MOISTURE LOSS FROM BALED BAGASSE DURING STORAGE

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INTRODUCTION

In Australian raw sugar mills, bagasse is burnt as boiler fuel for steam generation. Typically there is a net surplus of bagasse and most mill boilers operate at reduced efficiencies to incinerate the excess bagasse and thereby reduce disposal problems. Currently there is no viable market for surplus bagasse although there are potential uses for this material. In Australia, recent investigations into these uses include pulp for paper (Foster, SRI unpublished), feed for ruminants (Tudor and Inkerman, 1989), and compost (Lucas *et al.*, 1990).

A significant problem in the use of bagasse as a raw material is its low packing density (80 to 120 kg m^{-3}) which results in high transport costs. The packing density can be increased by pelleting or baling, although baling is preferred because of the lower cost and relative simplicity of the equipment (Cullen and Mason, 1982).

It is generally accepted that to achieve reasonable preservation of fibre quality and to minimise storage losses, the bagasse should have a moisture content of less than 20 per cent. Usina Santa Lydia (Brazil) (Pinto, 1986) has patented the Bagatex-20 process by which it is claimed that a moisture level of 20 per cent can be achieved within 20 days of the commencement of storage. In this process, a 'biochemical catalyst' is sprayed onto the bagasse just prior to baling. Thereafter, the bales are stored in a well ventilated position facilitating the rapid loss of water.

The studies described in this paper were carried out to determine the rate of moisture loss in baled bagasse covering a range of chemical and biochemical additives, including a simulation of the Bagatex-20 process.

MATERIALS AND METHODS

First trial

In the first baling trial, a CPL baler designed for compressing waste paper and cardboard was used to produce bales with average dimensions of $1.27 \times 1.27 \times 0.91$ m. There was little variation in bale size. However, the bale packing densities of 360-440 kg m^{-3} were at the lower end of the range recommended for the Bagatex-20 process.

Fresh bagasse was fed by conveyor and discharged approximately 1.5 m above the baler. The bagasse then fell through a spray of the appropriate mixture of additives into the baler where it was compressed into bales weighing 560-680 kg with initial moisture contents of 46.6 to 54.3 per cent. The additives (on a weight basis) were water (2.5 per cent); dilute milk of yeast (4.7 per cent); urea (2.25 per cent); and ethanol (4.0 per cent). The milk of yeast was used as the biochemical catalyst (i.e. similar to the Bagatex-20 process), while the urea concentration corresponded to the equivalent nitrogen content of the milk of yeast. Two bales

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were made for each additive, one of which served as a control while the other was cored every second day to measure internal moisture content and pH over a period of 30 days. The bales were weighed periodically over a five week period.

Bale temperatures were monitored with thermocouples placed approximately 100, 200, 300, 450 and 600 mm from one side of each bale. The initial moisture content was determined on a 200-gram sample (after mixing but before baling) by drying to constant weight at 105 °C in air. The pH was measured on the extract obtained after vigorously stirring 20 g of cored bagasse sample for 30 minutes at 20 °C in 400 mL of 0.1 M potassium chloride solution. No correction was made for the dilution (Inkerman *et al.*, 1988).

Second trial

A second group of bales was prepared using the SRI continuous baler (Cullen and Murray, 1982) which allowed higher densities of approximately 600 kg m^{-3} to be attained. The additives used in this second group of bales consisted of mixtures of various concentrations of dried yeast, sucrose and dilute dunder. The mixture of yeast (2.5 per cent dry weight) in dilute dunder (8° brix) containing 0.25 per cent sucrose closely simulates the Bagatex-20 biochemical catalyst detailed in French Patent 2586706 (Pinto, 1986). Higher concentrations of yeast (5 and 10 per cent) with proportionally higher sucrose levels (0.5 and 1.0 per cent, respectively) in dilute dunder were also used as additives. The other additive used was the simulated Bagatex-20 combination with a greatly increased sucrose content (2.5 per cent).

The fresh bagasse and additives were well mixed in a three-tonne grain mixer and then compressed into bales with an initial mass of 430 to 512 kg. Difficulties were experienced with the strapping of the bales resulting in variations in bale density (528 to 656 kg m^{-3}) and length (1.05 to 1.95 m).

The bales were stored on pallets in a single layer in a well ventilated area, with ample space between bales to ensure that air circulation was maximised. Bales were monitored for centre temperature, pH, and weight loss daily for the first five days, and thereafter every second day for a further 25 days. Monitoring procedures were the same as for the first trial.

RESULTS

Moisture

The changes in the moisture content of the bales used in both trials are shown in Figures 1 and 2, together with the data reported by Lacey (1980) on raw bagasse and Atchinson (1986) for the Bagatex-20 process. Initial moisture levels for all bales in both trials were between 45 and 50 per cent, with the exception of the urea treated bales prepared in the first trial. The moisture level of 54 per cent in these bales was caused by the addition of significantly more urea solution than was intended, due to poor flow control on the pump. This fault was rectified for the other bales. The moisture levels decreased to about 40 per cent after the first five days, and to about 30 per cent after 20 days. A 20 per cent moisture level was not achieved until after 30 days of storage.

To compare rates of moisture loss during this study and those of Atchinson (1986) and Lacey (1980), the data from Figures 1 and 2 have been normalised to provide the moisture ratio data shown in Figure 3. Overall, the rate of moisture loss was reasonably constant and similar for both trials. By comparison, Lacey (1980) and Atchinson (1986) reported rates of moisture loss in excess of three times the rate obtained in this study during the first four days of storage. Thereafter, both authors reported rates of moisture loss similar to these trials, although a slower drying rate was obtained by Lacey after 15 days of storage.

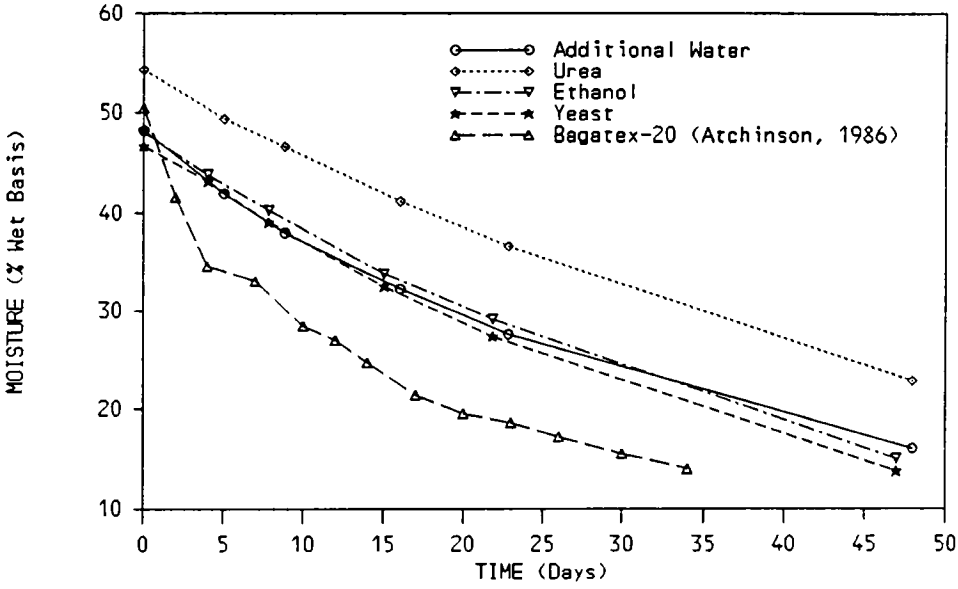

Fig. 1—Moisture loss for the bales in the first trial.

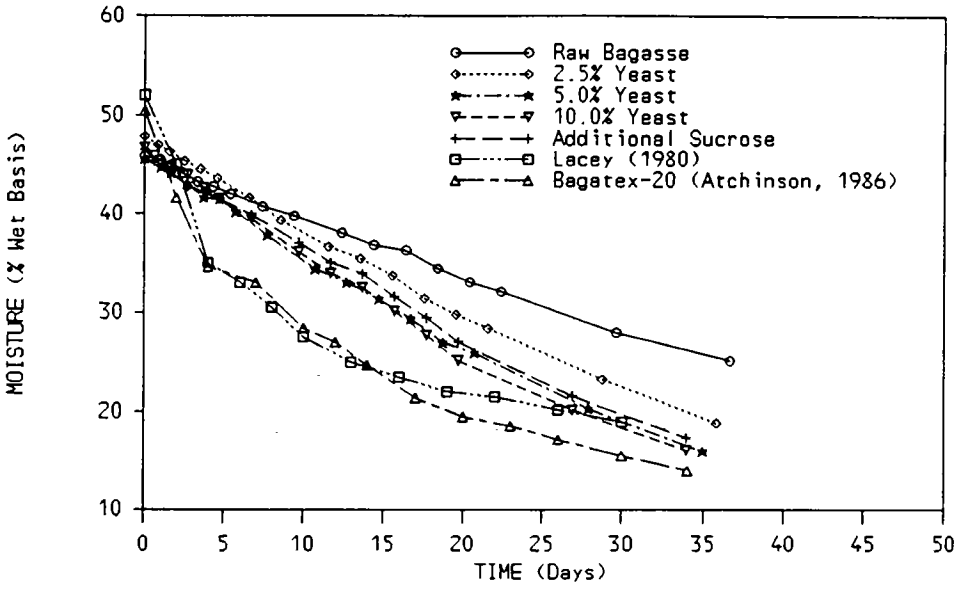

Fig. 2—Moisture loss for the bales in the second trial.

Temperature

In the first trial, temperatures increased gradually from the surface to the centre of the bales. There was no evidence of preferential heating adjacent to the surface of the bale during the drying period.

Figure 4 shows representative centre temperature profiles for the bales in both trials, as well as the data of Lacey (1980) and Atchinson (1986). All of the bales in the first trial exhibited very similar characteristics except for those containing ethanol. Maximum centre temperature was reached by the fourth day, although

temperatures remained at approximately 60 °C for at least 30 days. The bales treated with ethanol did not exhibit the typical rapid temperature rise to 65 °C. In this case, the temperature rose to only 53 °C after two days and then increased slowly to stabilise at 60 °C after a further 18 days.

The bales in the second trial did not achieve as high a temperature as did those from the first trial, stabilising at approximately 55 °C after eight days. Bales made from untreated bagasse showed a lower temperature profile similar to that reported by Lacey (1980). In comparison, the bales in the second trial exhibited heating profiles more closely resembling the Bagatex-20 data of Atchinson (1986).

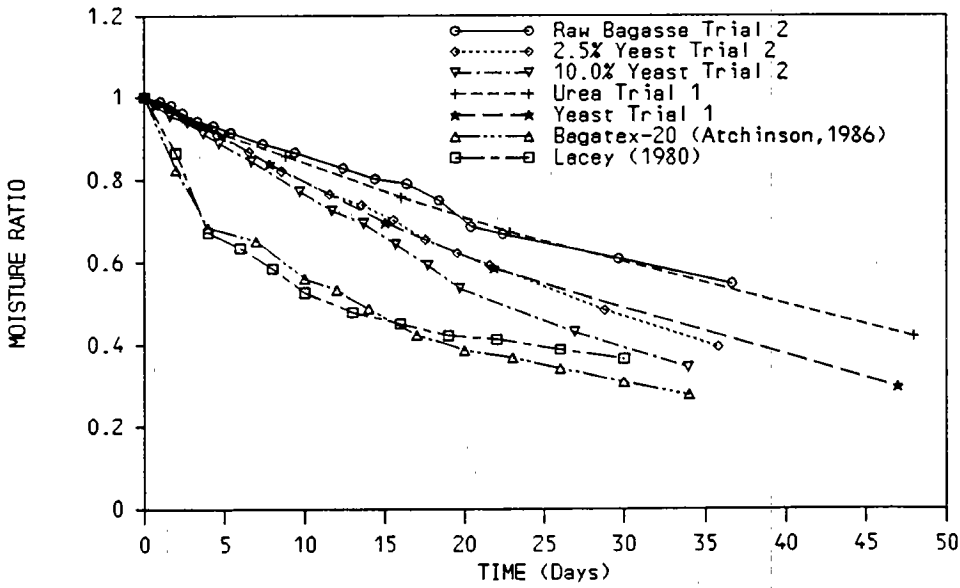

Fig. 3—Moisture ratio for representative bales in the first and second trials.

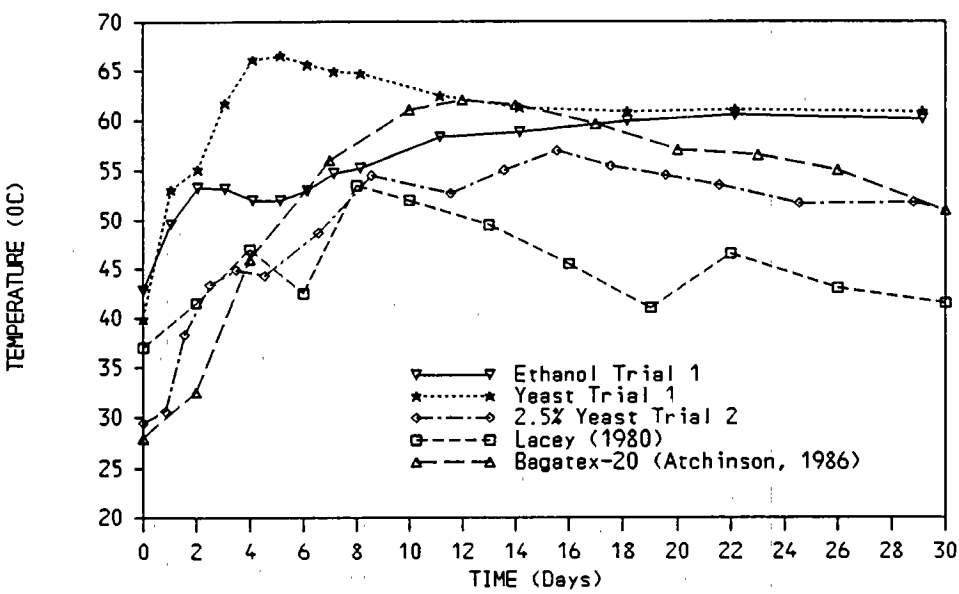

Fig. 4—Centre temperature profiles for representative bales in the first and second trials.

Surface area and density effects

The moisture loss data shown in Figures 1 and 2 were analysed to determine the influence of bale surface area and packing density on the drying rate. A drying rate coefficient, defined as water loss per unit external surface area per unit time, was calculated for each bale. This coefficient can be used to describe the effective mass transfer in the surface layer of a bale.

For both the first and second trials, the drying rate coefficient of the bales decreased on average from 1.40 kg $m^{-2}d^{-1}$ on the first day to 0.35 kg $m^{-2}d^{-1}$ after 28 days. The coefficient was also modified to include the temperature differential between the bale centre temperature and ambient temperature. However, there was no significant alteration to the relative order or characteristics of the bale drying curves.

The drying rate coefficient data for each bale were averaged over 28 days with no distinction being made between bale additives. Similar data calculated from that reported by Lacey (1980) and Atchinson (1986) for Bagatex-20 did not include measurements for the first five days where the drying rate coefficients were significantly higher (3.5 and 5.5 kg $m^{-2}d^{-1}$ respectively). For bales of similar density, there appeared to be a trend of increased drying rate coefficient with bale surface area. However, insufficient data were available for the various density groupings to confirm this trend.

An increase in drying rate coefficient with density was obtained for bales in the second trial irrespective of the additive used (Figure 5). This trend could not be extended to the bales in the first trial as the density range was too narrow.

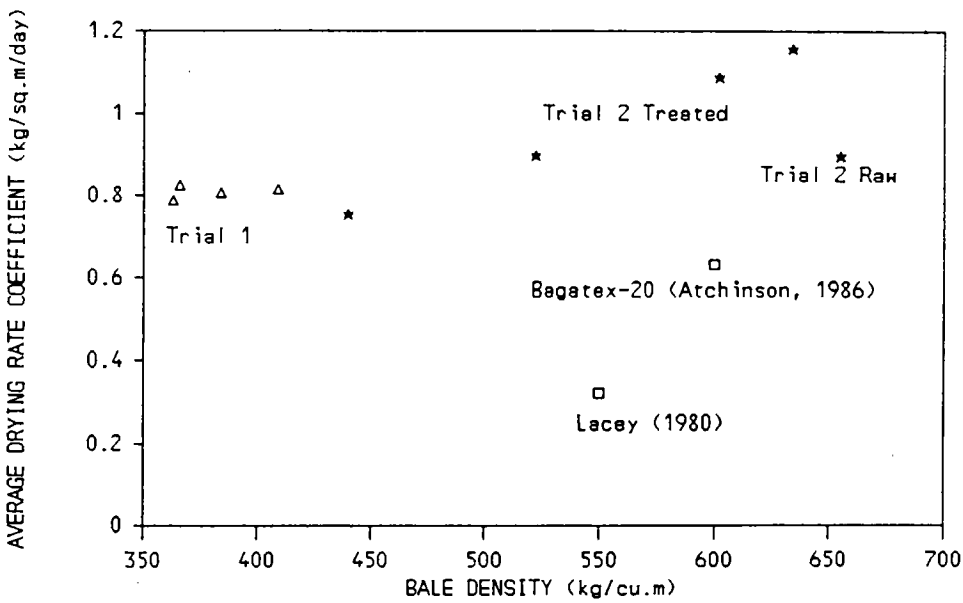

Fig. 5—Variation of drying rate coefficeint with density for all bales.

pH

Initially the apparent values of pH for the baled bagasse in both storage trials were about 5.1 (Figure 6). Following a drop to approximately pH 4 after five days, the pH increased to between 5.3 and 5.5 after 15 days and stayed at this level for the remainder of the monitoring period. For comparative purposes, the pH data of Lacey (1980) and Atchinson (1986) are also shown in Figure 6. In the case of the Bagatex-20 process, the initial pH was reported as 7.0, whereas Lacey (1980)

reported a figure of 5.9. The pH curve for the Bagatex-20 process shows a markedly greater initial decrease in pH than was obtained in these trials. In addition, it remains at a low pH for a longer period prior to the increase to pH 6.0 after approximately 30 days. In comparison, the data reported by Lacey (1980) were similar to that obtained in this study.

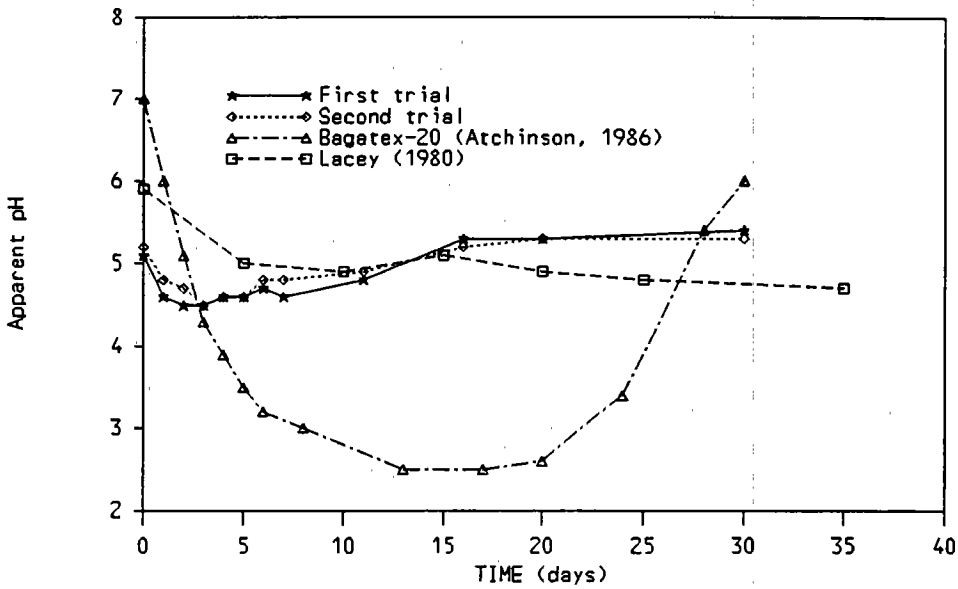

Fig. 6—The apparent values of pH for baled bagasse during storage.

DISCUSSION

Drying rate characteristics

The rate of moisture loss from all of the bales in this study was relatively constant throughout the entire monitoring period. In contrast, the drying rates reported by Atchinson (1986) for the Bagatex-20 process and by Lacey (1980) for fresh raw bagasse were more than three times higher during the first four days. Thereafter, their rates decreased to approximately the same as that obtained in this study. Overall, the difference in the drying rate data obtained in this study from that reported by both Lacey (1980) and Atchinson (1986) is restricted to the first four days of storage.

In the first trial, the differences obtained in the drying rates between the control and treated bales were not significant (Figure 1). Although some differences were observed between the bagasse and the treated bales in the second trial (Figure 2), they were not substantial. However, there was the suggestion that the drying rate was slightly elevated by increasing the yeast concentration in the biochemical additive. By comparison, increasing the sucrose content, and presumably the microbial activity, did not appear to have any noticeable effect on the drying rate. The small difference in drying rates between treated and raw bagasse bales is supported by Lacey (1980), who baled fresh raw bagasse, and Atchinson (1986), who used the additives reported in the Bagatex-20 process. The drying rate profiles reported by both of these authors were very similar (Figure 3). This suggests that the biochemical catalyst has little effect on the drying rate. Furthermore, differences in drying rates cannot be explained on the basis of different mill extraction performances in the various locations where the studies were carried

out. The effect of this parameter was investigated in this study by the addition of higher levels of sucrose, which had no noticeable effect on the drying rate.

The results of this study demonstrate that baled fresh bagasse dries to a 20 per cent moisture content in about 30 days, compared to 20 days for Bagatex-20 reported by Atchinson (1986) and 27 days for Lacey (1980). These shorter drying periods are a direct result of the much faster rate of moisture loss during the first four days of storage. Significantly, the temperature during this same period was only 50 °C or less at the centre of the bales (Figure 4). For these two characteristics to be reconciled, it would be necessary for either a significant temperature elevation to be generated close to the bale surface to evaporate near-surface moisture, or for significant changes to occur in the desorption kinetics of the bagasse fibres which would facilitate moisture release at such low temperatures (Gray, 1989).

The analysis of drying rate coefficients (Figure 5) also highlights the discrepancy in drying characteristics between the bales in these studies and the data of Lacey (1980) and Atchinson (1986). These discrepancies in drying rate behaviour have yet to be resolved. In this regard, the data of Lacey (1980) and that for the untreated bagasse of the second trial support the influence of density on drying rate coefficient for bales of raw bagasse.

Heating and pH characteristics

The packing density appeared to have an effect on the thermal behaviour of the bales. In the first trial, a rapid increase in centre temperature occurred (Figure 4) which has been observed in a number of previous trials on loose and baled bagasse (Walter, 1980; Cullen and Mason, 1982; Dixon, 1988). At the higher packing densities obtained in the second trial, the rate of increase in centre temperature was significantly lower and similar to the data of Lacey (1980) and Atchinson (1986). Though the centre temperature increased at higher densities for bales in the second trial, the values were lower than the temperatures obtained for the bales of lower density in the first trial, and even lower than those measured for loose bagasse.

The pH data obtained for baled bagasse in this study are comparable to those reported by Lacey (1980). However, they differ significantly from the large changes in pH reported by Atchinson (1986) for the Bagatex-20 process (Figure 6). In the latter case, dramatic changes must have occurred in the microbial populations present in the bales as a result of these pH changes during the storage period. To date, no similar data have been reported for baled bagasse. As no details were given by Atchinson (1986) on the procedure used to measure the bagasse pH, direct comparison of pH data may not be justified. On this basis it may be argued that the present study has not entirely duplicated the Bagatex-20 process as reported by Atchinson (1986).

CONCLUSIONS

Studies on the baling of bagasse have shown that treated bales dry faster than those containing no additives, although the differences are not substantial. There were also no significant differences between additives. The physical characteristics of the bales (packing density, size) did not have a major influence on their drying behaviour although there was some variation in their thermal histories. A calculated surface drying rate coefficient showed variations with density and surface area.

A major difference between the drying behaviour reported here and that published by Atchinson (1986) for Bagatex-20, and by Lacey (1980) for raw bagasse bales is the rate of moisture loss in the four days immediately after bale formation. Subsequent drying behaviour for all bales is generally similar. A satisfactory explanation for the discrepancy has yet to be developed.

A significant point which should be emphasised is that dried bagasse of less than 20 per cent moisture content can be produced after a storage period of between 20 and 30 days. The finished product is microbiologically and chemically inactive and constitutes a high quality chemical feedstock or energy source for heating and steam generation. The technique of baling is fairly simple and the costs are relatively low. Currently, the baling of bagasse appears to offer the most cost effective method of producing and storing dried bagasse and of minimising transport costs.

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