In the model, the leaching parameter set at 50% of field capacity.

6.3 The soil nutrient module includes organic turnover, inorganic nutrient movement in the soil, nutrient adsorption and atmospheric losses of nitrogen (Johnson 2005).

6.4 The pasture species module enables particular species, such as perennial, annual, legume, C3 or C4, to be identified for each farm.

6.5 The stock module requires individual farm data relating to animal type, number, size, lactation length and calving dates. Details relating to supplementary feeding are also required in this module. Since pasture and supplementary feeding are substitute inputs, the intake levels of both are required.

Minimum and maximum daily amounts for concentrates and supplementary fodder are stipulated in the model. Supplementary feeding options are calculated in terms of the milk target and minimum daily concentrates are applied regardless of pasture availability. The model default for the minimum daily amount is used, while the maximum amount that could be given in the simulation is specified as the figure calculated for each individual farm. A similar approach is used for the supplementary fodder but the minimum forage is only applied if the metabolic energy requirements (ME) falls to the minimum.

6.6 The fertiliser module allows for the application of nutrients in response to soil nutrient status at specific dates. Decisions can be based on using a fixed date, rotational grazing or soil testing. Only four applications are possible in the model and the applications have to reflect both the commercial fertiliser and dairy effluent spread on a farm over a one-year period.

6.7 The irrigation module is used only if the farmer irrigates pasture. The irrigation decision, that is, whether irrigation is based on a fixed time and amount, or is in response to plant or soil or rainfall deficit, needs to be known, as does the percentage of land irrigated.

6.8 The climate module, the driver of the biophysical processes, requires climatic details, including the latitude of each farm. If the location of each farm is established, the relevant climatic data to be obtained from climatic data bases such us, SILO, a regional data base of the Queensland government. Data showing daily rainfall, maximum and minimum temperature, radiation and potential evapotranspiration is required.

Once the individual farm data are inputted into each module of DairyMod, the model can be set for the simulation to run for each farm over a ten-year period so that the full impact of the farming activity on the level of leaching and run-off can be calculated. The performance of the model in terms of simulating the biophysical processes is enhanced the longer the period over which the model runs. The first two or three years over which the model runs is less accurate than the figures given in later years as it takes time for the processes to establish in the model. Data relating to 'paddocks' or the area in the middle of the farm are also likely to portray more accurately the levels of leaching or run-off, than a 'paddock' or area on the farm's boundary. The first paddock, (the area on the boundary of the simulated farm) is likely to experience a greater build up of nutrients than what might realistically occur. Accordingly the selected simulated data used for economic analysis can relate to land located in the middle of the farm.

The output from the biophysical model can be combined with the private production function to give an integrated model of the farm production process. As claimed by Weaver et al. (1996) p. 176, 'the biophysical component of an integrated model provides a useful basis for estimation of the environmental effects based on simulation'. Farm level activity is linked with off-site impacts in an attempt to examine the relationship between land use and the environment. The biophysical and the economic processes of a farm's production system are integrated in one model from which to derive a social measure of performance.

7.   Limitations of the biophysical model

While the model is useful in determining the level of leaching and run-off from each farm, there are some limitations, mainly relating to the application of nutrients. The number of fertiliser applications is limited to four in any one year and in calculating the amount spread in any one application, there is a need to ensure that no more than the recommended application of 200 kgN/ha is spread in one year. Effluent can not be treated separately to fertiliser applications.

It is also acknowledged that rainwater and water from yard washing add to the volume of effluent created in the dairy and to include these variables would entail measuring the yard and also the amount of rainfall received in any one year. This may not always be possible.

Feed pads are acknowledged as an important source of nutrients and the variation between feed pads is high, making it difficult to factor their contribution into any

analysis. Dung and urine patches in paddocks and laneways used to access the dairy are other sources of nutrients which are also difficult to take into account.

While a figure for the extent of leaching and run-off can be derived from the biophysical simulation model and included with the economic model in estimating a farm's performance, the level of actual leaching is not as important as the soil type and the extent of travel from source to the water body (Skop and Schou 1999). Individual soil types are required in DairyMod and are reflected in the extent of leaching predicted. The decay processes however include processes that occur from the time nitrate is leached from the plant root zone and until it reappears in the stream. Hence the longer it takes for nitrate to reach the water body, the more nitrate that can be removed by denitrification which will control the nitrate concentration in soil solution, or retained by accumulation in biomass or sediment. The location of an individual farm, and in particular its proximity to waterways, is significant when examining the wider environmental factors, and in the selection of appropriate policies to protect the environment. The amount of nitrogen leaching and run-off, obtained from Dairy Mod, needs to be modified depending on the closeness of waterways and the extent of vegetation cover on the riparian zones.

Despite such limitations, the model enables biophysical and economic data to be integrated for performance evaluation. Being dependent on site specific soil and climate conditions the integrated assessment model can simulate behaviour in a way that is consistent with established scientific understanding. However environmental impacts are acknowledged to be highly location specific and reflect local conditions. Hence the reliance of the model on farm level data for explaining spatial variation could be argued to limit its usefulness.

The interaction of agriculture with the environment means that there will be in any one region, a large number of farms emitting waste products. Point source emissions, such as dairy effluent or nutrients in run-off, may be relatively visible, while others, for example leaching, may not be so visible and their impact may extend beyond an individual farm. The extent to which agricultural nutrients will be transported across surfaces or in ground depends on farm site characteristic, including soil type and structure, production practices, such as fertiliser application rates, climatic events before and after the application of fertiliser, and the particular environmental characteristics of watersheds that serve the farm (Hall and Hartwig 1978, Eckard 2001). Identification of emissions from diffuse sources becomes difficult if not impossible.

Farm level models can assist overcome such difficulties. Analysis at the individual farm level enables the interactions between the decision behaviour and the preferences of the farmer, to be considered together with the uncertainties existing in the environment and the dynamics of the managed resources (Drechsler and Wätzold 2006). If statistically reliable field specific production and environmental data are available (for example from statistically representative samples of the population) key parameters can be measured and the results used to represent the region.

Both agriculture production and environmental impacts depend on highly location specific environmental conditions (Just and Antle 1990). Specific farm or field level data on production needs to be combined with environmental data to measure the relationship between farm production and environmental impacts. Examples of whole

farm modelling being used to analyse the interactions of economic and ecological demands on agricultural land use include the use of the model MODAM, by a research station in Bavaria (Meyer-Aurich 2005). In England, a database for crop treatments and N loss generated with a weather model, IACR SUNDIAL, was linked to an economic model, FARM-ADAPT, to assess the economic impact of measures to reduce nitrate loss in a root cropping system (Gibbons et al. 2005). The integration of agri-environmental indicators shows the complex interactions which occur when environmental concerns are incorporated in the objective function. The calculation of trade-offs illustrate the relationship between agri-environmental indicators and economic returns.

The aim of this paper is to highlight the need to integrate a physical and an economic model at the farm level to capture the diversity that exists in both the economic behaviour of individual farmers as well as the physical environment. The method of analysis could be extended to a wider group of farms, or to the whole dairy region, or to all dairy regions in the country, with the use of catchment-wide or regional models such as the Erosion Productivity Impact Calculator (EPIC), or the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS). Both models have been integrated with economic models to undertake analysis of policies developed to manage predominantly water related environmental impacts of agriculture at a regional level.

Aggregation, necessary for regional models, needs to ensure that the heterogeneity that exists within a region as well as the non-separability that exists between the environment and the agricultural activity is fully captured (Wossink et al. 2001). Individual farm data could be aggregated and combined with the percentage of land use in the catchment or region devoted to dairy farming to determine the extent of run-off and leaching and, hence, the impact on water quality. In addition, while the present analysis focuses on just two environmental impacts, the use of a wider catchment or regional model would enable other impacts to be included in the analysis and allow for a wider and more detailed analysis of the sector's social performance.

An alternative to such models, while still taking into account biophysical characteristics, is to model the environmental impacts according to farm and soil type, using a geographic information system (GIS) based framework (Skop and Schou 1999). Skop and Schou (1999) used an integrated analytical framework based on spatially distributed farm data to examine the interaction between N losses and economic output in Denmark.

8. Conclusion

Leaching and run-off carry nutrients from their source to surface or ground water resources. Water quality off farm does not affect farm land value or a farmer's private productivity. However, from society's perspective, any impact on water quality should be included in farm performance evaluation.

If performance measurement truly reflects the production process, the reliance of the agricultural sector on the environment should be sufficient to ensure environmental impacts are included. However, traditional performance measures, using only marketed inputs and outputs, tend to dominate the literature on Australian agriculture performance. The scientific community argues for, and DPI extension activities focus

on, the need to consider environmental consequences resulting from agricultural practices. However, the impact of environmental practices on measured farm performance tends to be ignored. Economic analysis needs to extend beyond the traditional measures and produce performance measures that more closely reflect the expectations of society presented to the farming community. The science and economic disciplines need to work together. Data obtained by scientists needs to be combined with economic statistics on marketed output and inputs such as production levels, cost of inputs and prices received for output, to undertake a more comprehensive performance analysis. By being able to quantify the performance of individual farms when such variables are included in an analysis, farmers may view the selection and adoption of appropriate farm management practices to minimise negative environmental impacts more favourably.

An understanding of the biophysical processes is critical to any performance analysis of an agricultural sector. Biophysical modelling allows for the integration of the economic and science disciplines to examine the complex linkages that exist between producer behaviour and the physical and biological dimensions of a farming system. By focusing on the interactions between system components, modelling brings a holistic approach to performance analysis (Weatherley et al. 2003). Environmental effects are a result of integrating the private good production processes with the biophysical processes. The environmental input needs to reflect as closely as possible the public resource that is being used. Using detailed farm level data, integrating the two disciplines in performance evaluation provides a comprehensive analysis.

Comprehensive databases containing information on soil types, land use, livestock, N surplus etc. are collected for some European countries, notably Denmark and Holland. Such data bases provide a rich source of data for analysis of farm performance (see for example, Reinhard et al. 1999, Skop and Schou 1999, Fernandez et al. 2002, and Ondersteijn et al. 2005). A similar database is needed for the Australian Dairy Industry to enable quantitative analysis of farm performance to extend to the wider social context. Farm level data is required since farm site characteristics and production practices in relation to surface and ground water transport of chemicals are important. The extent of N leaching and loads, where the N load reflects the decay process that occurs during transportation, vary in space and farm type (Skop and Schou 1999).

To obtain the required comprehensive data may be difficult, but with the use of biophysical models, simulated data can be obtained and used in modelling agricultural practices or in designing agricultural-environmental policies. Some effort towards a more holistic approach is required.

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