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# **Implications of alternative mill mud management options in the Australian sugar industry<sup>1</sup>**

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Sugar mills produce a range of by-products during the process of sugar extraction. Mill mud is one of the by-products produced in significant volume. The practice of spreading mill mud over nearby cane fields has been the primary means of disposing of mill mud for many years. The continued application of mill mud at high rates, without appropriate recognition of its nutrient content, the soil condition, crop nutrient requirements, slope and proximity of application sites to environmentally sensitive areas has raised a number of concerns in recent years, including over-fertilization, heavy metal contamination, leaching, and offsite impacts from drainage to waterways. This study develops a regional mathematical programming model to determine optimal rates of mill mud application for various soil types and distances from the mill in Mackay region in central Queensland.

Keywords: mill mud, by-product, spatial, nutrients, economic, GIS, mathematical model

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## Introduction

The Australian sugar industry generates a number of by-products (waste materials) during the process of sugar production including bagasse, mill or filter mud, ash, mill effluent, dunder/biodunder and trash.<sup>2</sup> The Australian sugar industry has a long history of utilising these by-products primarily as a source of energy (bagasse) but also as a source of nutrients and as soil ameliorants (especially the organic materials) (Chapman, 1996; Barry *et al.*, 2000). The estimated size of the nutrient resource in mill mud alone produced by Queensland sugar mills is 7,300 tonnes of nitrogen (N) and 4,500 tonnes of phosphorus (P) each year. For phosphorus, this represented 60% of the estimated 7,700 tonnes of phosphorus applied as fertiliser to Queensland canelands in 1994, while a significant amount of nitrogen is also available (Barry *et al.*, 2000). The re-use of these by-products has been of mutual benefit to the farming and milling sectors as well as supporting the industry's endeavours to be viewed as clean, green, and responsible (Barry *et al.*, 2000). There is also an argument that since these products originally came from cane farms, it makes sense to return them to the farms thereby reducing the dependence on imported commercial fertilisers. Current practice distributes mill mud back to those farms which are in close proximity to the mills (less than 20 km) due to its great volume and high moisture content. Spreading the mill mud on farms further away from a mill has been seen as financially unattractive in the past. However, the continued application of mill mud at current rates (i.e. approximately 150 wet tonnes/ha), without appropriate recognition of the nutrient status of the soil and crop requirements, has raised a number of concerns regarding over-fertilisation of P and long term accumulation of heavy metals on cane farms in close proximity to mills (Barry *et al.*, 2000). Other issues include offsite effects such as impact on the riverine environment. An excess of nutrients increases the risk of leaching which can damage the environment and also incurs costs to landholders. Excessive amounts of nutrients lead to increased algal growth, reduced water clarity, increased water treatment costs and altered fisheries, possibly even fish kills (Lory, 2000).

If mill by-products are applied, their application must be appropriate and account for their nutritional values. Farmers should reduce their commercial fertiliser applications where mill mud has been applied. A comprehensive mill mud management strategy should also consider locational characteristics of farms, such as soil types and paddock layouts, and other geographic features. Estimates of the cost of each mill mud application (including supplementary commercial fertiliser cost) at various distances from the mill is necessary. To achieve economic optimality, it is essential to estimate the marginal value product of each application rate of mill mud for each soil type. This paper has developed a spatial mathematical programming model to determine optimal mill mud application rates on various soil types and at various distances from the mill in the Mackay region of central

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<sup>2</sup> Bagasse is the fibrous residue left after the juice is extracted and is mainly used to fuel the mill boilers to generate steam and electricity. Mill mud or filter mud is the solid material left after filtering cane juice while ash is the residue produced when bagasse is burned in boilers. Mill effluent is largely the water contained in the cane supply. Dunder or biodunder is the liquid waste from fermenting and distilling molasses to make ethanol which in Australia is usually carried out in distilleries that are separate from the raw sugar production facility. Trash is the residue of leaves and tops left after harvesting cane.

Queensland. In the following section, an overview of mill by-products in the Australian sugar industry is presented. This is followed by with a discussion on the theoretical concepts underpinning the determination of economically optimal mill mud application rates. Issues pertaining to the case study area and need for effective mill mud management are then discussed. Mathematical models and mill mud management options are reviewed in the following section. Then follows a brief overview of the case study area and application of mill mud on cane-farms in Mackay region. The concluding section presents the spatial model for mill mud management with results and discussion that leads to some recommendations.

### **Mill by-products in the Australian sugar industry**

The sugar mills in Australia generate between 0.02 and 0.06 tonnes of mud for each tonne of cane crushed (Chapman, 1996). Harvesting conditions affect the extraneous matter and soil content of the cane supply which, in turn, affects the quantity of mud. The rate of mill mud production varies with harvesting conditions. Wet weather harvesting and associated stool damage results in an increased amount of soil attached to the cane entering the mill increasing mill mud production. In 1997, the Queensland and New South Wales sugar mills in total produced two million wet tonnes of mill mud and one million wet tonnes of boiler ash (Barry *et al.*, 1998). Generally, a combined by-product of mill mud and ash contains 75 to 80 % moisture.

Traditionally, mill by-products (such as mill mud and ash) have been applied more often as a soil ameliorant than as a substitute for commercial fertilisers. These applications have been made to improve the quality of salt-affected soils and soils with other problems. Cane growers use ash as a soil amendment for sodic soils, heavy clay soils, and subsoils exposed by erosion and land planning. Applying ash improves the structure, water holding capacity, and aeration of soil (Chapman, 1996). Kingston (1999) argued that mill by-products contribute towards better yield, productivity, and profitability by affecting the physical condition of the soil, such as reducing bulk density in the surface soil and by raising pH of the surface soil.

Mill by-products have also been applied to normal soils as a cheap source of nutrients. There is plenty of evidence that cane yield increased following application of mill mud (Chapman, 1996; Kingston, 1999). Schroeder *et al.* (1998) undertook a review of the current basis for nutrient recommendations in the Australian sugar industry and reported that many growers were adopting their own approaches to fertiliser management, often applying nutrients in excess of the recommended rates. They repeated Wegener's assertion that cane growers were trying to maximise their utility or satisfaction by keeping farm incomes within a tolerable risk level. The risk averse nature of farmers and the uncertainties they face often leads them to use nutrient applications greater than necessary to maximise expected profits (Wegener, 1999).

Stockpiling, transport and farm storage of mill mud may also cause pollution problems, particularly in tropical conditions where high intensity rain can lead to rapid flood events. Similar to other soil additives, excess application of mill mud can release volatile

chemicals into the air or nutrients into ground or surface waters, through normal leaching processes. For example, nutrients from mill mud contamination can increase nitrate levels in groundwater and cause bacterial contamination and fish kills in surface waters.

For sustainable disposal and reuse of industry by-products, distribution to minimise deleterious impacts and maximise benefits as fertiliser and soil ameliorant is critical. Economic feasibility is an important factor in even distribution of mill by-products; especially in the case of mill mud which has high moisture content, and this makes its application less attractive due to high freight charges for farms a long distance from the mills. Appropriate recommendations for mill mud application require quantitative estimates of plant nutrient requirements and availability of nutrients at different application rates as well as an estimate of the quantity of additional fertiliser required to balance the plant's needs. Without a comprehensive understanding of mill mud application rates and their nutritional value, there are potential risks of either under-fertilisation or over-fertilisation. Under-fertilisation may result in reduction in yield and productivity while over-fertilisation may result in excessive leaching and damage to the environment.

Appropriate management of mill mud and other by-products requires knowledge of their composition and current application rates as well as the amount of commercial fertiliser being applied by the growers. There are indications that over-fertilising of cane land is occurring and this may be a result of excessive mill mud application and partly due to excessive use of commercial fertilisers. An excess of fertiliser nutrients also increases the risk of leaching which damages the environment and also incurs costs to landholders.<sup>3</sup> Prudent fertiliser application practices are necessary to reduce the environmental impact of their use and also play a significant role in overall profitability of the farm.

The costs associated with transport of mill mud over the distances involved in the mill area may make the practice of spreading it onto distant cane fields uneconomic and so investigation of nutritional values of each nutrient in dollar terms, and comparisons of these costs with commercial fertilisers, is appropriate. There is also need to examine the economic impacts of mill mud application, including on-farm (private) and off-farm (social) costs and benefits. The on-farm costs depend on the nutritional management options available and involve a comparison of the nutritional value of mill mud with commercial fertilisers on different soil types. The off-farm impacts should take account of environmental costs such as those that occur from leaching or odour due to stockpiling (either at a mill or at a farm), erosion or groundwater contamination due to over-fertilisation) and the opportunity cost of heavy metal contamination.

Policy makers and natural resource managers are searching for efficient ways to control nutrient loadings on the environment arising from mill mud application. Currently, there are no specific rules, regulations, or recommendations for the application of mill mud or other mill by-products by the regulatory or any other agencies or departments with

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<sup>3</sup> For example, in the case of nitrogen, only one third of the N applied as fertiliser to the sugarcane crop is used by the crop. The rest of the N goes into the soil reserves or is lost by volatilisation, denitrification, or leaching (Calcino, 1994).

environmental responsibilities. Application rates for mill mud vary between different regions. Chapman (1996) reported that cane growers apply filter mud at rates up to 150 t/ha while Barry *et al.* (2000) reported that mill mud application varied between 150 and 250 t/ha. There is an argument that the current application rate of 150 to 250 t/ha is well above crop requirements and soils in relatively close proximity to the mills are showing elevated levels of nutrients and heavy metal concentrations due to previous applications (Barry *et al.*, 2000). A reduction in application rates could extend the area treated with mill mud and make better use of the nutrients, in particular P, which is applied excessively in some cases (Chapman, 1996).

A recent study by Qureshi *et al.* (2000) focussed particularly on mill mud and analysed the economic feasibility of mill mud application rates in the Mackay region of Queensland. The authors estimated on-farm costs for six different mill mud application rates (varying from 12.5 t/ha to 150 t/ha) for six different distances from a sugar mill. They also estimated supplementary fertiliser costs to balance the nutrients required by sugarcane in the region for each application rate and distance. They estimated total mill mud costs and compared them with the costs of commercial fertiliser for these distances and found that application rates of 150 and 100 t/ha are less expensive than commercial fertiliser for distances up to 20 km from the mill, while application rates of 75 and 50 t/ha were less expensive up to 40 km. An application rate of 25 t/ha is less expensive up to 60 km, but the application rate of 12.5 t/ha is less costly for all the distances compared to the application of traditional fertiliser. They concluded that 12.5 t/ha was the most attractive application rate in the Mackay region for growers who are paying full cost of mill mud application. The recommended application rate of 12.5 t/ha may not be the most efficient rate of application because the study did not identify the situation where the marginal costs and benefits associated with mill mud application were equated for all application sites in the mill area. Ideally, the policy recommendation should take into account a variety of soil characteristics such as productivity, erosion potential, porosity, salinity, assimilative capacity and other characteristics such as proximity to the surface and groundwater and the slope of the land. Thus, there may be differences in costs and benefits between different soil types in limiting the quantity of mill mud application.

### **Economically optimal mill mud application – theoretical background**

The condition of optimum use of an input is that the marginal value product (MVP) equals the price of the input.<sup>4</sup> If MVP is lower than price, the resource is over-utilised and lowering the quantity used at the current price will increase the MVP towards optimality. On the other hand, if MVP is greater than price, the resource is under-utilised and using more of it will bring additional gains to the grower. Allocative efficiency is only achieved when the ratio of MVP to price is equal to one (i.e.  $MVP/P = 1$ ). Under profit maximisation conditions, inefficiencies in the use of an input (such as mill mud) arise when the actual MVP is less than or greater than the expected MVP for current input and output prices.

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<sup>4</sup> The marginal value product of applied water is a product of output price, marginal product of effective water, and irrigation efficiency (Boggess *et al.*, 1993).

In situations where there are a number of crops, efficiency dictates that the marginal net benefit (marginal revenue of product less marginal cost of input) be equalized for all crops. If marginal net benefits are not equal, it is always possible to increase aggregate benefits by transferring mill mud from those crops with low marginal net benefits to those with higher marginal net benefits provided there is enough flexibility to allow mill mud application and distribution. The benefits given up by those crops to which less input is applied are less than those gained by crops receiving additional mill mud. At this stage, mill mud is efficiently applied and no other outcome can improve the welfare of the grower.

The same concepts can be applied in a spatial context. If a farm or region has various soil types, then a similar economic principle applies in the allocation of mill mud to each soil type, and maximisation of farm profit is achieved only if there is an optimal level of mill mud application on each soil type and the marginal productivity of mill mud is the same for all soil types. Efficiency dictates that the marginal net benefit be equalized for all sites or soil types for each crop. When there is a single crop dominant in a region (due to either economic or agronomic conditions), the optimal level of water or nutrient application is still achieved when the cost of one additional unit of input is equal to the additional revenue it generates.

Figure 1 presents a graphical illustration of the efficient allocation of mill mud application to two different soil types on a farm<sup>5</sup>. The x-axis represents the weight of mill mud applied in wet tonnes per hectare. The y-axis represents the MVP for soil type i and soil type j for the application of mill mud. The gently downward sloping curve indicates the MVP for mill mud on the i<sup>th</sup> soil type and the steeply downward sloping curve indicates the MVP of mill mud on the j<sup>th</sup> soil type. If mill mud application to each of the i<sup>th</sup> and j<sup>th</sup> soil types is restricted to, say 12.5 t/ha of mill mud per hectare, the total value product (TVP) for the two soil types is given by area x + y:

$$TVP_{15 \text{ t/ha}} = x + y$$

If the TVP for the system is analysed on the basis that different application rates are applied on the basis of their marginal profitability, the grower will apply a higher amount of mill mud, say 20 t on one site and 10 t on the other site. As a result, the total mill mud applied on two sites is still 30 t, whereas the total value product has increased:

$$TVP_{\text{differential application/ha}} = x + y + z$$

For the farm as a whole, the total value product increases by:

$$TVP_{15 \text{ t/ha}} - TVP_{\text{differential application/ha}} = z$$

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<sup>5</sup> This principle has been described in detail for poultry litter application in Arkansas by Govindasamy and Cochran, 1995), and adapted here for mill mud application.

However, there may be an increase in management cost due to more precise application and distribution and this can be represented as IMC, so that the net benefit to the farm as a whole can be depicted as:

$$z - \text{IMC} = \text{NB}$$

Where NB represents the total net benefits associated with differential mill mud application rates after the management cost of mill mud.

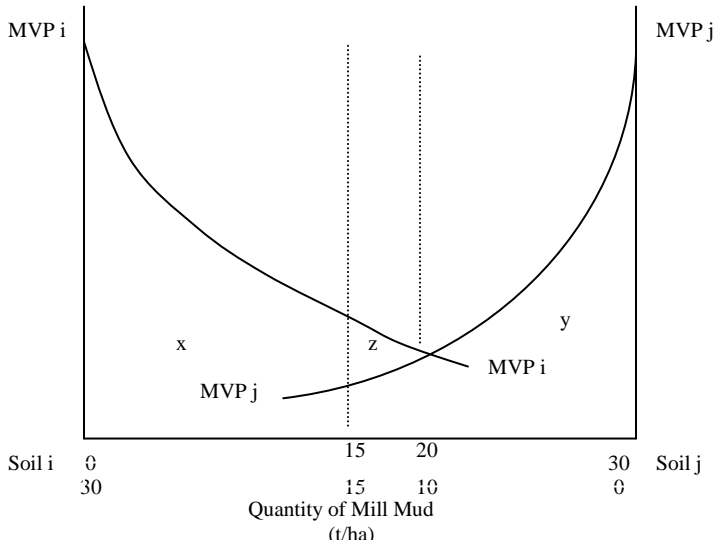


Figure 1: Graphical presentation of efficiency of mill mud for two soil types  
Source: Modified from Govindasamy and Cochran (1995)

### Mathematical models in mill mud management options

Mathematical programming models can help in determining optimal levels of an activity and resource input. They are quantitative in the sense that they indicate, for example, the number of units of each commodity or output to be produced or number of units of each input to be used if a stated goal such as profit maximisation is to be attained. Linear programming (LP) has been widely used in the analysis of resource systems and agricultural planning. Mathematical programming models have also been used to determine demand for irrigation water and water pricing policies and impact of these policies on water demand and farm profitability. Maji and Heady (1978) used LP models for inter-temporal allocation of irrigation water, and considered the stochastic nature of monthly inflows and examined economic impact due to the introduction of new high-yielding crop varieties. Panda and Kheper (1985) used deterministic LP and chance-constrained LP to maximise net return from irrigation planning. Govindasamy and Cochran (1995) used an LP model to demonstrate that a wide range of marginal values for land exist depending on the response to poultry litter application, rates of application of litter, fertility and other characteristics. Tisdell (1996) used an LP model to estimate various demand functions for water by varying water charges in Queensland, Australia.



Mainuddin et al, (1997) used an LP model to determine the cropping pattern to ensure optimal utilisation of available land and water resources in a groundwater irrigation project. Ulibarri et al. (1998) estimated the change in farm profitability from imposing full-cost federal water and power rates using an LP model in California.

The study by Govindasamy and Cochran (1995) on the problem of poultry litter application is similar to the problem of mill mud application because there is no constant nutritional value in either poultry litter or mill mud. The nutrient concentration increases with the increase in application rates and the determination of optimal rate and marginal value of mill mud for various soil types and other characteristics is similar to the poultry litter application. However, the nutritional value of mill mud is comparatively lower than the nutritional value of litter and additional nutrient applications by supplementary commercial fertiliser are necessary to maintain the balance of nutrients required by sugarcane where mill mud is applied. The analytical approach adopted in this analysis resembles the approach of Govindasamy and Cochran (1995), except the current analysis explicitly estimates costs of mill mud application including supplementary commercial fertiliser costs on various soil types for various distances.

### **Case study: Application of mill mud on cane-farms in Mackay region**

The Mackay region is one of the major sugarcane growing regions in Queensland, Australia. The average cane yield in Mackay from irrigated farms varies from 90 to 100 tonnes per hectare while rain-fed farms produce between 75 and 90 tonnes per hectare. The average yield from the district in 1998 was 95 tonnes per hectare. Yields in 2000 and 2001 were considerably lower due to poor seasonal conditions. Fertiliser applications for sugarcane are sometimes adjusted by canegrowers depending on soil fertility levels, measured by soil analysis, but more frequently they apply the recommended amounts or higher in the belief that “more is better”. Other factors considered are crop class, potential crop size, and availability of water from rainfall or irrigation (Chapman, 1996). Mill mud, ash, and combinations of mill mud and ash have been used regularly in the Mackay region for many years. In Year 2001, 322 326 tonnes of mill mud was produced by four mills in the Mackay region. If mill mud is applied as a substitute for commercial (market) fertiliser, then the benefits of these nutrients need to be estimated in the context of the recommended rate for each nutrient and appropriate management of soil without affecting soil quality or yield of cane. It is also desirable to apply an appropriate quantity of mill mud for the sustainability of the local and regional environment, especially considering its impact on the riverine environment and soil quality either in the form of erosion at the time of heavy rainfall or over-fertilisation, or as the result of heavy-metal contamination. Therefore, economically optimal distribution of mill mud is critical and will help to deal with this major by-product of sugar production in the region.

### **Spatial regional programming model for mill mud management**

Linear programming (LP) has been used to develop a regional mathematical programming model of mill mud management (SRMMM) in Mackay region. The SRMMM model of sugarcane farms in the region has been developed in GAMS (General Algebraic Modelling System) (Brooke et., 1998) to determine the optimal application and

spatial distribution of mill mud on various soil types and distances from a sugar mill in the Mackay region by considering mill mud and supplementary fertiliser costs including freight charges. The model can estimate cane profitability per hectare for each soil type and distance from the mill both with and without a cost-sharing program between the miller and the growers for mill mud distribution.

It is assumed that farmers are risk neutral and their objective is maximisation of profit from their income generating activities. The assumptions made by Qureshi *et al.* (2000) are adopted in this analysis. The analysis is carried out for a whole region, therefore the additional assumptions are:

- the total quantity of mill mud is produced by one single mill and distributed immediately without any delay (time lag) between production and application;
- there is no issue of stockpiling either at the mill or on farm and no leaching occurs;
- there is no cost of mill mud charged by the mill and no cost sharing program operating for mill mud. (This condition was relaxed later in the analysis.)

For the analysis, it is assumed that farmers apply optimal levels of mill mud to each soil type  $s$ . The area of land resources allocated to crops  $c$  is equal to the area of plant cane only (because mill mud is commonly applied before planting), mill mud application is  $r$  at distance  $d$ . Aggregate net revenue is calculated by deducting total costs from total revenue.

Thus the objective function becomes maximisation of net economic benefits

$$\begin{aligned} \text{Max } \pi = & \sum_{s=1}^{10} \sum_{d=1}^5 \sum_{r=1}^7 (Y_{s,d,r} P(0.009(CCS - 4) + 0.578) - C_r) X_{s,d,r} \\ & - \sum_{s=1}^{10} \sum_{d=1}^5 \sum_{r=1}^7 (IC_{s,d,r} + OPC_{s,d,r} + FC_s) X_{s,d,r} \end{aligned}$$

where:

$\pi$	is the aggregate difference between returns and costs
$s$	is soil type
$d$	is distance from the mill
$r$	is mill mud application rate
$P$	is sugar price
$X_{s,d,r}$	area in hectares of $s^{\text{th}}$ soil, at $d^{\text{th}}$ distance, with $r^{\text{th}}$ mill mud application rate
$Y_{s,d,r}$	is yield associated with $s, d, r^{\text{th}}$ activity
$CCS$	is percent sugar content in the cane
$CCS - 4$	is the term designed to allocate approximately 1/3 of the proceeds from the sale of raw sugar to the miller and the balance 2/3 to the grower as payment for cane
0.009, 0.578	are constants that reflect 90% mill efficiency and a shift parameter to adjust cane payments to growers, respectively

$C_r$	is cost of applying $r^{\text{th}}$ rate of mill mud application
$IC_r$	is irrigation related costs
$OPC_{s,d,r}$	is operating costs associated with $s, d, r^{\text{th}}$ activity
$FC_s$	is fixed cost of soil $s$

The objective function is subjected the following constraints (omitting other land, labour and water constraints):

**The soil class constraint can be represented as**

$$\sum_{d=1}^5 \sum_{r=1}^7 X_{s,d,r} \leq A_s$$

where  $A_s$  is the available hectares of  $s^{\text{th}}$  soil type

**The contratints on area of soils at different distances can be presented as**

$$\sum_{r=1}^7 X_{s,d,r} \leq (AA)_{s,d}$$

where  $(AA)_{s,d}$  is the available area of  $s^{\text{th}}$  soil at distance  $d$

**The mill mud application constraint can be represented as**

$$\sum_{s=1}^{10} \sum_{d=1}^5 \sum_{r=1}^7 (X_{s,d,r} QMMA_r) = M$$

where:

$QMMA_r$	is the quantity of mill mud applied at rate $r$
$M$	is the total available quantity of mill mud

#### *Details of data acquisition*

The total quantity of mill mud in year 2001 produced in the whole region (from four mills, namely Farleigh, Marian, Pleystowe and Racecourse) was provided by the Cane Supply Section of the Mackay Sugar Milling Cooperative. Yield (tonnes per hectare) for each major soil group was derived from the 2001 year cane production figures for the Mackay Sugar area. A previous study by Holz and Shields (1983) gathered data about various soil types where sugarcane was grown in Mackay district/region and examined land suitability of growing cane in the region. The maps from that study were available in an electronic format from Mackay Sugar and have been utilised in the current study. The information about spatially represented sugarcane paddocks including paddocks and yield data were also obtained from the Mackay Sugar. As both the data sets could be cross-referenced spatially, yield (t/ha) for each soil type was extracted from the data. The paddock areas were summed and yields were averaged for each soil type. Yields in 2000 and 2001 were about 45% lower than the average yield in the region due to poor seasonal

conditions. Therefore, a factor of 45% has been added in the average yield of each soil type. To formulate the mathematical programming model, the area of 10 major soil types (namely alluvial, black earth, grey clay, mountains and hills, non-calcic brown soil, podsollic, prairie, sand, solodic and soloth) which total 79 138 ha and represent about 98% of the total cane growing area of the region (which is 91 480 hectares) was used in the analyses. It is to be noted that currently there is no information available about application of mill mud on cane productivity and it is assumed that each mill mud application will result in the same yield. However, the required nutritional levels for the cane plant was balanced by supplementary commercial fertiliser and a high mill mud application will incur lower costs for commercial fertiliser and vice versa. Information on the technical and economic systems of the cane farms in the study area was obtained from published literature, various public departments, and sugar industry organizations including the Department of Natural Resources and Mines, Bureau of Sugar Experiment Stations, CANEGROWERS Mackay office (the organization of cane farmers) as well as Mackay Sugar (the mill owner and processor). Information from the various sources was crosschecked through informal discussion with local farmers and representatives of various organisations.

The study uses the information on nutrient concentrations in mill mud reported by Barry *et al.* (1998) and estimated the monetary values of the nutrient concentration in different application rates by following the procedure adopted by Qureshi *et al.* (2000). In that study, the cost of mill mud application and distribution (including freight charges and spreading costs) was estimated for a range of application rates to sugarcane farms located at 10, 20, 40, 60 and 80 km from a sugar mill in the Mackay region. The study also estimated supplementary commercial fertiliser costs and added these to mill mud costs to determine total nutrient costs.

Sugar production cost data were obtained from a survey report compiled by BSES (Small, 2000) and from the office of CANEGROWERS in Mackay with fixed costs estimated by the ABARE Farm Survey (ABARE, 1996) The information about permanent (family) labour hours used and labour costs were estimated after discussion with growers and from CANEGROWERS. Sugar content data were obtained from the local sugar mill and an average of the past 10 years was used. Similarly, the average pool price of sugar in Queensland was used and the price paid to growers was estimated using the standard sugar price formula. Water charges for groundwater and surface water were obtained from the local office of the DNR&M. Electricity charges were estimated on the basis of the appropriate electricity tariff and pumping costs for groundwater as well as surface water.

## **Results and discussion**

The preliminary results obtained from this analysis are discussed in terms of each soil type and distance from the mill at which the mill mud is applied. Each of the scenarios is analysed first by using total mill mud costs paid by the growers and not subsidised by the miller (i.e. no mill mud cost sharing program applies) and then by using the mill mud costs after deducting the miller's contribution to mill mud application (i.e. a cost sharing

program is in place). As mentioned above, it is assumed in the current study that each mill mud application rate will result in the same yield (t/ha) for the soil type because of supplementary applications of commercial fertiliser. This means the optimal application rate will be same for all soil types but different for each distance as the total cost of mill mud application at each distance varies. The optimal application rate for the distances of 10, 20, 40, 60 and 80 km were 50, 25, 10, 10 and 10 t/ha, respectively. This means that at greater distances, lower rates of mill mud are economically desirable. When the shared costs of mill mud are used, costs are lower, and the optimal application rates are mostly higher: for the distances of 10, 20, 40, 60 and 80 km they are 25, 25, 25, 25 and 10 t/ha, respectively. This means that optimal application rate reduces from 50 to 25 t/ha at the distance of 10 km (due to low freight charges), remains the same for the distances of 20 and 80 km (i.e. 20 and 10 t/ha) but increased for the distances of 40 and 60 km from 10 tonnes to 25 tonnes.

Net economic benefits to the whole region when full mill mud costs are used are \$4,918,939 and increase to \$6,160,303 (more than one million dollars extra benefits. (But the cost of the transport subsidy to the mills must be deducted in this case since it represents a transfer of cost from growers to the mill).

Gross profits per ha for each soil type for each distance for each scenario (i.e. with and without the cost sharing program) are presented in Tables 1 and 2, respectively. The figures in each table indicate that gross profit per ha is higher when mill mud costs are subsidised than unsubsidised, which was expected. The gross profit from cane growing on alluvial soil is highest and varies from \$598 to \$751 per hectare while the gross profit of growing cane on grey clay soil is lowest and varies from \$168 to \$321 per ha. Similar trends were found in the subsidised cost program.

Table 1: Gross profit/ha for each soil type at each distance (no cost sharing)

Soil type	Gross profit (\$/ha)				
	10 km	20 km	40 km	60 km	80 km
ALLUVIAL	750.76	705.59	651.42	623.58	598.25
BLACK EARTH	446.22	401.05	346.88	319.04	293.71
GREY CLAY	320.56	275.39	221.22	193.38	168.05
MOUNTAIN AND HILLS	412.49	367.32	313.15	285.31	259.98
NON-CLACIC-BROWN SOIL	623.35	578.18	524.01	496.17	470.84
PODZOLIC	400.25	355.08	300.91	273.07	247.74
PRAIRIE	381.01	335.84	281.67	253.83	228.5
SAND	701.54	656.37	602.2	574.36	549.03
SOLODIC	369.77	324.6	270.43	242.59	217.26
SOLOTH	398.75	353.58	299.41	271.57	246.24

Table 2: Gross profit/ha for each soil type at each distance (costs shared)

Soil type	Gross profit (\$/ha)				
	10 km	20 km	40 km	60 km	80 km
ALLUVIAL	782.93	771.34	748.66	726.15	673.25
BLACK EARTH	478.39	466.8	444.12	421.61	368.71
GREY CLAY	352.73	341.14	318.46	295.95	243.05
MOUNTAIN AND HILLS	444.66	433.07	410.39	387.88	334.98
NON-CLACIC-BROWN SOIL	655.52	643.93	621.25	598.74	545.84
PODZOLIC	432.42	420.83	398.15	375.64	322.74
PRAIRIE	413.18	401.59	378.91	356.4	303.5
SAND	733.71	722.12	699.44	676.93	624.03
SOLODIC	401.94	390.35	367.67	318.05	292.26
SOLOTH	430.92	419.33	396.65	331.57	321.24

## Conclusions

During the process of sugar production, the sugar industry produces a number of by-products including mill mud. The Australian sugar industry has been utilising these by-products as a source of nutrients and as soil ameliorants for many years. The use of mill mud has been of mutual benefit to the farming and milling sectors. However, the continued application of mill mud without appropriate management of the soil has raised a number of concerns, especially on cane farms in close proximity to mills. This study is part of a wider investigation that has analysed plant nutritional values of mill by-products and the distribution and application of these products as well as issues of concern due to over-fertilisation and excessive use of mill mud.

Economic analysis of the application of mill mud at different application rates on cane farms in the Mackay region has been carried out to determine the optimal application for each distance and profitability on major soil types. The nutritional value of mill mud and costs of mill mud application at different distances from the mill, have been estimated. Total value of the nutrients has been calculated for six different application rates using market prices for those nutrients, and costs estimated.

The current study findings suggest that even at optimal rates of mill mud and fertiliser application, cane production on some soil types is barely profitable even when a policy to subsidise the cost of transporting mill mud to the farms is in place. This conclusion obviously has wider implications for the continuing production of cane in parts of the Mackay region, irrespective of whether mill mud continues to be subsidised by the mill or not.

Clearly, application rates that vary with distance from the mill are the most efficient if they can be achieved (but this depends on the soil type and nutrient status of each paddock. Lower nutrient costs for the whole district will result if differential rates of mill mud are spread on farms. If instead of the full transport costs, subsidised costs of delivering mill mud are used for the balanced nutrient application rates, then the use of mill mud becomes more attractive to local farmers, because costs of applying mill mud to achieve balanced nutrients applications are lower than the costs of commercial fertilisers.

## **Recommendations**

The volume of mill mud has increased due to mechanisation of the harvesting operation in the sugar industry and more recently it has increased again due to adoption of the practice of green cane harvesting and trash blanketing. As a first best policy, the industry should seek to reduce the level of soil in cane at harvest time and the quantity of mill mud produced. This could be achieved by adopting improved harvesting technology such as the use of harvesting sensors which can help achieve precision in the height of cut from the ground level, thus minimising soil contamination.

This study assumed that mill mud is distributed and applied with its existing moisture content without any modification; and contemporary vehicles and equipment are used for transportation. There is scope to examine the possibilities for modifying mill mud (such as reduced moisture content or composting), and even modifying cane bins that could be used to return mill mud back to the farms using the cane transport railway or modifying the delivery vehicles to allow smaller applications to be made. Currently, there is no information about impact of different mill mud application rates on cane yield for each soil type. The study assumed that each application rate would result in the same yield; therefore, it was not possible to determine marginal value of each soil type for each application rate.

The analysis of the cost effectiveness of mill mud summarised in this paper considered only private (on-farm) costs and benefits of various mill mud application rates for a range of distances. This study therefore does not take into account environmental costs such as those that occur from leaching or odour due to stockpiling (either at the mill or on a farm), erosion or groundwater contamination due to over-fertilisation) or costs of heavy metal contamination. Similarly, benefits of mill mud due to its ameliorant nature, and other beneficial effects were not included. These issues need further investigation.

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