# ENVIRONMENTAL EFFICIENCY: MEANING AND MEASUREMENT AND APPLICATION TO AUSTRALIAN DAIRY FARMS


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



## Abstract

Technical efficiency has been widely studied in the literature, but in its pursuit, many of the inputs used can impact on the environment. Environmental effects can be modelled as undesirable output or, as has been the case in more recent studies, as conventional inputs. This paper examines the concept of environmental efficiency and how it can be used to evaluate the performance of Australian dairy farming, using nitrogen surplus, arising from excessive applications of fertilizer, as a detrimental input. Farming promotes the image of clean and green production and if this image is to be maintained, there is a need to ensure activities are environmentally friendly



## Key Words:

Efficiency, detrimental inputs, nitrogen surplus, DEA,

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*Address for correspondence:
Mary Graham
School of Accounting, Economics and Finance
Faculty of Business and Law
Deakin University, Victoria, 3280

Email: grahamm@deakin.edu.au
Phone: 03 55 633 568
Fax: 03 55 633 320

## 1. Introduction

The dairy industry in Australia is a major industry in terms of the value of production, employment and as well as an important source of exports. With an estimated gross value of production of nearly $3 billion a year, dairy ranks third behind wheat and beef in terms of output value at the farm gate. Edwards (2003) reports that over the last 30 years the number of dairy farms has fallen 70 per cent, but average farm size has increased and average milk produced per cow has almost doubled.

The pressures on dairy farmers industry to remain efficient have increased following deregulation of the industry in July 2000, and the introduction of a competitive market structure (Edwards, 2003). These changes follow on from significant deregulation earlier to the dairy processing industry that lead to dairy farms being exposed directly to world market forces (Doucouliagos and Hone, 2000).

The movement towards a more open and competitive environment for Australian dairy farms, apart from changing the structure of the industry, means that efficiency will become an increasingly important determinant of financial success at the farm level and of economic viability at the sector level. Identification of possibilities for improving efficiency should enhance farm profits and strengthen the competitive position of the industry (Weersink et al. 1990). Changes in technology have been biased towards using more purchased inputs and the dairy sector is no exception to this trend. These inputs have been significant in increasing productivity but they have also been responsible for environmental damage. Over the past decade or so, it has been repeatedly shown that nutrient run-off and leaching from agricultural sources, including dairying, is a significant source of ground and surface water pollution. Hence any attempts towards improving efficiency needs to consider environmental consequences. Farmers now have to apply marketable inputs as efficiently as possible to be competitive, and deal efficiently with the environment to create an environmentally friendly agricultural sector and promote the image of clean and green production. Rapid intensification of livestock production in the Netherlands as a result of increasing productivity is reported to have contributed to a large increase in nutrient surpluses (Ondersteijn et al. 2001).

The conventional definition of efficiency can be traced back to the work of Farrell (1957) where the efficiency of a farm was measured directly from observed data, using a single output and multiple inputs. Efficiency consisted of both technical, which refers to the ability of a farm to produce maximum output from a given set of inputs, and allocative efficiency, which refers to the ability of a farm to optimise on the use of inputs given their respective prices. More recently, and in recognition of the impact agriculture has on the environment, a third type of efficiency, environmental efficiency, is being defined and measured.

In this paper by exploiting the ideas of productive efficiency theory (Tyteca 1996), I examine possible ways of accounting for the environmental impacts associated with dairying, to be able, at a later stage, to compare farms in a region, monitor their performance over time and assess their impact on the environment. Farmers generally are more conscious of the environment and many are willing to be pro-active in their behaviour, although environmental damage will depend on the natural conditions of a region, such as soil type and climate, as well as the management of the inputs.

McGuckian (2000) claims the Australian Dairy Industry has recognised the need to ensure the sustainability of its industry through improved productivity, improved profitability and a healthier environmental base to dairy production, and agricultural policy today reflects these concerns. Parallel to this evolution, there is a need for tools to allow proper objective quantification or measurement of the performance of farms with respect to the environment.

Tyteca (1996) argues for an objective quantification or measurement of the performance of firms with respect to the environment. Efficiency will become an increasingly important determinant of financial success at the farm level and of economic viability at the sector level. The possibility of increasing efficiency, both technical and environmental, should benefit both the individual, in terms of farm profit, and society, in terms of social costs being reduced, and thus strengthen the competitive position of the industry. With increasing public awareness and consciousness of the environment, promoting the environmental performance of dairy farming will be beneficial to the sector's public image.

## 2 Meaning of Efficiency

In general terms, efficiency refers to "how well" or "how effectively" a decision making unit combines inputs to produce an output. That is, it expresses the percentage of attainable production that is actually achieved and can be distinguished from productivity which considers the amount of output produced with a certain amount of inputs. In the theory of productive efficiency there are two main components – technical efficiency and allocative efficiency. Technical efficiency focuses on output produced from a given bundle of inputs and technology, while allocative efficiency focuses on the ability and willingness of an economic unit to minimise costs of production for a given set of input prices through substitution or reallocation of inputs. Quantifying these measures allows comparisons across similar units to determine relative efficiencies and to identify the factors that are responsible for the variations between units. That is, both the level and source of the problem can be identified and appropriate policy developed.

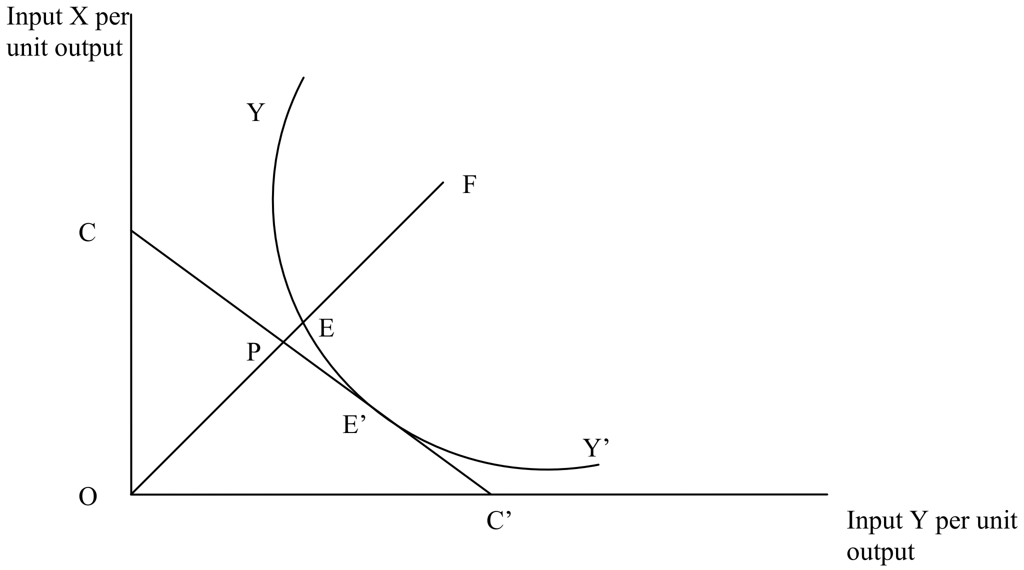
Today, environmental efficiency, an additional type of efficiency and one for which an estimate, separate to technical efficiency, can be provided, is of growing importance (Reinhard et al.1999). Inputs used in the production process can have an impact, either positive or negative, on the environment and environmental efficiency aims to take account of this impact in ranking economic units according to their level of efficiency. If policy to improve the environmental performance of dairy farming in Australia is to be developed, the impact of various characteristics on environmental efficiency needs to be identified.

Technical efficiency refers to the ratio of actual to best practice (or "frontier") production (De Koeijer et al. 2002). That is, it refers to the ratio of observed output to maximum feasible output as specified by the production frontier. It is a relative measure – the efficiency of a farm relative to other farms in the sample. Farrell (1957) argued that it is more appropriate to compare a farm's performance with the best actually achieved rather than with some unattainable ideal. The existence of persistent technical inefficiencies over time, offers an opportunity to reduce inputs without reducing outputs (input-reducing technical efficiency) or to increase output from the same amount of input (output increasing technical efficiency). If constant returns to scale are assumed, actual production is compared with one specific best practice on the frontier, namely where input use per unit of output is minimized (de Wit 1992). For this specific best practice, the input-reducing and output-increasing technical efficiencies are identical. In agricultural production studies, the input reducing and output increasing technical efficiency under variable returns to scale are commonly used (De Koeijer et al. 2002).

Allocative efficiency focuses on the ability of an economic unit to minimise the cost of production for a given set of input prices by substituting or reallocating inputs. It is given by the ratio of cost efficiency to technical efficiency.

The relationship between the different types of efficiency can be presented graphically by looking at the relationship between two inputs and one output. In Figure 1 below, YY' depicts the different combinations of two inputs that can produce a given level of output for a technically efficient firm. The efficiency of a firm using inputs defined by point F is given by the ratio of the distance OE to OF. Inputs could be reduced by this amount while maintaining the same level of output. If costs are known, CC' represents the combinations of the two inputs that can be selected for a given budget. For firm F, the ratio of OP to OF represents cost efficiency, with PF depicting cost inefficiency. However, P is not technically efficient. Point E' shows the mix of inputs where both production costs and input levels are minimized for the given level of output. This is the point of full allocative efficiency. Allocative efficiency for firm F is the ratio OP to OE. Total or overall economic efficiency (EE), is defined as the ratio OP/OF. It is the product of technical and allocative efficiency. The distance PF can be interpreted in terms of cost reduction. Economic efficiency is a key measure of the economic performance of any industry but to be successful both market and non market flows need to be included and priced according to their full opportunity cost, that is their social opportunity cost.

**Figure1: Technical and Allocative Efficiencies**

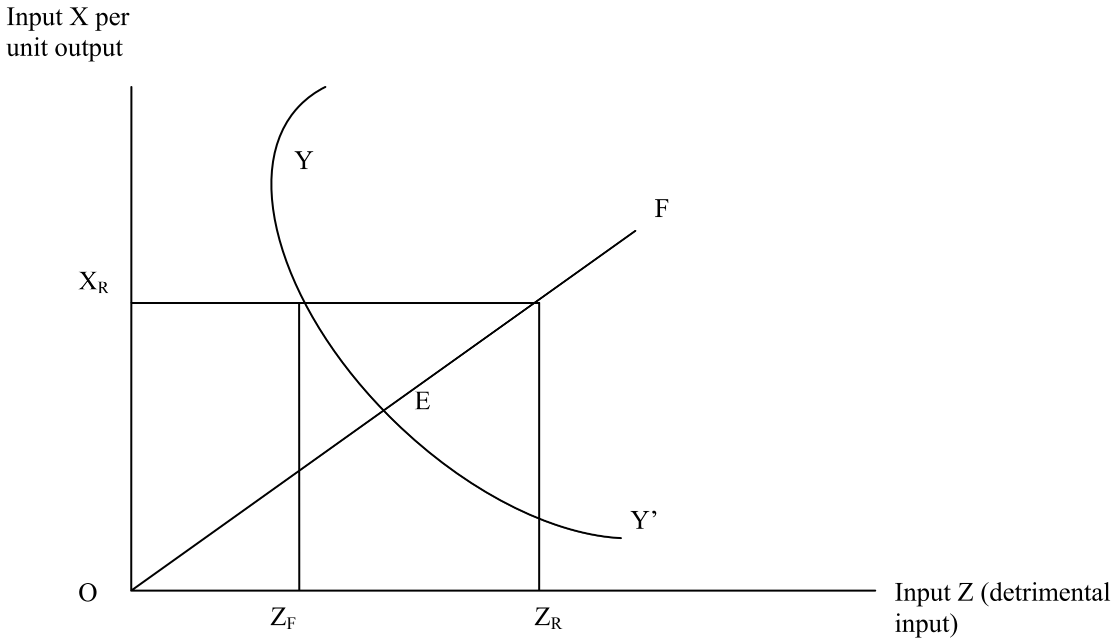



*Source: Avkiran (2002,) p.143*

Calculation of the technical efficiency highlights the possibilities of improving the environment by reducing the extent to which any environmentally damaging inputs, such as nitrogen or phosphorous fertilizers, are applied, or, more importantly, the extent to which the associated environmentally detrimental impacts, such as increased nutrient run-off, can be reduced by more efficient use (De Koeijer et al. 2002). In agricultural production, nitrogen pollution comes from two sources, the application of fertilisers and the application of manure, both in excess of plant requirements. Environmental problems such as the eutrophication of waterways, evaporation as ammonia, contributing to acid rain, and depending on soil type and structure, the leaching of nitrates into groundwater supplies are created.

In calculating technical efficiency, the full cost of many of these flows is difficult to quantify and hence are ignored. However, the inputs used to create the output can be quantified and thus are considered in the measurement of efficiency. Reinhard et al. (1999) in their assessment of Dutch dairy farms define environmental efficiency as the ratio of minimum feasible to the observed use of an environmental detrimental input. Environmental efficiency is essentially one aspect of technical efficiency in that it focuses on one input which has negative environmental consequences. This measure is then a non radial input orientated measure since only one of many inputs is examined. A reduction in the level of polluting inputs will impact on both technical efficiency and environmental efficiency. If input y (Fig.1 above), is assumed to be an environmentally detrimental input, input z, the production function could be represented as in Fig.2 below:

**Figure 2: Production Frontier with input X, and detrimental input, Z**




*Source: Reinhard et al.(1999), p.49*

A measure of environmental efficiency (EE), is provided by the non-radial input-oriented measure

EE = $|OZ_F|/|OZ_R|$, where $Z_F$ is the minimum feasible environmental detrimental input given the production function and observed values of the conventional input X and output YY'.

Reinhard et al. (1999) claim technical efficiency is both a necessary and sufficient condition for environmental efficiency, although a high degree of technical efficiency could be compatible with a relatively low degree of environmental efficiency if high levels of the environmentally detrimental input are applied. Reinhard et al.(1999) study of the Dutch dairy sector report technical efficiency of 89% throughout the period 1991-94, but only 43% to 45% environmental efficiency over the same period. Likewise, a low degree of technical efficiency is compatible with a high degree of environmental efficiency at low input mixes of the environmentally detrimental input. The extent of the divergence between the two measures depends on how much the detrimental input can be substituted in the production process.

The levels of environmental and economic efficiency of farms can be compared and differences analysed to determine reasons for differences in performance and the options for improvement. If farmers can improve their use of any inputs which have negative environmental impact, economic and environmental objectives will be simultaneously achieved. With increasing environmental legislation and mounting popular concern for the environment, the importance of good environmental performance, in terms of reducing input emissions and wastes, is now recognised.

## 3. The Theoretical Development of Environmental Efficiency Measurement

A variety of performance indicators have been proposed in the past, and they can be grouped into two categories: those which adjust conventional indexes of productivity change, and those which adjust conventional measures of technical efficiency. Tyteca (1996) reports on the general research strategy and claims the approaches used have been to consider environmental effects as undesirable outputs and to recalculate the technical inefficiency accounting for these undesirable environmental effects. Productive efficiency is measured while accounting for pollution, essentially in the form of "undesirable outputs". Emphasis is on overall productive efficiency with no attempt towards defining or quantifying environmental efficiency. The methods used to quantify efficiency vary with regard to the assumptions on the outer bound of the frontier, which may be either deterministic or stochastic, and with regard to the measurement approach, which may either be non-parametric or parametric.

Pitman (1983) was one of the earliest studies to incorporate environmental effects into production efficiency estimates. Both desirable and undesirable outputs were taken into consideration in developing a "multilateral productivity" indicator, in which environmental effects were treated as additional undesirable outputs whose disposability is costly. This approach raises the need for shadow prices since undesirable outputs are not generally priced in markets.

Fare et al. (1989) also treated environmental effects as undesirable output and developed an "enhanced hyperbolic productive efficiency measure" that evaluates a producer's performance in terms of the ability to obtain an increase in desirable outputs and a reduction in undesirable outputs, subject to the constraints imposed by the inputs and the technology. They modified Farrell's (1957) measure of technical efficiency, the nonparametric mathematical programme, Data Envelope Analysis (DEA), to construct a production frontier and calculate the enhanced efficiency measure. Output quantities, rather than prices, were used and the efficiency measure could generate a variety of performance measures, depending on what is being maximized, minimized and held constant.

Fare et al. (1993), followed by Hetemaki (1996), also treated environmental effects as undesirable outputs and used a distance function where the shadow prices of undesirable output are calculated from the model. Tyteca (1996) claims the approach could be modified to derive an environmental performance indicator as the ratio between the overall productivity measure, (using both desirable and undesirable output), to the gross productivity index where undesirable output is ignored.

Ball et al. (1994) provided an empirical application of the DEA model in which nitrogen surplus was treated as an undesirable by-product and a variety of adjusted efficiency measures and the corresponding shadow prices of the undesirable output were calculated and used to produce a Tornqvist productivity index for US agriculture. Their analysis highlighted the significance of including undesirable output in any analysis.

Tyteca (1996) also viewed environmental effects as undesirable outputs, and using a non-parametric approach, developed 3 alternative DEA models to the measurement of productive efficiency, claiming each model expanded the initial idea of DEA, i.e., minimize the ratios of weighted sums of inputs to weighted sums of desirable output. The first model was an undesirable output-orientated model, where both desirable and undesirable outputs were combined with the inputs to yield a value for environmental efficiency. Undesirable outputs are viewed as peculiar outputs, which are minimised with respect to other production factors (inputs and desirable outputs).The second model minimised the ratio of the weighted sum of inputs and undesirable outputs to desirable output, while the third used a normalised undesirable output approach, where the weighted sums of the undesirable output were scaled by the desirable output.

The above studies have all included three sets of factors: inputs, desirable outputs and undesirable outputs. Environmental effects were incorporated in the output vector, and the measure of technical efficiency incorporated the generation of one or more environmental effects as by products of the production process.

Reinhard et al. (1999, 2002) adopt a different strategy. Econometric techniques are used to obtain efficiency estimates. Using a single output, a stochastic production frontier, rather than a stochastic distance function is estimated relating the environmental performance of individual farms to the best practice of environment friendly farming. Perhaps more significantly, the environmental effect, excess application of nitrogen, is modelled as a conventional input, rather than as an undesirable output. Reinhard et al. (1999) claim the environmental detrimental input can be measured but the environmental repercussions can't be measured. Undesirable outputs can't then be incorporated in the model; hence nitrogen surplus is taken as a proxy for the environmental repercussions. Focusing on just one of several inputs it is said to be an input-oriented, single factor measure of the technical efficiency of the environmentally detrimental input. It is a non-radial notion of input efficiency and allows for a differential reduction of the inputs applied compared to the standard radial measure, which treats the contribution of each input to productive efficiency equally. Separate estimates of technical efficiency and environmental efficiency are provided, enabling an assessment of the compatibility of both types of efficiency.

De Koeijer et al. (2002), although following the approach of Reinhard et al. (2002), apply the non-parametric DEA to obtain estimates of technical efficiency and environmental efficiency of Dutch sugar beet growers. The question of which farms are relatively technically efficient and relatively environmentally efficient and whether of not the two types of efficiency are compatible is raised.

De Koeijer et al. (2002) claim that it is important to account for the fact that environmental damage depends on the area over which the total damage spreads, and define environmental efficiency per unit area to take account of the carrying capacity of the environment. To minimize the observed environmental impact, an acreage constraint replaces output maximization constrain in the technical efficiency measurement, and ensures pollution per unit is minimized while searching for efficient farms. The environmental impacts of polluting inputs, rather than the amount of observed inputs, are used to measure environmental efficiency. Area-oriented environmental efficiency, (EEa), is distinguished from the conventional output-oriented environmental efficiency, (EEo) and is then used as an indicator of sustainability.

## 4 Measuring Environmental Efficiency of Victorian Dairy Farms

### *4.1. The Approach To Be Used*

DEA is a relatively straightforward and flexible non-parametric linear programme which can be used to calculate the efficiency frontier and the distance to that frontier for each individual farm. The frontier is found by enveloping the data points of the observed "best practice" activities that are the most efficient farms (De Koeijer et al. 2002). DEA presents a scalar measure of the relative efficiency of each unit and so assesses not only the efficient farms that comprise the efficiency frontier, but also assigns a score for all farms not on the frontier, that is, those that are inefficient A relative measure, the TE of a farm relative to others in the sample, is derived. TE measures by how much each input can be radially reduced (or output increased) to produce an efficient outcome.

Callens and Tyteca (1999) claim the principal advantage of using DEA to compare farm performance is its objectivity, since no judgment of any kind from any person is required, and no a priori weighting is given to any of the factors taken into account. The robustness of linear programming and the ability to include a variable that is neither an economic resource, nor a product, but is an attribute of the environment or of the production process, are claimed to be the advantages in using a non-parametric approach. DEA can incorporate both physical and monetary data, and provides a clear and obvious standardisation by using a score from 0 (worst performer) to 1 (best performer), and can be used as a benchmark for other farms. It is a simple but relatively effective system to monitoring farm level efficiency and allows local action to deal with relative inefficiency once identified. The ability to respond locally to observed inefficiencies is an important feature on any farm extension programme aiming to raise overall standards of performance.

Three categories of factors, inputs, desirable output and pollutants in the form of undesirable inputs, (as against undesirable outputs as in much of the literature) will be used. For dairy farming, production can be measured in terms of litres of milk, or kilograms of butterfat. Measures of butterfat can be converted into a common output measure of litres of milk. Among the inputs considered for inclusion in the model are farm size, the number of milking cows, water use, in particular data relating to irrigation, fertiliser use, labour inputs, including family and hired labour, feed, capital value and overhead costs. Limiting analysis to one dairy region, farms can be assumed homogeneous in terms of soil type, climatic conditions and other physical parameters. Combining the inputs in varying quantities to produce the marketable output, the efficiency of a farm, compared to others using similar production technology, can be determined.

Using an input orientation model and assuming constant returns to scale, (CRS), the linear program to be estimated, following the approach of Coelli et al. (1998), is as follows:

$$\min_{\theta\lambda}\theta$$

subject to

$$Y\lambda - y_i \geq 0$$

$$\theta - X\lambda \geq 0$$

$$\lambda \geq 0 \qquad (1)$$

where we assume that we have K inputs, M outputs, N farms and that $x_i$ and $y_i$ are the inputs and outputs for the i-th farm. X is K by N input matrix, Y is an M by N output matrix, $\theta$ is a scalar and $\lambda$ is a N * 1 vector of constants.

The value of $\theta$ estimated will be the efficiency score of the i-th farm. It will satisfy the condition $\theta \leq 1$, with a value of 1 indicating a point on the production frontier and thus a TE farm. A value less than one indicates the farm, given the set of observations in the sample, can improve the efficiency of its inputs by forming benchmarking partnerships and emulating the best practices of its reference or peer group of farms. The problem needs to be solved N times, once for each farm in the sample, to derive a value for $\theta$. Essentially, the DEA contracts radially the input vector, to produce a projected point, $(X\lambda, Y\lambda)$, within the input set (the production frontier). Referring back to Figure 1, the radial contraction of the input vector would result in production at point E, rather than F.

### *4.2 Quantifying the Environmental Impact*

Some inputs, for example nitrogen fertiliser, have been found to contribute to environmental degradation. Larson and Vroomen (1991) report that in the United States and the European Community, fertilisers have contributed to the contamination of water supplies, while in the United Kingdom, environmental management techniques have been developed in response to research into the environmental impact of agricultural activities (Skinner et al. 1997). In Australia, water and salinity are perhaps at the forefront of environmental concerns, and nitrogen as a pollutant can affect water quality.

For dairy farming, and in particular, dairy farming in Victoria, the main environmental issues centre on the quantity of water used, nutrient run-off and leaching polluting surface and ground water sources, loss of bio-diversity and green house gas emissions. These issues have arisen from land clearing and the associated loss of environmental services, increasing herd size, and intensification of farming. Greater intensification increases the reliance on irrigation, the use of fertiliser for pasture growth and the amount of animal waste and dairy shed effluent, all of which can have detrimental environmental impacts, both at their source and also many kilometres from their place of origin.

Environmental impacts are not only those that can be measured chemically and biochemically. There are also visual/aesthetic impacts such as the appearance of the landscape, and socio-economic considerations, such as implications for rural communities. Although these issues are beyond the scope of the present paper they are nevertheless important.

Environmental effects can be difficult to quantify. However, an input, whose use creates the effect, can be quantified and used to analyse economic and environmental performance of dairy farms. A nitrogen budget has been used for studies on farm environmental efficiency in the Netherlands where suppliers of compound feed and fertilizer and buyers of milk periodically (i.e. once a quarter) provide an overview of the flow of nutrients to the farmer**.**

European farming systems use huge amounts of nitrogen fertiliser on cereal crops and grasses for animal feeds. In Australia, pastures provide the major source of nutrients for dairy cows. The environment supplies nitrogen by deposition, mineralization on peat soils and N fixation. Traditionally, farmers have relied on $N_2$-fixation for their pasture N requirements but symbiotic $N_2$-fixation rarely supplies sufficient N to achieve more than 70% of all pasture production. Nitrogen fertiliser is used to help fill expected feed gaps on dairy farms, and over the last 15 years, Eckard (1996) claims with increased stocking rates and tighter calving patterns increasing the demand for feed on Australian dairy farms, the use of N has increased dramatically.

In addition to fertilizers, livestock waste is also a significant source of nitrate. The N loadings in intensive industries such as dairying tend to be high, since large numbers of animals are managed on relatively small areas of land. Dung and urine are both very high in nitrogen. The average dung patch is equivalent to applying 130 to 220 kg nitrogen per hectare, while the average urine patch applies the equivalent of 800 to 1300 nitrogen per hectare (Eckard and McCaskill 1999).

Both nitrogen fertiliser and manure requires careful management to minimize losses to the environment. The major pathways for N loss, apart from the removal of harvested product, are via the processes of leaching, surface run-off, denitrification and volatilisation. Nitrogen is transported off-site in gaseous, dissolved or particulate forms. The loss mechanisms, and the extent to which they occur, are dependent on many factors, including climatic conditions, application rate, soil type, amount of soil cover, type of cultivation and timing of rainfall relative to fertiliser or manure applications.

Eckard and MCCaskill (1999) claim both dung and urine are high in N and more than 60% of N in a dung patch may be lost through leaching and volatilisation. Minimising the time cows spend in laneways and the spreading of effluent back on pastures can assist in minimising this loss. Nitrate leaching occurs when the soil nitrogen washes down the soil profile and is of great environmental concern as water entering streams and aquifers may be polluted. Denitrification occurs when nitrate is converted to nitrous oxide, a process more likely under warm than cold conditions and not likely to be common in SE Australia where soils are usually either water logged and cold in winter or warm and dry in summer.

To assist farmers improve nutrient efficiency on their farm, nutrient budgeting, used extensively in the Netherlands, as indicated above, is an important best management practice. A nutrient budget is a balance sheet of total nutrients brought on to the farm in fertilisers and feed, balanced against the total nutrients leaving the farm in animal product (Eckard and McCaskill 1999). Total output minus total inputs equals the surplus of nutrients left on the farm during the production process. To calculate the surplus, additional data to that used in estimating technical efficiency, is required. All output, not just the milk sold to the milk processing companies, but also saleable milk that is fed to calves, plus the number of animals sold during the period under study must be included. Additional input data required includes details about the siting of the farm – soil type, drainage, slope, rainfall, - pasture species, grazing management, proximity to streams/water catchments, as well as details about the type of fertiliser used, the timing and rate of application. This surplus will find its way into the environment through emissions to soil, water and air (ammonia). Inputs minus output determine the surplus N applied.

*Table 1: An Example of a nitrogen budget for a dairy farm*

| | |
|---|---|
| *Nutrient Surplus* | |
| *N Inputs* | *N Output in Products* |
| N fertiliser | Milk |
| N2 fixation | Meat |
| Rainfall | |
| Hay | |
| Grain | |
| Total N Inputs | Total N Outputs |
| | *N Surplus* |
| | *N use efficiency ratio (%)* |
| | *(products produced/nutrients applied)* |

Source: (Eckard and McCaskill 1999)

Breembroek et al. (1996) claim the surplus is an indicator of the on-farm efficiency of the production process. To reduce a nitrogen surplus at the farm level, a farmer has two options, either to raise the efficiency of nutrient use, by reducing the amount of nutrients in products bought or by raising the amount of (nutrients in) products sold or removed.; and/or reduce livestock intensity, either by reducing the number of animals or by increasing the farm area.

The model to be used to assess environmental efficiency is formulated in the same way as the model used to determine technical efficiency, except that rather than treating all inputs the same, variables that impact on the environment will be included directly into the LP formulation. Environmental variables are assumed to able to be radially reduced (by θ) just like a regular input. Following the approach of Coelli (1998), the input-oriented LP in (1) above is used with L environmental variables added to become:

$$
\begin{aligned}
&\min_{\theta\lambda}\theta \\
\text{st}\quad & Y\lambda - y_i \geq 0 \\
& \theta x_i - X\lambda \geq 0 \\
& \theta w_i - W\lambda \geq 0 \\
& \lambda \geq 0 \qquad\qquad (2)
\end{aligned}
$$

The environmental variables are denoted by the L *1 vector $w_i$ for the i-th farm, and by the L*N matrix W for the full sample.

The environmental variable to be used here, the N surplus, is a detrimental input in the production process, thus the measure will need to be inverted before including it in the W matrix, or, a restriction of the form $W\lambda - \theta w_i = \geq 0$ can be used (Coelli et al. 1998).

In addition to calculating the level of environmental efficiency, the nitrogen budget can be analyzed in more detail to determine both positive and negative environmental consequences. The N surplus can be split into beneficial flows, in terms of nitrogen either being returned to the atmosphere or acting as a fertilizer, and external detrimental flows in terms of the amount that is lost through the processes of volatilisation, denitrification and leaching. The output split can be modelled using N CYCLE, a computer-assisted learning (CAL) module, developed at the Institute of Grasslands and Environmental Research, England. Mundy (2001), in an evaluation of this model, reports that the model, using the mass balance approach, displays the amounts of N that annually move through the different pools within a grassland system. Lockyer et al. (1991) suggest that although designed for grassland grazed by beef cattle, the model has wide application with the inclusion of a mineralisation sub-model, which is sensitive to soil type, pasture age, soil history, and climatic zone. Mundy (2001) claims the model, after modification, can display annual flows of N, making it potentially suitable for predicting N cycling, for both irrigated and non irrigated pastures.

To use the model, site-specific parameters to the model need to be collected and set in the model. Data relating to climatic zone, soil type, drainage status, paddock history and pasture age has to be specified so that the mineralisation sub-model can adjust the mineralisation process for these conditions. The sub models then calculate and display the annual fluxes of N.

The impact of the N fluxes, in terms of both private and social benefits and costs needs to be determined since benefits and costs that are relevant to an individual farmer may not be relevant to society and vice versa. Sensitivity analysis can be used to determine the costs associated with the nitrogen surplus flows. An external outcome is one that arises when the production of one individual or group of individuals affects the activities of another individual or group of individuals and no compensation is paid for the effect. Both private (individual farm) and social (private plus external) benefits and costs need to be derived and used to estimate the environmental consequences of the farming practices using excess N.

Off-site effects (losses), of nitrogen can be ignored by an individual farmer however, from a social point of view, the cost of the nitrogen run-off could be large. Experience in other countries such as Britain, the Netherlands and New Zealand shows that sustained high rates of N fertiliser application can lead to losses of N from farms to waterways and the atmosphere, with potential adverse impacts on the environment and quality of water supplies for human consumption (Eckard 2001). Eckard (2001) also claims there is insufficient quantitative information readily available on N cycling processes in dairy farm systems in south eastern Australia. Thus any farm management practice with the potential to assist in minimising the off-site movement of N needs to be encouraged. For example, adoption of more accurate methods of identifying fertiliser needs, such as soil tests, combined with more precise application techniques, such as Nutrimatch,[1] will reduce costs and therefore improve profits while also reducing N losses, which is important from a social viewpoint. Stocking rates and stock intensity also need to be considered. Higher stocking rates increase the potential for loss. In addition, nitrogen should only be applied when pasture is growing and can use the nitrogen. It will be most effective if applied soon after grazing when active growth is occurring. Pasture species, soil temperatures and moisture, slope of land, application rate, other nutrients, as well as grazing management all need to be considered. Lower application rates, applied often, will be more effective than higher rates applied less frequently.

## 5. Conclusion

In Australia,, as in many European countries, for example, Great Britain and the Netherlands, there has been an increase in research into the environmental impacts of agricultural activities and the development of focused environmental management techniques in agriculture (Skinner et al. 1997). To avoid some of the negative environmental consequences associated with nitrogen, research in Australia has focussed on the recommended best practices for N fertiliser use and the factors to consider in determining if and how much nitrogen to apply.

The approach outlined in this paper, aims to quantify the effect of nitrogen use. If the nitrogen surplus is used to detect causes of inefficiencies, industry groups and governments will be provided with adequate tools to provide field extension activities or adopt incentives that will ensure improved performance in terms of economic and environmental efficiency and the overall sustainability of dairy farming. Policy, focussing on incentives to reduce N input and hence run-off, could be developed.

[1] Nutrimatch, as reported in WestVic Dairy News, Jan.2004, takes a whole farm approach to nutrient management. A farm's fertiliser requirements can be determined by looking at nutrients imported into the farm (for example in feeds), and exported in for example, milk. Nutrimatch is available on the Target 10web site, (www.Target10.com).

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