The economics of sugar mill waste management in the Australian Sugar Industry: Mill mud case study

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45th Annual Conference of the Australian Agricultural and Resource Economics Society, Adelaide, South Australia, 23-25 January 2001

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Abstract

Sugar mills produce a range of by-products during the process of sugar extraction. Mill mud is one of the by-products that is produced in significant volume. Often mill mud is mixed with mill ash from the firing of bagasse, which together forms the bulk of mill waste available for disposal from raw sugar mills. The practice of spreading mill mud over nearby cane fields has been the primary means of disposing mill mud for many years. Mills generally promote the practice by offering freight subsidies to reduce the cost burden on growers who use this practice as a routine measure. The low level of nutrients and high moisture content makes mill mud a dilute source of nutrients, and supply of mill mud often exceeds the demand, leading to stockpiling of mill mud at most mills. Moreover, the continued application of mill mud and ash at high rates, without appropriate recognition of the soil condition and crop requirements, has raised a number of concerns in recent years. The risk of over-fertilization and heavy metal contamination of cane fields, and the concerns relating to offsite impacts from spillage to waterways, have raised questions about the indiscriminate use of mill mud in the industry. This study examines the issues relating to more responsible management of mill mud and reports on the cost-effectiveness of its application across a wider range of farms more distant from the mills as a means to minimise environmental risks.

Key words: Plant nutrients, heavy metal concentration, waste management, efficient mill mud management,

Introduction

Milling of cane stalks for the extraction of raw sugar yields several by-products of varying usefulness. These by-products include wastewater, molasses, bagasse, mill mud, and boiler ash. Often mill mud is mixed with boiler ash from the firing of bagasse, which together forms the bulk of the waste available for disposal from raw sugar mills. On average, each tonne of raw sugar produced yields seven tonnes of waste products. Those mills that process molasses to make ethanol also produce biodunder as a further by-product. The Australian sugar industry has a long history of utilising these by-products: bagasse is mainly used to fuel the mill boilers and generate electricity and mill mud or filter mud and ash are mainly used as soil ameliorants or, to lesser extent, as plant nutrients. Mill mud is one of the by-products that is produced in significant volume.

Depending on seasonal conditions, sugar mills generate from 0.02 to 0.06 tonnes of mud for each tonne of cane crushed in Queensland (Chapman, 1996).

Mechanised harvesting under unfavourable weather conditions increases the level of field contaminants popularly known as extraneous matter, which forms the bulk of the mill mud. The practice of spreading mill mud over nearby canegrowing properties i.e. within a radius of 10 to 20 km from a mill, has been the primary means of disposing mill mud for many years. Mills generally promote the practice by offering freight subsidies to reduce the cost burden on growers who adopt this practice as a routine measure to maintain soil fertility. The low level of nutrients and high moisture content makes mill mud a dilute source of nutrients, and supply of mill mud often exceeds the demand, leading to stockpiling of mill mud at most mills. In 1997, the Queensland and New South Wales sugar mills produced more than two million wet tonnes of mill mud and one million wet tonnes of boiler ash (Barry *et al*., 1998).

The low cost of material and the availability of freight subsidies have encouraged growers in areas adjacent to raw sugar mills to apply mill mud as a routine practice, often unaware of its implications. In recent years, the continued application of mill mud and ash at high rates, without appropriate recognition of soil conditions and crop requirements, has raised a number of concerns. The risk of over-fertilization and heavy metal contamination of cane fields, as well as the concerns relating to offsite impacts from spillage to waterways, have raised questions about the indiscriminate use of mill mud in the industry. This study examines the issues relating to more responsible management of mill mud and reports on the cost-effectiveness of its application across a wider range of farms at greater distances from the mills as a means to minimise environmental risks.

Use of mill mud as a soil additive

Notwithstanding the benefits to raw sugar mills of having a ready avenue to dispose of mill waste, responsible use of mill mud as a routine production input in cane farming needs to consider both the nutrition and soil ameliorative properties of mill mud against the costs of its use. For a grower, efficient management of mill mud requires knowledge of benefits and costs of its application from a broader perspective. First, the practice must be cost-effective, in that they need to achieve a reasonable return, based on the agronomic merits of mill mud, on the financial cost involved. On the other hand, growers have a duty of care with respect to the environment which implies that an efficient mill mud management plan also requires them to consider the wider environmental impacts of mill mud application.

Agronomic benefits of using mill mud as a soil ameliorant and source of plant nutrients are discussed in the following sub-section. Some environmental concerns about indiscriminate use of mill mud are examined in the next sub-section. Then a case study is presented into the economic feasibility of applying mill mud at a range of application rates and at various distances from a mill in Mackay region. The study also discusses ways of efficient mill mud management.

Agronomic benefits of mill mud application

The basic rationale for the use of mill mud as an input to cane production is based on a philosophy that the material extracted during harvesting and processing is best returned to its source. The practice of spreading mill mud on canegrowing land was initially trialled at properties owned by mills, and eventually extended to other farms around the mill as cane area expanded and the supply of mill mud increased. The beneficial properties of mill mud are derived from the improvements to both chemical and physical properties of soil. Although it is believed that the application of mill mud may increase the biological properties of soils, no conclusive evidence yet exists to support or refute this belief. It is well established that mill mud can be used as a partial supplement to replace nutrients being removed in the crop at harvest, when applied in conjunction with chemical fertilisers (Chapman, *et al*., 1981; Chapman, 1996; Barry *et al*., 1998; Barry *et al*., 2000).

Mill mud contains important plant nutrients including nitrogen, phosphorous, potassium, calcium, and magnesium. Mill mud also contributes 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 soil pH (Kingston, 1999), while a mixture of mill mud and ash has been applied as a soil conditioner or amendment to improve soil structure, water holding capacity, and aeration. BSES (1994) reported application of mill mud and ash to salt-affected cane land in north Queensland with beneficial effects on soil structure. The moisture holding capacity also increased substantially resulting in yield improvements. However, as a waste material sourced from a milling process, the beneficial properties of mill mud can vary significantly reflecting weather conditions, crop characteristics, soil conditions on farms supplying cane, etc (Table 1).

Table 1: Comparison of nutrient concentration (in average applications of products)

Nutrient	Nutrient content in 150 tonnes mill mud (kg)		Nutrient content in 150 tonnes of ash (kg)		Nutrient content in 150 tonnes of mud/ash mixture (kg)	
	Barry et al.	Chapman	Barry et al.	Chapman	Barry et al.	Chapman
Nitrogen	555	465	56	80	229	360
Phosphorus	341	360	64	100	154	300
Potassium	143	120	345	285	296	195
Calcium	878	645	341	350	566	600
Magnesium	236	135	255	165	240	165
Sulfur	10.10	57	26	N/A	49	N/A

Source: Adapted from Barry et al. (1998) and Chapman (1996)

Overall, the estimated size of the nutrient resource in mill mud produced by Queensland sugar mills is 7 300 tonnes of nitrogen and 4 500 tonnes of phosphorus each year. This represented 60% of the estimated 7 700 tonnes of phosphorous applied as fertilizer to Queensland cane fields in 1994, while a significant amount of nitrogen is also available (Barry *et al*., 2000). In this sense it is important to capture the beneficial effects of this material that are available to the industry in a manner that is financially and environmentally sound.

Environmental impact of mill mud application

Concern about the repeated application of mill mud over a limited area emanates from the risks associated with environmental pollution. In particular, recycling of nutrients in mill mud has led to increase in phosphorous levels in canefields adjoining sugar mills as well as a potentially harmful build-up of toxic heavy metals.

Mill mud is not currently categorised as a harmful waste, and there are no specific rules, regulations, or recommendations regarding the application of mill by-products by either the industry or any regulatory agency. Application rates for mill mud vary between different regions. Chapman (1996) reported that cane growers applied filter mud at rates up to 150 t/ha while Barry *et al*. (2000) reported that mill mud applications varied between 150 and 250 t/ha. Qureshi et al (2000) indicated that phosphorous is likely to be provided in excess of plant requirements even when the application rate is reduced to 50 t/ha. Barry *et al (*2000) argued that the application rate of 150 to 250 t/ha is well above the sugarcane requirements and soils in relatively close proximity to raw sugar mills (10 to 20 km) are showing elevated levels of nutrients and heavy metal concentrations due to repeated applications. The heavy metal concentrations can be harmful to plants, domestic animals, and humans. Continued high application rates of mill mud/ash (greater than 150 t/ha) could lead to long-term problems, especially in the case of cadmium which is a non-essential plant nutrient and is toxic to humans and animals. A reduction in application rates could extend the area treated with mill mud and make better use of nutrients, in particular P, which is applied excessively in some cases (Chapman, 1996).

Presence of heavy metals in mill mud also raises the risk that its use even in small quantities over several years could lead to soil accumulation at levels prohibitive for crops other than cane that are used directly for human and stock consumption. That is particularly important given the possibility that some land may be withdrawn from cane production due to declining profitability. From a social viewpoint, foreclosing any future land use options may be undesirable.

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. The excessive nutrients (such as nitrogen) can result in leaching.[1] 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 fertilizer management, often applying nutrients in excess of the recommended rates. They repeated Wegener's assertion that cane growers are 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 led them to use nutrient applications at levels higher than necessary to maximise expected profits (Wegener, 1999).

[1] For example, the case of nitrogen, only one third of the N applied as fertilizer to the sugarcane 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).

Stockpiling, transport and farm storage of mill mud also cause pollution, 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.

Phosphorous can be released in runoff from cane fields and accumulate in surface water impoundments such as dams and waterholes. Increasing the amounts of nutrients entering a stream or lake will increase the growth of aquatic plants and other organisms, disrupt the natural ecology and reduce the quality of water. Excessive amounts of nutrients lead to increased algal growth, reduced water clarity, increased water treatment costs, altered fisheries and fish kills, and in the most extremely degraded water, growth of cyanobacteria (blue-green algae) capable of producing human and animal toxins (Lory, 2000). Phosphorous is carried in runoff water and can travel attached to particles of soil. It can also dissolve into runoff water as it passes over the surface of the field. The progressive deterioration of water quality from over stimulation by nutrients, called eutrophication, means that once a stream or lake has excess phosphorous, it takes time to improve water quality (Lory, 2000a). An excess of nutrients (as a result of excessive mill mud application) also increases the risk of leaching which can damage the environment and also incurs costs to landholders.

Under sugar industry production conditions, nitrogen, phosphorous, potassium, as well as micronutrients, which come from mill mud, move through a cycle. These nutrients go from the field crop at the time of harvest to the sugar mill, to the soil, and back again to mill mud and soil. Some nutrients move out of the cycle and may be used by the next crop but, at the same time, more nutrients enter into the cycle through commercial fertilisers. When nutrients do not stay in this cycle and are lost, there is the potential for environmental pollution. On the other hand, progressive recycling can lead to excessive buildup of toxic elements and thereby pose a threat to sustainable land use. For these reasons, the industry must seek to find more efficient solutions to manage mill waste, for example, by reducing the incidence of waste and introducing quality control of cane brought into mills. While stipulating quality controls could add to growers' and millers' costs, it is important that measures are adopted to minimise the net social cost of industry operations.

A partial mitigating strategy currently being considered by the industry is to spread mill mud over a larger area, thus minimising the risk of harmful accumulation of toxic substances. While it is only a very short-term strategy to remedy the problem, we investigate below the cost effectiveness of such a strategy using a mill area in the Mackay region as an example.

Cost effectiveness of mill mud application

Economic feasibility is an important factor in even distribution of mill by-products, especially for mill mud which has high moisture content and this makes its application less attractive for farms a long distance from the mills due to high freight charges. If mill by-products are applied, their application must be appropriate and account for their nutritional values. As a consequence, commercial fertilizer applications should be reduced where mill mud is applied but this recommendation may be difficult to implement without quantitative estimates of plant requirements and availability estimates of nutrient concentration in different products. Without a comprehensive understanding of mill mud application rates and their nutritional value, the variability of the product in nutrient content, and the slow rate of release of nutrients in their organic form, 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 current application rates for mill by-products as well as the amount of commercial fertilizer being applied by the growers. This will also reduce offsite impacts of the application of mill by-products as well as commercial fertilisers. Qureshi *et al* (2000) carried out an economic analysis of various rates of mill mud application at a range of distances from the mill on a representative cane farm in Mackay. There, as in other districts, mill mud, ash, and combinations of mill mud and ash have been used regularly as soil ameliorants and as a source of plant nutrients for many years. A summary of the findings is presented in the following section.

This analysis used the nutrient concentrations in mill mud estimated by Barry *et al*. (1998) to compare the value of nutrients from mill mud with the cost of fertilizer on a commercial farm size of 72 ha potentially located at 10, 20, 40, 60, 80 and 100 km from a sugar mill in Mackay region. The assumptions made in the study were that the current yield of crop and sugar content will remain the same, the level of nutrients is maintained either through mill mud or through commercial fertiliser, mill mud is distributed and applied with its existing moisture content without any modification, and contemporary vehicles and equipment are used for transportation.

Amounts of the key nutrients applied by canegrowers in Mackay were provided by the senior extension officer at BSES, Mackay (Willcox, *pers. comm.,*). A list of various products with proportions of different nutrients, application rates, and prices per bag (1000 kg) was obtained from Pivot (fertiliser firm), Mackay. Prices per kg of nutrients were calculated on the basis of their proportion in these products. Total costs of these nutrients for a crop cycle of five years (plant and four ratoon crops) were calculated. According to these figures, the most expensive nutrient for a five-year cane crop is N ($662), followed by K ($369), P ($144), Ca ($135), S ($115), and Mg ($112) while total cost for the crop cycle is $1537/ha. Total costs of chemical fertilizers, freight, and application charges for a 72 ha farm were calculated, which for distances of 10, 20, 40, 60, 80 and 100 km from the mill, were $130 746, $131 300, $132 409, $134 072, $135 735, and $136 844 respectively.

Costs of mill mud including transporting and spreading up to 40 km were obtained from the Mackay Sugar Milling Corporation. At the time of this analysis, there were no cost for mill mud and the milling company subsidised the cost of mill mud distribution and spreading. These data were used to estimate the costs of transporting and spreading mill mud at distances up to 100 km from the mill. The estimated costs for the distances of 10, 20, 40, 60, 80 and 100 km from the mill were \$2.60, \$3.95, \$6.50, \$9.00, \$11.25 and \$14.00 per tonne, and the costs paid by growers for these distances were \$0.87, \$1.31, \$2.17, \$3.0, \$3.75 and \$4.66, respectively. Application rates above 50 t/ha do not require a spreader and a vehicle of 12.5 tonnes capacity can be used to spread the material directly onto the cane block. Therefore, no estimates of spreading costs were included for application rates of 75, 100 and 150 t/ha. However, for application rates of 50 t/ha and below, a semi trailer (of about 25 t) could be used to carry mill mud to take advantages of freight reductions while a dedicated 'muck' spreader is used to distribute the mud on farm. A spreading cost of \$50/ha was therefore included in each of the three low application rates (i.e. 12.5, 25 and 50 t/ha) accordingly. Freight charges were assessed on the basis of hours used for the semi-trailer, and the cost per hour (i.e. \$85/25 = \$3.40/t). The number of hours required for mill mud delivery at distances of 10, 20 and 40 km are 0.25, 0.5 and 1.0 hr respectively. Therefore, the freight charges for these distances are \$0.85, \$1.7 and \$3.4/t respectively.[2] Spreading costs using an end-loader and spreader were charged at the rate of \$100/hour and, when spreading takes 30 minutes per ha, are \$50/ha irrespective of distance. These charges are not subsidised and the grower has to pay the full cost of spreading at these application rates.

The analysis compared content of key nutrients in various mill mud application rates with recommended rates of these nutrients and estimated the difference in the form of surplus or deficit. Nutritional values for a 150 t/ha (for example) mill mud application and surplus (or deficit) of the required nutrients are presented in Table 2.

Table 2 Nutritional value of 150 t/ha application of mill mud

Nutrient	N available (kg)	P (kg)	K (kg)	Ca (kg)	Mg (kg)	S (kg)
Nutrients in mill mud	139[a]	341	143	878	236	101
Plant Cane Recommended application rate	150	80	80	900	80	25
Ratoon Cane Recommended application rate	180	0	100	0	0	25
Total nutrient requirement for crop cycle	870	80	480	900	80	125
Surplus (or deficit)	-731	+261	-337	-12	+156	-24

[a]The nitrogen content of 150 t/ha of mill mud is estimated at 555 kg but only 25 % of this amount (i.e. 139 kg) is considered to be available. The remaining N in mud is mineralised over time, but no adjustment is made to fertiliser N applications for ratoons.

An application rate of 150 t/ha of mill mud provides all nutrients in sufficient quantity except N, K and Ca. According to the recommendations, P, Ca, and Mg are not applied to ratoon crops. Commercial fertiliser applications are required to make up the deficiency of N, K and S. Fertiliser costs to meet the respective deficiencies are \$556/ha, \$259/ha and \$22/ha respectively. Total cost of these nutrients is \$837/ha for the crop

[2] These costs are based on the assumption that about two-thirds of the freight charges are paid by the milling company and one-third is paid by the growers who apply mill mud. This footnote is wrongly located.

cycle and total outlay for the whole farm is $60 238. Costs of commercial fertiliser, total freight charges, additional nutrient costs, subsidised mill mud costs, and total costs for a farm at distances of 10 to 100 km were calculated and compared with the cost of applying conventional fertiliser. The differences in favour of mill mud (negative or positive) were also found.

Table 3 Total costs of mill mud application and comparison with fertiliser cost

Distance (and freight charges for mill mud)	10 km @$2.60/t	20 km @$3.94/t	40 km @$6.50/t	60 km @$9/t	80 km @$11.25/t	100 km @$14/t
Mill mud costs	28836	42552	70200	97200	121500	151200
Freight charges	1252	1430	1788	2324	2861	3218
Additional nutrient costs	77690	77869	78227	78763	79300	79657
Total costs for nutrients	106526	120421	148427	175963	200800	230857
Costs of commercial fertiliser	130746	131300	132409	134072	135735	136844
Difference in favour of mill mud	24220	10879	-16018	-41891	-65065	-94013

The full costs of mill mud application, for farms 10 to 100 km from the mill, range from $106 528 to $230 857 (Table 3). These figures indicate that a mill mud application of 150 t/ha at distances of 10 and 20 km is cheaper (lower cost) than the commercial fertiliser but this application rate is more expensive at distances over 40 km compared with the cost of commercial fertiliser. This occurs because the cost of using mill mud as the source of nutrients increases more sharply with distance from the mill than the costs of commercial fertiliser. However, when subsidised costs of mill mud are used to estimate these costs (canegrowers pay only 1/3 of total instead of full freight charges), then the total costs of application range from $87 086 to $129 985. These figures indicate that a mill mud application rate of 150 t/ha is cheaper (i.e. lower cost) at all distances than commercial fertiliser.

Total costs of commercial fertiliser and total costs of mill mud including costs of freight charges, supplementary nutrients, and application charges, at rates of 100, 75, 50, 25 and 12.5 t/ha were also estimated. The quantity of supplementary nutrients required from commercial fertiliser depends on the rate of mill mud application (i.e. a high application rate requires less additional nutrients and vice versa). Application rates of 100 and 75 t/ha mill mud provide excess P and Mg similar to the application rate of 150 t/ha. P is also provided in excess when application rate is reduced to 50 t/ha. However, the implications of any surplus availability of nutrients on plant or ratoon crops are not considered in this analysis.

When mill mud is applied at the rate of 100 t/ha, then total costs of using mill mud as a source of nutrients are less than commercial fertiliser at distances of 10 and 20 km and more expensive when the distance is 40 km or greater. When application rate is 75 t/ha, then the total costs of this application rate are less expensive for 10, 20 and 40 km but more expensive for 60, 80 and 100 km. At similar distances, application of mill mud is less expensive if it is applied at the rate of 50 t/ha compared to commercial fertiliser but more expensive for other distances.

When application rate is reduced to 25 t/ha, then the total costs of nutrient application are less expensive for mill mud at distances up to 60 km but more expensive for 80 and 100 km. Total costs of mill mud application at the rate of 12.5 t/ha are lower for all the distances compared to the total costs of commercial fertiliser. Therefore, economically, this is the most attractive application rate in the Mackay region. If instead of total costs, subsidised costs of mill mud are used, all the mill mud application rates are less expensive than the costs of commercial fertiliser for all distances.

Towards efficient mill mud management

An efficient mill mud management and application system should meet, but not exceed, nutrient needs of the crop, and minimise pollution. Prudent mill mud and fertiliser application practices are necessary to reduce the environmental impacts of their use and also play a significant role in achieving overall profitability of the farm. The application of mill mud to agricultural lands should occur in ways that provide benefits to subsequent crops without causing food contamination, occupational safety, or environmental concerns. Suppliers and end-users have a ‘duty-of-care’ to ensure that the method of disposal is managed in a sustainable way (Barry et al., 2000). Responsible land management requires that the industry adopts methods that will not contaminate soil or water resources, but maintain the stability of the agricultural production system, and ensure that land-use alternatives remain available to future generations (Canegrowers, 1998).

It is necessary to consider application rates and the nutrients together with fertilizer applications when the effects of management practices on heavy metal budgets for cane lands are assessed. The sugar industry needs to be aware of the extent of past applications of mill by-products on cane lands and the impact of current practices on long-term sustainability. If these by-products were included in the ‘list of regulated wastes’ by the regulatory agencies, then the whole industry would incur considerable costs in order to comply with the ‘waste tracking requirement’ (Barry et al., 1998).

Mill mud should be applied to land to meet the nutrient requirements of the crop and should be based on realistic yield goals. Yield goals may be estimated using previous yield data over a five- to 10-year period, provided management remains same. Another important factor to consider in establishing yield goals is soil type. Soil tests are necessary to determine nitrogen, phosphorous and potassium levels in the soil so that mill mud can be applied at the proper rates to meet the needs of crop.

Extended periods of wet weather can interrupt mill mud deliveries to farms and result in stockpiling of these materials. These materials can remain on farms or in other locations for periods up to one year but the effect of stockpiling on the nutrient value is not known. Also, environmental implications in terms of nutrient runoff and leaching during rainfall events are not known (Barry et al., 2000).

If mill by-products are applied, their application must be appropriate and account for their nutritional values and, as a result, reduce current commercial fertilizer use where necessary. This requires knowledge about the economic impact of on-farm nutritional management options including comparisons of the nutritional value of mill mud with commercial fertilizers. Also, there is a need to examine the feasibility of using mill mud from both the millers' and growers' points of view, including long-term and sustainable management of mill mud. This requires accounting of private (on farm) costs and benefits of mill mud application as well as social or environmental (off-farm) costs including leaching or odour due to stockpiling (either at a mill or at a farm), erosion, or groundwater contamination due to over-fertilisation which are borne by society. It is also necessary to take into account the opportunity cost of mill mud application due to heavy metal concentration that restricts the use of current land only for sugarcane production in the future. Soil types and location of farm and paddock, especially the sensitivity of an area to a creek or river, as well as topography will affect the appropriate application rates. These factors will also affect the marginal productivity of different soil types in different sites. There is scope of modifying mill mud (such as reduction in moisture content or composting), modifying cane bins that could be used to return mill mud back to the farms, or modifying the delivery vehicles to allow smaller applications to be made. These topics warrant further investigation in a more comprehensive analysis on a regional basis.

Conclusion

Although currently not classified as a waste material, by nature of its origin, mill mud essentially remains an excludable impurity in cane brought into mills for processing. As a first best policy, the industry should seek to minimise the level of this impurity, so that the potential pollution hazard can be minimised at source. The volume of mill mud has increased due to mechanisation of the sugar industry especially due to adoption of green cane trash blanketing. Reduction in the level of mill mud at harvest time could be achieved by adopting improved harvesting technology such as the use of harvesting sensors which can help achieve high level precision in the height of cut from the ground level, thus minimising soil contamination.

Historical developments in the industry, payment systems, and operational objectives may have led to current thinking that use of the waste as a productive material is the best solution to its disposal. However, changing community concerns, potential for irreversible damage to cane land and other environmental risks, means that all industries are required to eliminate sources of pollution in the best manner possible. Failure to do so may result in regulatory pressures in the interest of wider community. While industry is seriously investigating effective measures to utilise these by-products in an environmentally responsible manner (such as modification by reducing moisture content or composting), their ultimate use will depend on the cost-effectiveness of measures and the flexibility available to industry to enhance the cost-effectiveness. In this regard, further research is necessary to establish both the scientific merit of alternative ways of minimising pollution generating activities and to find more efficient ways of altering the nature of the by-product to reduce the environmental risks.

Mill mud is considered a useful source of plant nutrients, but it has the potential to cause externalities. It is therefore, important to examine alternative ways of obtaining nutrients, in ways that are conducive to responsible environmental management. Incorporation of legume species (such as soybean) into crop rotations to fix atmospheric nitrogen is one such possibility. Such crops can also augment the financial viability of the cane enterprise while bringing other complementary benefits and enhancing the benefits of integrated pest management approaches (Bell, et al., 1998).

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 costs in the form of leaching or odour due to stockpiling (either at a mill or at a farm), erosion or groundwater contamination due to over-fertilisation) as well as costs of heavy metal contamination discussed elsewhere in the paper. Similarly, benefits of mill mud due to its ameliorant nature, and other beneficial effects were not included. A comprehensive mill mud management strategy should also consider locational characteristics of farms, such as soil types and paddock layouts, and other geographic features that can be efficiently incorporated within a GIS analysis. These topics warrant further investigation.

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