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BALING SUGARCANE TOPS AND LEAVES: THE THAI EXPERIENCE

Prepared by:

Winrock International
Institute for Agricultural Development
1611 North Kent Street, Suite 600
Arlington, Virginia 22209 USA

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BALING
SUGARCANE TOPS AND LEAVES

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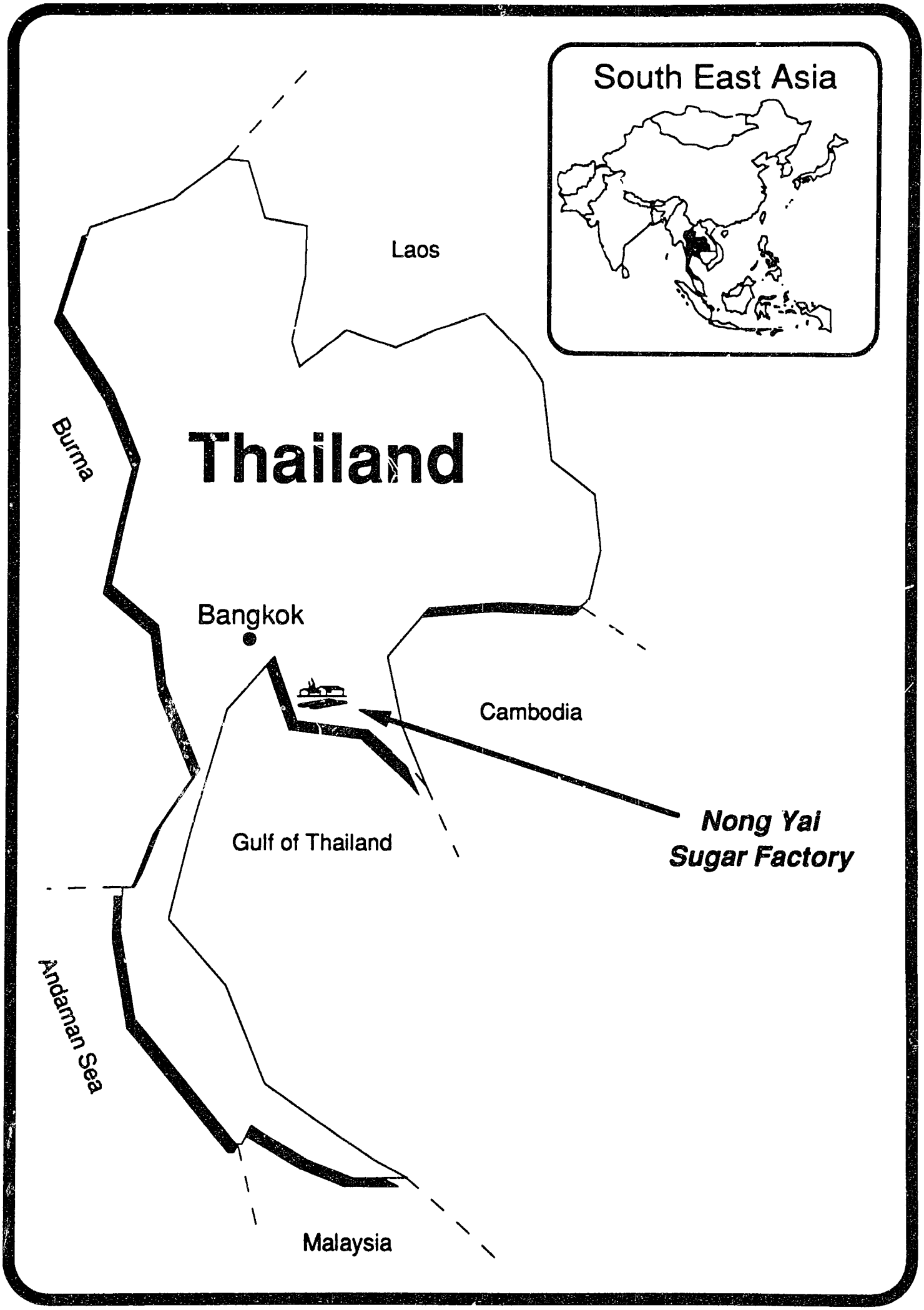
ABBREVIATIONS AND ACRONYMS

A.I.D.	Agency for International Development
APM	Assistant Program Manager
ATCL	Anglo-Thai Company, Limited
β	Baht — conversion rate used throughout: $1 = β25.5
BEST	Biomass Energy Systems and Technology Project
BST	Bioenergy Systems and Technology Project
BTU	British Thermal Units
CLGC	Central Laboratory and Greenhouse Complex
DTEC	Department of Technical and Economic Cooperation
EGAT	Electricity Generating Authority of Thailand
ERSES	Eastern Region Sugarcane Experiment Station
GJ	Gigajoules
GW	Gigawatt
GWh	Gigawatt-hour
ha	Hectares
HSPA	Hawaiian Sugar Planters' Association
kg	Kilogram
km	Kilometer
KURDI	Kasetsart University Research and Development Institute
kW	Kilowatt
kWh	Kilowatt-hour
mcwb	Moisture content wet basis, defined as the weight of moisture in the material divided by the total weight of the material
MEA	Metropolitan Electricity Authority
MOI	Ministry of Industry
MOU	Memorandum of Understanding
MW	Megawatt
MWh	Megawatt-hour
NAMC	National Agricultural Machinery Center
NYSF	Nong Yai Sugar Factory
OCSB	The Office of the Cane and Sugar Board
PEA	Provincial Electricity Authority
PM	Program Manager
rai	Unit of area: 6.25 rai = 1 ha
RTG	Royal Thai Government
S&T/EY	Science and Technology/Energy; A.I.D.'s Office of Energy
t	Tonne (1000 Kg)
USAID/Thailand	A.I.D.'s Mission to Thailand
USAID	United States Agency for International Development
Winrock	Winrock International Institute for Agricultural Development


South East Asia
Laos
Burma
Thailand
Bangkok
Cambodia
Nong Yai
Sugar Factory
Gulf of Thailand
Andaman Sea
Malaysia

EXECUTIVE SUMMARY

This report presents the results of research conducted at the Nong Yai Sugar Factory in the Chon Buri Region of Thailand from December 1989 through April 1990 to determine the costs and agronomic impacts of the collection and storage of sugarcane tops and leaves. The research was sponsored by Winrock International Institute for Agricultural Development with support from the United States Agency for International Development.

This research is part of a global effort to investigate the feasibility of using cane tops and leaves to supplement bagasse as a boiler fuel for generation of electricity in sugar-producing countries. Related efforts have been undertaken at other locations, most notably the Dominican Republic, Jamaica, the Philippines, Hawaii and Puerto Rico. Results of the trials in Thailand correspond quite closely with predictions of performance based on other experience.

In the Thailand research, USAID's Office of Energy competitively procured six sets of standard forage harvesting equipment including six side delivery rakes, three square balers (which produce rectangular bales weighing less than 40 kg), three round balers (which produce cylindrical bales weighing between 300 and 400 kg), and bale moving equipment for the round bales. The equipment was modified in Thailand for use with sugarcane field residues. The main objective of the research program was to document performance data for the harvesting equipment during a full season of operation. Cane residue recovery programs at other locations have systematically recorded and published data only for relatively short trial periods.

Farmers harvest cane by hand in Thailand and do not burn cane fields prior to harvest. Sugarcane tops and leaves were allowed to dry in the field for two to six days before baling operations began. The tops and leaves were then raked into windrows and baled with either the round or square balers. The average moisture content upon

and baled with either the round or square balers. The average moisture content upon baling was between 9.8 and 11.2 percent mcwb (mcwb is moisture content wet basis, defined as the weight of moisture in the material divided by the total weight of the material), considerably lower than expected.[1]

Over the season, the equipment in Thailand produced 1,945 tonnes of square bales and 2,731 tonnes of round bales at a real cost of $26.55/t and $20.53/t respectively.[2] Included in baling costs are amortized capital equipment, rented equipment, maintenance, fuel, twine, labor, and payments to the farmers for their participation in the program. Fixed costs for transporting square and round bales to the factory averaged approximately $3.69 and $5.79, respectively, for the portions of the operation involving loading bales onto trucks in the field and unloading bales at the factory. These costs include amortized capital equipment, rented equipment, fuel, and labor. The variable costs of equipment, labor, and fuel associated with the actual transport from the field to the factory averaged $0.25 t-km and $0.10 t-km for square and round bales. For a one-way distance of 10 km, total transportation costs for square and round bales were $6.20 and $6.81, respectively, making the total cost of baled cane residues delivered to the factory $32.75/t and $27.34/t. Balers' effective coverage was about 1.6 hectares per machine per 8-hour day.

The primary differences in the per tonne costs between the two systems involve capital requirements, maintenance requirements, twine requirements, and operating productivity. The round baling system was capable of baling almost 30% more field residues per unit time. Spare parts and maintenance costs were $2.29/tonne higher for the square balers. Similarly, the cost for twine for the square balers was almost $2/tonne more than for the round balers.

At 10% moisture content, the baled sugarcane tops and leaves have a net heat value of approximately 15,813 kJ/kg (6,800 BTU/lb). The baling and transport costs reported above correspond to a cost of approximately $1.87/GJ ($1.77/million BTU) for fuel delivered to the factory compared with oil that costs approximately $2.91/GJ ($2.76/million BTU) when purchased at $19 per barrel.[3] Trash storage and processing, and the costs of any deleterious agronomic effects must still be accounted for. Combustion efficiencies for bagasse and field residues are also different than for oil. Nevertheless, whether used as a fuel to provide steam and power for sugar refineries or to produce electricity for sale to the grid, baled sugarcane field residues are clearly a cheaper delivered source of fuel than oil.

Experience gained during the trial suggests that costs could be reduced to about $25/tonne for cane residue recovery operations managed by private industry. This corresponds to a collection cost of $1.58/GJ ($1.50/million BTU) for baled sugarcane tops and leaves.

Although agronomic impacts of residue removal cannot be accurately assessed for several years, preliminary observations made in the fields during the baling operations showed no marked difference between fields in which the baling equipment operated and those in which it did not. Researchers dug soil pits to examine soil compaction, ratoon damage, and tilth. The current Thai practice of burning tops and leaves left in the field after harvest to prepare for the next crop provides some nutritive value to the next cane crop, primarily phosphorus and potassium. Further research will have to be carried out to determine what steps are necessary to compensate for nutrient loss and other agronomic impacts.

The report begins with a chapter that reviews the studies and events that led up to the trial year, beginning with a 1986 report on the prospects of electric power from cane residues in Thailand and culminating with a work plan outlining the specific objectives and responsibilities for the trial year.

Chapter 2 focuses on the trial year itself. It begins with a summary of how the trial year activities were conducted and includes sections on the performance of the baling equipment, bale collection and transportation operations, and concludes with the lessons learned. The analysis in this chapter compares the technical performance and cost effectiveness of round versus square balers. However, neither one is clearly superior in terms of either of these two criteria. This report does not address bale storage or processing of bales for feeding into existing bagasse boilers.

In Chapter 3 some future work is outlined. The Nong Yai Sugar Mill has requested and received permission from the Ministry of Industry to use the equipment on their own during the 1990-91 crushing season. The projected costs and benefits of the proposed operations are reviewed. Also included are discussions of the replicability of these operations in other areas and a program for further examining the agronomic impacts of cane trash harvesting operations.

Notes

(1) The typical range of moisture content expected for this material is 20% - 30%.

(2) All US dollar figures are in 1989 dollars. Where Thai Baht (β) are used, the conversion rate is β25.5 = $1.

(3) Oil cost is based on a bunker "C" fuel oil higher heating value of 6.3 million BTU/Bbl and assumes crude oil costs 8.61% more than bunker "C". *Monthly Energy Review*, February 1990, Energy Information Administration, Document No. DOE/EIA-0035 (90/02).

Chapter One

BACKGROUND
THE TRIAL YEAR OBJECTIVES

1.1 Review of Previous Work

The Cane Energy Trial Year Program was conducted in Thailand at the Nong Yai Sugar Factory from December 1989 to April 1990. The foundation for the program was laid in two studies commissioned in 1986 and 1987, the signing of a Memorandum of Understanding in 1988, and an attempt to implement trial year activities during the 1988-89 cane crushing season. This section briefly reviews that work and the sequence of events that led to the trial year program.

Work undertaken at other locations on the collection of sugarcane tops and leaves led to the current study. Data from Puerto Rico, the Philippines, and the Dominican Republic are included in the Second Pacific Biofuels Workshop Proceedings published in April, 1987. References for these proceedings and other important work are provided in the notes at the end of this Chapter.[1]

Collection of sugarcane tops and leaves continues at the Central Azucarera de Tarlac in the Philippines. Although valuable information on the performance and cost of baling sugarcane tops and leaves using standard forage baling equipment has been collected, the primary purpose of the operations at Tarlac has been the provision of jobs and income for local people. Both the fields and factory at Tarlac are under the same management. The most recent published information from Tarlac was presented at the Second Pacific Biofuels Workshop.

1.1.1 Electric Power from Cane Residues in Thailand

In 1986 the Office of Energy, United States Agency for International Development (USAID) published *Electric Power from Cane Residues in Thailand: A Technical and Economic Analysis*[2]. The report was based on the findings of a team of specialists that visited Thailand in early 1986 to investigate ways in which the sugar cane industry might improve its economic prospects by selling new products.

The study concluded that the most attractive option for the sugar industry in Thailand was the generation of electricity for sale to the national utility grid during the non-cane-crushing season. The team recommended that sugar mills use cane field residues (the tops and leaves left in the field after the harvest — also known as cane trash) to supplement excess bagasse as a boiler fuel. The team estimated that by using residues as supplementary fuel the sugar industry in Thailand could generate between 270 and 715 megawatts of power year round. The study presented several alternative approaches to power generation, ranging from minor alterations of current boilers and generators to complete change-outs of existing equipment to achieve greater efficiencies. Based on the data collected in 1986, it was further concluded that, after the costs of production were covered, electricity could be sold to the grid at prices lower than the transfer price then being paid to the Electricity Generating Authority of Thailand (EGAT) by the Provincial Electricity Authority (PEA), the agency charged with distributing power to rural regions of the country.

Although the overall findings of the report were quite positive, two major uncertainties were delineated. One was institutional and involved Royal Thai Government (RTG) approval of private electricity sales and introduction of the resulting power into the national grid. At that time, the team was encouraged in their discussions with key Government agencies and the EGAT, since spokesmen for those organizations expressed a willingness to consider private electricity sales, especially from co-generators and those using "special" fuels, i.e., agricultural wastes and other renewable energy sources.

Another uncertainty was technical: the feasibility (technical, financial, and environmental) of collection and transport of cane trash to the mill for combustion. At that time, although small studies on this issue were being conducted outside Thailand, none were on the scale envisioned for Thailand. The team recommended a low-cost pilot program to investigate cane trash collection and transport that provided the impetus for the trial year program. The report suggested an appropriate set of technical steps to manage the trash-collection process, and detailed the cost calculations which formed the basis of the economic analysis. The cane energy trial year was an outgrowth of this study.

It is important to note that the 1986 study used data from five mills to arrive at preliminary technical estimates of such things as generating capacity, fuel demands, and investment needs, but the Nong Yai Sugar Factory was not among those mills.

1.1.2 Trial Year Program Proposal: Nong Yai Sugar Mill

In 1987 USAID's Office of Energy published *Trial Year Program Proposal: Nong Yai Sugar Mill — Thailand*.[3]. It proposed a 1-year cane energy trial project at the Nong Yai Sugar Factory. The proposal was prepared in July and August, 1987 by a five-person team of specialists, sponsored by the USAID Office of Energy.

The proposed program had two major objectives:

(1) The determination of cost and agronomic impacts of collection, storage, and transport of cane tops and leaves in Thailand and the estimation of the quantity available for use as fuel.

(2) The demonstration of steady, controllable generation of electricity by the sugar industry both during and out of the processing season.

An underlying theme in the analysis of costs and benefits was the team's belief that, for the trial year, all parties involved should emerge as "winners." This meant that The Office of the Cane and Sugar Board (OCSB) and USAID would gain the information needed to determine the attractiveness of cane/energy production, the sugar mill lending its facilities for the trial year would not suffer financial loss, the participating farmers would receive compensation for the provision of cane trash, and EGAT would receive electricity at a price low enough so as not to be subsidizing the experiment.

The team's analysis showed that in order for Nong Yai to achieve a payback period of less than 5 years (based on an investment of $843,400) the mill would have to sell electricity to the grid at a price of β1.10($0.043)/kWh. This price was below the then current average transfer price (β1.26($0.049)/kWh) for EGAT.

1.1.3 Memorandum of Understanding[4]

Included as an appendix to the 1986 report was a proposed Memorandum of Understanding (MOU). The purpose of this document was to obtain agreement of all parties to be involved in the trial year activities prior to committing capital and management resources. The signatories to the document included ranking representatives from the Ministry of Industry, EGAT, Nong Yai, USAID, and the Department of Technical and Economic Cooperation (DTEC).

The MOU governs Phase One of a perceived two phase program. Phase One, which was to be conducted during the 1988-89 cane harvesting season was to fulfill the objective of determining "the feasibility and cost associated with the collection, storage, transport, and combustion of cane trash." Upon "successful" completion of Phase One, Phase Two was to be initiated. Phase Two was to fulfill the other objective of demonstrating "the feasibility of steady, controllable generation of electricity by the sugar industry both during and outside the processing season."

Under the MOU for Phase One, USAID agreed to procure agricultural machinery for the trial year and to provide some technical assistance. Nong Yai agreed to manage overall collection of cane tops and leaves including the provision of tractors and equipment operators. OCSB agreed to help with the collection of data through its Eastern Region Sugarcane Experiment Station (ERSES). This final version of the MOU was signed by all parties between October and November of 1988 and the trial year was officially initiated.

1.1.4 1988-89: The First Attempt

The baling equipment procured and shipped by USAID arrived at the mill site in February 1989 — towards the end of the cane harvesting season. The imported equipment included the following items:

3 Round (cylindrical) balers: Ford-New Holland Model 853
3 Square (rectangular) balers: Ford-New Holland Model 326
6 Rakes: Ford-New Holland Model 258
1 Bale mover: Ford-New Holland Model 82 [5]
2 Front end loaders: Farmhand Model 190 (1140)
Miscellaneous spare parts for the above

For just over 2 weeks, one set of equipment (i.e., one round baler, one rectangular or square baler and one rake) was operated on fields near the factory with the assistance of technical specialists provided by USAID. Nearly 20 tonnes of cane trash were baled in this period, not nearly enough time to demonstrate commercial viability. There was not enough cane trash collected to conduct boiler tests, nor was the equipment operated long enough to determine the technical feasibility and costs associated with the collection, storage, and transport of the cane field residues.

1.2 Cane Energy Trial Year Work Plan — 1989-90

In late 1989 a work plan for the implementation of the trial year activities for the 1989-90 cane harvesting season was developed by the Office of Energy's BEST Project.[6], with assistance from USAID/Bangkok. After review by most of the original MOU participants, the work plan was approved in November 1989.

The organizations which played a major role in carrying out trial year program were the Royal Thai Government's Office of the Cane and Sugar Board (OCSB), the Nong Yai Sugar Factory, the Kasetsart University Research and Development Institute (KURDI), the Hawaiian Sugar Planters' Association (HSPA), and Winrock International.

With the responsibility for the management of the program, Winrock International placed both a program manager and an assistant in the field at Nong Yai to oversee the trial year activities. The program manager was responsible for overseeing the operations of the program, collating and interpreting the data, writing the final report, and providing the necessary liaison among the various participants. The assistant program manager, a Thai engineer, had several responsibilities, including the day-to-day supervision of the field laborers, ATCL mechanics, and tractor operators, and assisting with the field scheduling. He also recorded equipment performance data in a daily log. Winrock contracted with Anglo-Thai Company Limited (ATCL) to provide tractors, operators, and mechanics. The ATCL mechanics, in addition to repairing and maintaining the equipment, acted as foremen for the tractor operators.

The Eastern Region Sugarcane Experiment Station, the regional arm of the OCSB, provided three main functions. They were responsible for scheduling the fields to be baled, measuring residue yields, and collecting and analyzing cane trash samples for moisture content. To accomplish these tasks OCSB provided a field coordinator who was resident in Nong Yai during the crushing season. OCSB is also responsible for disseminating the results of this research to the Thai sugar industry.

The Nong Yai Sugar Factory, in addition to hosting the program, also assisted by providing information concerning farmers interested in participating in the trial year and by promoting interest in the program among farmers.

KURDI, and its affiliate organizations the National Agricultural Machinery Center (NAMC) and the Central Laboratory and Greenhouse Complex (CLGC), carried out much of the data collection and analysis. They provided engineers and technicians to carry out time and motion studies of the harvesting equipment. They also studied the bale transport performance and performed ash, calorific value, plant, and soil analyses.[7]

The Hawaiian Sugar Planters' Association, in conjunction with KURDI and OCSB, formulated the test procedures that were used during the trial year. They had their project leaders present for cane residue recovery research and agronomic impact research in Thailand at the initiation of the trial year to monitor and assist the researchers from KURDI and OCSB.

Notes

(1) Work carried out on the collection of sugarcane tops and leaves has been reported in a variety of other sources. Early work was carried out by Alex Alexander in Puerto Rico and reported in Alexander, A.G. 1985. *The Energy Cane Alternative*. Elsevier, New York, 509 pp. Other important sources include:

ABA International and SERCITEC. 1983. *Informe Final: Estudio de Recogido, Acopio, Manipulación, Transporte y Almacenamiento de Barbojo en los Ingenios Barahona, Consuela y Quisqueya*. Corporación Dominicana de Electricidad, Santo Domingo, Republica Dominicana.

ABA International and SERCITEC. 1984. *Technical Report: Study of Machinery Systems for Harvesting Cane Trash and of the Biomass Fuel Requirement for the Thermoelectric Power Plant San Pedro I*. Corporación Dominicana de Electricidad, Santo Domingo, Republica Dominicana.

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Lopez, P. 1987. Field Experience in the Collection and Transport of Cane Trash (Barbojo) at Central Romana. In *Cane Energy Utilization Symposium: A Report from the 2nd Pacific Basin Biofuels Workshop*. Volume II: Presented Papers, pp. IV-1-6.

Varua, V. F. 1987. Trash for Fuel: A Luisita Project. In *Cane Energy Utilization Symposium: A Report from the 2nd Pacific Basin Biofuels Workshop*. Volume II: Presented Papers, pp. V-1-8.

(2) F. Tugwell, et.al., 1986. *Electric Power from Cane Residues in Thailand: A Technical and Economic Analysis,* Washington, D.C.: Office of Energy, U.S. Agency for International Development.

(3) J. Kadyszewski, et.al., 1987. *Trial Year Program Proposal: Nong Yai Sugar Mill -- Thailand,* Washington, D.C. Office of Energy, U.S. Agency for International Development.

(4) The text of the final Memorandum of Understanding covering the trial year is included as Appendix A.

(5) Three bale movers were ordered, however only one arrived at Nong Yai. Subsequently, the other two were manufactured in Thailand.

(6) In October 1989, the ten-year-old Bioenergy Systems and Technology Project was succeeded by a new project entitled the Biomass Energy Systems and Technology (BEST) Project managed by Winrock International Institute for Agricultural Development under a cooperative agreement with the USAID Office of Energy. Thus, at that point Winrock International assumed responsibility for the management of the trial year program.

(7) The data collected by Kasetsart University Research and Development Institute will be issued in a forthcoming report by the Hawaiian Sugar Planters' Association.

Chapter Two

TRIAL YEAR RESULTS

2.1 Summary of Activities

The cane trash harvesting operations were conducted between December 15, 1989 and March 9, 1990. With the exception of two holidays (4 days total), the equipment was operated continuously 7 days per week, 8 hours per day. Two areas were selected for the harvesting campaign — the fields contiguous to the factory and fields in the district of Bo Thong (about 30 km from the factory). For most of the campaign, the three round balers were operated in the Bo Thong district and the three square balers in the factory fields.

Fields were scheduled between 3 and 5 days in advance of baling operations, by the OCSB field coordinator in conjunction with the assistant program manager — without the benefit of knowing the factory's cane quotas. As will be seen in the next section on baling equipment performance, this resulted in periods when the equipment was idle waiting for fields to be scheduled for baling operations.

As outlined in Chapter One, Winrock International signed a contract with Anglo-Thai Company, Limited (ATCL) to provide Ford tractors, operators, and mechanics to assist in the trial year activities. For the majority of the campaign ATCL used nine tractors and operators to run the rakes, balers, and bale movers; and kept three mechanics on hand to service and repair the equipment. Additionally, since ATCL is the Ford-New Holland representative for Thailand, they enlisted the services of a technical representative who provided advice on operations and servicing procedures. This representative recommended several modifications to the baling equipment to improve their effectiveness in the sugarcane fields. These modifications which were designed to improve their performance, are discussed in Section 2.2.3. Winrock paid ATCL for

tractors and operators regardless of whether the balers were in operation. Only the charge for fuel was deducted on days when baling equipment was idle.

After traditional hand harvesting, cane trash was allowed to dry in the field from 2 to 6 days before it was raked and baled. Only two rakes were necessary to provide sufficient windrows for the six balers: one for the three round balers and one for the three square balers.

Originally, both the round and square bales were to be collected and moved to interim storage sites near the fields from which they were taken. Using the three bale movers provided by USAID, round bales were moved from the field to these sites usually within three days of bale harvesting. Bale transportation to the factory was not originally a part of this phase of the trial year effort. However, after some experimentation with square bale removal and interim storage, Nong Yai decided to provide equipment and some laborers to collect the square bales in the field and transport them directly to the factory. Several hundred round bales were also transported from interim storage areas to the factory after the season ended.

An important aspect of the trial year campaign was the research conducted by three Thai organizations, the National Agricultural Machinery Center (NAMC), the Office of the Cane and Sugar Board (OCSB), and the Central Laboratory and Greenhouse Complex (CLGC) in collaboration with the Hawaiian Sugar Planters' Association (HSPA). NAMC, OCSB, and CLGC obtained a range of data as outlined in a research plan for the trial year designed by HSPA and KURDI.[1] NAMC researchers were in Nong Yai from January 23 - March 24, 1990 obtaining equipment performance data on the baling and bale transportation operations. They observed the operations on 25 separate fields (covering over 53 ha) during the course of their time in Nong Yai. On the same fields, the OCSB field coordinator collected cane trash samples and generated residue recovery yield data and moisture content analysis figures. (Moisture content data was independently verified at the Nong Yai laboratory and by a laboratory in the U.S.A.) CLGC took the samples from OCSB and further analyzed them for calorific values and ash and nutrient content. In addition to the research efforts of NAMC, the assistant program manager kept daily records of the performance of the raking, baling, and bale moving equipment to provide aggregate data from which to make final cost and performance estimates.

2.2 Baling Equipment Performance[2]

2.2.1 Technical

Throughout the campaign, the six balers were in the field for a total of 468 machine-days, harvested cane trash from 510 ha (3,186 rai), out of a total area of 36,000 ha

(225,000 rai) supplying cane for the Nong Yai Sugar Factory. The square balers harvested 194 ha (1,210 rai) and the round balers harvested 316 ha (1,976 rai).

There were several observable differences in field conditions between the two areas where harvesting operations took place. First, in the Bo Thong area, the average furrow depth was 20.2 cm, compared with 18.8 cm in the factory area (the difference equals about one standard deviation from the mean values). Second, fields in Bo Thong in which baling operations took place, tended to be more hilly than those near the factory. Third, tree stumps and large rocks tended to be more plentiful in Bo Thong than near the factory and caused several accidents to the round balers, resulting in considerable downtime. Finally, within a 3 kilometer radius around the Nong Yai Sugar Factory, there is an irrigation system which supplies waste water from the factory. No such irrigation system exists in Bo Thong. The fields there only receive irrigation during planting. Among these differences, probably the most significant to the baling operations was the quantity of tree stumps and large rocks, since the major cause of round baler downtime was accidents.

The quantity of trash available in Bo Thong was slightly less than that in the factory area, but the difference was well within one standard deviation of the average. In the seven fields in Bo Thong sampled by NAMC, the average pre-bale residue was 12.44 t/ha (1.99 t/rai) with a standard deviation of 2.81 t/ha, and in the 18 fields sampled in the factory area, the average pre-bale residue was 12.63 t/ha (2.02 t/rai) with a standard deviation of 1.75 t/ha.

The square balers, in the field for 234 machine-days, produced 123,905 square bales weighing from 12 to 19 kilograms each. Initially, the average weight of the square bales was about 17 kilograms, but these heavy bales were difficult to handle for laborers who manually loaded the trucks. Consequently the balers were adjusted to reduce the average weight per bale to about 13 kilograms. The total estimated weight harvested by the square balers was 1,945 tonnes — at 9.8% mcwb (moisture content wet basis).

The moisture content of trash samples was determined by researchers at the Eastern Region Sugarcane Experiment Station of OCSB. The values for moisture content of the cane residues are less than half the minimum that was expected. Therefore, independent analyses were conducted by the laboratory at NYSF and by Huffman Laboratories, Inc. in Golden, Colorado, USA, both of which confirmed the low moisture content of the material. The method used by OCSB to determine moisture content is included in Appendix B, page 53. Moisture content wet basis is defined as the weight of moisture in the material divided by the total weight of the material. In brief, a sample of material was weighed before and after drying overnight in an oven at 85°C. The weight difference between the two is divided by the weight of the original material and multiplied by 100 to obtain the moisture content on a wet basis.

The round balers, in the field for 235 machine-days, produced 7,360 round bales weighing from 335 to 450 kilograms each — the average being 371 kilograms. The total estimated weight harvested by the round balers was 2,731 tonnes — at 11.2% mcwb.

The major purpose of importing two different types of balers for cane trash baling was to see which would have the best performance, operability, durability, and costs. However, there was no effort to operate both balers in each field area.

Another measure of the comparative suitability of the different baler types, that is not quantifiable, but that is nevertheless important, is the attitudes of farmers and mill owners. Among the farmers, the only concern was how soon the bales were removed from their fields. In that regard, since the only delays in bale removal occurred with the square bales, farmers were noticeably biased against square bales. Nong Yai managers continue to express concern with the round bales both in terms of difficulty in transport and bale processing inside the factory. The limited amount of data from the trial year indicates that variable costs for transporting round bales are lower, even though round bales loaded in a truck have more interstitial spaces. The average bulk density of round bales is 147 kg/m^3 compared with 100 kg/m^3 for square bales. The factory has constructed a bale processor or "smasher" designed to handle both round and square bales. The purpose of the bale smasher is to prepare the cane trash for the boilers by reducing the particle size. Square bales are be cheaper and easier to load into the existing smasher. Moreover, the present bale smasher design will allow a higher through-put with square bales. The square baler reduces the length of cane tops and leaves to 45 cm (the baling chamber width), whereas the round baler does not cut the trash, resulting in lengths up to 2 meters.

The overall performance of the round versus square balers is compared in Table 1. Partly because the round balers experienced less downtime, they were more productive in terms of tonnes baled per hour than the square balers. (The reasons for the high downtime percentages for both types of balers are discussed below.) The main reason for the round baler baling more tonnes per hour than the square baler was its ability to pick up windrows at a higher speed without choking on the trash. Although smaller windrows may have reduced choking, no attempt was made to modify windrows for square balers.

In general, the operators ran the tractors pulling the round balers in gear 3— or 4—low (about 5 — 8 km/hr), compared with gear 1-low with the square balers (about 2 — 3 km/hr). The reason is, in part, that with the square balers, much of the energy provided by the tractors is used to change the direction of the trash, cut it, wrap twine around it, and knot the twine, whereas for the round balers, the pick-up mechanism directly feeds the trash into the baling chamber without changing its direction, the trash is not cut, and wrapping twine around the bales is a separate operation which required stopping the forward motion of the tractor.

TABLE 1
BALER PERFORMANCE COMPARISON

	Units	Round balers	Square balers
Total scheduled operating time:	hrs	1,881	1,869
In-field production time:	hrs	1,455	1,375
Avoidable Downtime:	hrs	426	494
Unavoidable Downtime:	hrs	357	496
Area covered:	ha	316	194
Overall coverage:	ha/total hrs	0.17	0.10
Effective coverage:	ha/prod. hrs	0.22	0.14
Total bale production:	bales	7,360	121,560
Average weight:	kg/bale	371	16
Total weight baled:	tonnes	2,731	1,945
Recovery rate:	t/ha	8.64	10.03
Overall productivity:	t/total hr	1.45	1.04
Effective productivity:	t/prod. hr	1.88	1.41

NOTES:

Total scheduled operating time: The number of machine hours the equipment could have operated (i.e., the total number of operating days times 8 hours per day). The only reason for the difference between the two is that the round balers were operated one half day on the first day of the season, and the square balers were not.

In-field production time: The total in-field time less the hours of avoidable downtime.

Avoidable downtime: The number of hours the machinery was not operating due to bale transportation bottlenecks, field scheduling problems, and accidents.

Unavoidable downtime: The number of hours the machinery was not operating due to mechanical failures, rain, and other unavoidable causes.

Area covered: An estimate of the number of hectares baled. Although figures for the total number of hectares harvested is available from the receipts for farmer payments, this data was not correlated with the daily logs. Therefore, the number of hectares on which any machine operated on any given day was an estimate, although accurate in the aggregate.

Overall coverage: The estimated hectares baled divided by the total in-field time.

Effective coverage: The estimated hectares baled divided by the production time.

Total bale production: This number was obtained from bale counters located on each baler. Since this number includes mal-formed and broken bales, it probably overestimates the actual number of bales by 5% - 10%.

Average weight: The round bale average weight data was obtained from NAMC. For the square bales, the average weight changed when the balers were adjusted to make smaller bales to assist the bale transportation team when they began loading the transportation trucks directly without the assistance of the front end loader. The average square bale weight changed at this point from 17 kg/bale to 13 kg/bale.

Total weight baled: Total bale production multiplied by the average weight.

Recovery rate: Total weight baled divided by the estimated hectares covered.

Overall productivity: Total weight recovered divided by the total scheduled operating time.

Effective productivity: Total weight recovered divided by the production time.

Although the round balers covered more area, and produced more total tonnage, they had a lower recovery rate (t/ha) than the square balers. (Table 1) The reasons for the lower recovery rate probably lie in the field differences between Bo Thong and the factory area discussed earlier.

Table 2 compares the total equipment productivity with the expected productivity as outlined in Appendix B of the 1987 Trial Year Program Proposal report. The actual efficiency figures in Table 2 exclude the downtime due to field scheduling problems, accidents, and bale transportation bottlenecks. By doing so, a more realistic picture of actual baler efficiency is obtained for the trial year in comparison with expected efficiency, since these categories of problems were not included in the calculations for expected efficiency and should not exist when the baling operation is performed on a commercial basis. Accidents are excluded from this table because they are considered to be part of the learning curve for the trial year and are not expected to be a significant problem in commercial operations with experienced operators.

The baler effective capacity is so much lower than expected that even though the efficiency is higher, the daily output is still less than the expected daily output. The effective coverage and baler effective capacity were low primarily because field conditions did not allow the tractors to travel as fast as expected. In flat field, shallow furrow conditions, the tractor speed should increase significantly. It is notable that the dry basis yield, recovery efficiency, and net recovery were in the range of what was expected. Although the moisture content was less than half the expected amount, the dry basis yield prediction was similar.

As indicated in Table 1, there was a considerable amount of downtime experienced with both the round balers and the square balers. Table 3 shows the in-field performance of the rakes, round balers and square balers. While the rakes were not operating 10% of their time, the round balers were down 42% of the time, and the square balers were down 53% of the time. For both types of balers, more than half of the downtime was due to non-equipment problems that were associated with the learning process in this relatively new type of operation. If certain conditions are met, there is no reason to believe that these *avoidable* non-equipment problems will be repeated in future operations.

For the round baler, accidents and operator error accounted for over 30% of the downtime. The abundance of rocks and stumps in the Bo Thong region, where the round balers operated, caused several accidents. Typically the rakes forming windrows covered the obstructions, which were then struck by the round baler, causing damage to the pick-up area. The damage was so severe that parts had to be sent to a near-by city to machine shops to be re-formed or re-cast, resulting in up to 7 days delay. After three such accidents, the rake operators were made responsible for marking obstructions so that the round baler operators could avoid them. After that, no accidents occurred.

TABLE 2
COMPARISON OF ACTUAL AND EXPECTED AVERAGE BALER OPERATING PRODUCTIVITY

	Units	Range Expected	Actual
Baler effective capacity:	t/hr	6 — 10	1.4 — 5.6
Overall efficiency:	percent	56	64 — 76
Daily output:	t/day	40 — 63	7.2 — 34
Length of season:	days	100	78
Productivity:	t/season	4,032 — 6,272	562 — 2,656
Dry basis yield:	t/ha	11.0	11.1
Recovery efficiency:	percent	60 — 80	70.8
Net recovery (dry basis):	t/ha	6.6 — 8.8	7.9
Daily effective coverage:	ha/day	4.54 — 9.55	1.12 — 1.76

NOTES

Source of "Range Expected" data from J. Kadyszewski, et.al., 1987. Trial Year Program Proposal: Nong Yai Sugar Mill — Thailand, Washington, D.C. Office of Energy, U.S. Agency for International Development, page B-4.

Baler effective capacity: For the expected range it is the theoretical baler capacity multiplied by the field efficiency.

Overall efficiency: The overall efficiency expected included 70% field efficiency and 80% availability, which together include anticipated machine related downtime, rain and equipment moving time. Actual overall efficiency is the percentage of in-field production time based on round and square balers, excluding avoidable downtime due to field scheduling problems, accidents, and bale transportation bottlenecks.

Daily output: The hourly effective baler capacity multiplied by the machine availability times 8 hrs/day.

Productivity: The daily output multiplied by the length of the season.

Dry basis yield: Expected dry basis trash yield based on 16.5 t/ha x .6667 (factor for 25% mcwb); actual dry basis trash yield based on 12.56 t/ha x .8838 (factor for 10.41% mcwb).

Recovery efficiency: The trash recovered per unit area divided by the total trash in that area.

Net recovery: The dry basis yield multiplied by the recovery efficiency.

Daily effective coverage: Actual daily effective coverage is based on round and square baler effective coverage (Table 2-1).

Field scheduling problems caused 27.5% of the downtime for round balers. Under commercial management, where fields are scheduled in conjunction with farmer cane quotas and farmers are aware of the market for their residues, this problem should be eliminated entirely.

For the square balers, the major cause of downtime was bale transport bottlenecks. Moving the bales out of the field proved to be much more of a problem than was originally anticipated. Although the problem was solved during the season, bale transportation bottlenecks were responsible for almost 40% of the downtime experienced by the square balers. Field scheduling problems caused 10% of total downtime for the square balers. Accidents and operator error were not significant problems with the square balers, due mostly to the superior terrain in the vicinity of the factory.

TABLE 3
IN-FIELD PERFORMANCE OF BALING EQUIPMENT

Description	Rakes		Round balers		Square balers	
	Hours	Percent	Hours	Percent	Hours	Percent
Operating time	944.5	89.5	1,098	58.4	879	47.0
Unavoidable Downtime						
Tractor failure	24	2.3	51	2.7	31	1.7
Mechanical problems	18.5	1.8	135	7.2	352	18.8
Rain	9	0.9	22	1.2	10	0.5
Equipment moving*	59	5.6	68	3.6	46.5	2.5
Other	0	0	93	4.9	56	3.0
Avoidable Downtime						
Accident or operator error	0	0	203	10.8	12	0.6
Field scheduling	0	0	211	11.2	94.5	5.1
Bale transport bottlenecks	0	0	0	0	388	20.8
Total	1,055	100	1,881	100	1,869	100

* Equipment moving hours are based on an estimated time of one-half hour per piece of equipment each time they were moved from one field to another.

These periods of downtime (caused by both accidents and field scheduling problems in the case of the round balers and bale transportation and field scheduling problems in the case of the square balers) could have been avoided, and indeed should be avoided in any future baling efforts. For this reason, the presentation of cost and performance figures for much of this report is adjusted to eliminate the *avoidable* downtime. Where this is done, the figures are referred to as *rationalized.*

The *avoidable* downtime discussed above is omitted in Figures 1 and 2 to obtain a more realistic picture of what can be expected in future operations. The figures show that for both round and square balers, mechanical problems are the largest source of downtime. For round balers the total downtime due to mechanical problems was 127 hours (Table 4) and for square balers, 354 hours (Table 5).

For the round baler, adjusting and replacing apron chains and chain links was the largest single mechanical difficulty, causing 37% of the *mechanical* downtime. Plugging of the feeder area was the next largest source of downtime due to mechanical difficulties. The apron chain drive mechanism wore out completely on two of the three round balers resulting in almost 10% of the mechanical downtime.

FIGURE 1
ROUND BALERS: DISTRIBUTION OF UNAVOIDABLE DOWNTIME HOURS (369)

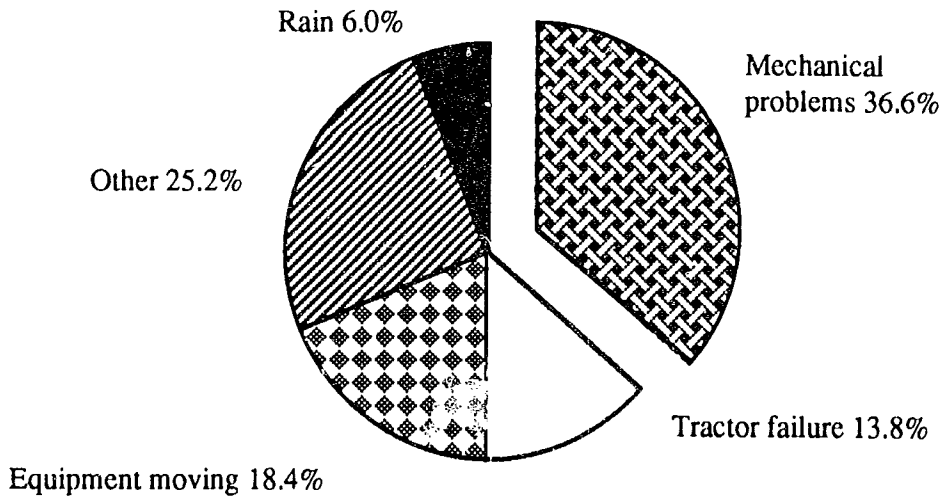

FIGURE 2
SQUARE BALERS: DISTRIBUTION OF UNAVOIDABLE DOWNTIME HOURS (469)

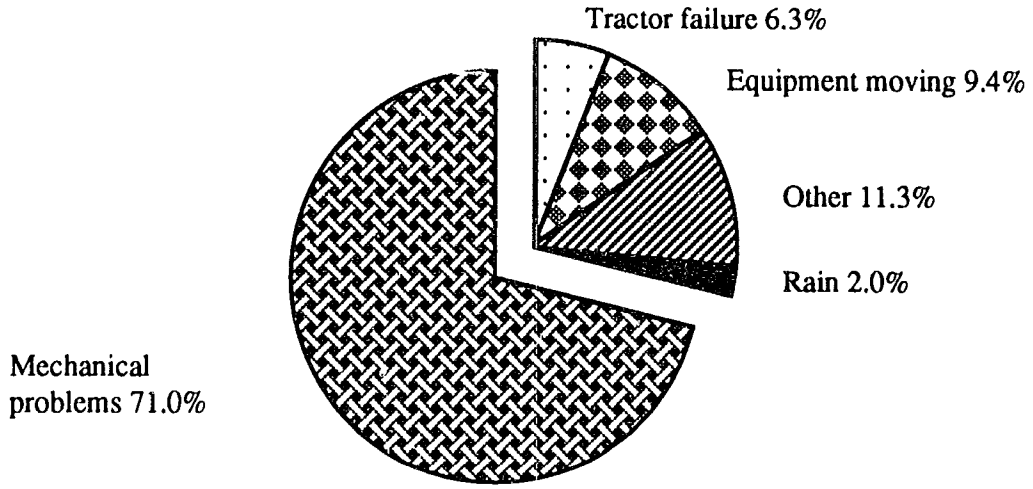

TABLE 4
ROUND BALER: MECHANICAL PROBLEMS

Mechanical Downtime Reason	Hours	Percent
Hydraulic failure	11.5	9.1
Missing, broken, or bent pick-up tines	7	5.5
Plugging feeder area from thick trash, millable cane, or high speed	14	11.0
Shear pin failure	7	5.5
Flat tire (on baling equipment)	4	3.1
Pick-up chain broken	3	2.4
Damage to pick-up gauge wheel	1	0.8
Damage to pick-up wind guard	4	3.1
Replacement of bent or broken apron chain tubes	9.5	7.5
Replacement or adjustment of apron chains	47	37.0
Missing reverse apron chain drive spring	1	0.8
Knife edge mis-adjusted	4	3.1
Apron chain drive mechanism failure	12	9.4
Twine feeding mechanism failure	2	1.6
Total	127	100

TABLE 5
SQUARE BALER: MECHANICAL PROBLEMS

Mechanical Downtime Reason	Hours	Percent
Missing, broken, or bent pick-up times	2	0.6
Plugging feeder area from thick trash, millable cane, or high speed	16	4.5
Knotter mis-adjusted	38	10.8
Sheer pin failure	1	0.3
Flat tire (on baling equipment)	12	3.4
Pick-up chain loose	9.5	2.7
Pick-up chain broken	6	1.7
Feeding fork broken	78	22.2
Broken knotter or knotter needle	189.5	53.8
Total	352	100

The largest single source of mechanical downtime with the square balers was the knotter mechanism and knotter needles. Several knotter needles broke, and the knotter mechanism on all three square balers needed frequent adjustment. Finally, two of the knotter mechanisms required replacement. The magnitude of this problem is also supported by the data from NAMC, which indicates that over one-fifth of the mechanical downtime was due to knotter maladjustment.

2.2.2 Financial/Economic

2.2.2.1 Rationalized Trial Year Baling Costs

The *real* or *rationalized* costs per tonne of the baling operations shown in Table 6 include capital equipment, rented equipment, fuel, equipment maintenance, equipment modifications, twine, and labor. For comparison the costs associated with round balers are segregated from those associated with square balers. The data reflect the real costs for the trial year by eliminating all avoidable downtime (avoidable downtime comprised 54.4% and 50.2% of all downtime for the round and square balers, respectively). Costs associated with bale collection and transportation are not included in this section. The calculations involved in trial year baling costs under these conditions are discussed in Section C.2 of Appendix C. The *actual* costs for the trial year are broken down in Section C.1 of Appendix C.

TABLE 6
SUMMARY OF TRIAL YEAR BALING COSTS ($/t)

	Round bales	Square bales	Average
Capital equipment:[1]	$6.44	$6.99	$6.67
Rented equipment:	3.85	4.81	4.25
Maintenance & spare parts[2]	4.26	6.55	5.21
Fuel:	1.51	1.89	1.67
Twine:	2.39	4.36	3.21
Labor:	0.67	0.73	0.69
Farmer payments:	1.42	1.22	1.34
Total	$20.53	$26.55	$23.03

NOTES:

Cost per tonne figures are based on 2,731 and 1,945 tonnes harvested for the round and square balers respectively. See Appendix C, Section C – 2 for details.

(1) Capital equipment is the yearly cost of capital amortized at 20% for 5 years.

(2) Maintenance and spare parts includes repair labor and lubrication.

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Capital Equipment:

The capital equipment included in the baling costs was three rakes, three round balers, and three square balers. The costs of bale moving equipment is not included in Table 6. The prices for equipment are in U.S. dollars delivered to Nong Yai — exclusive of duty or taxes. Capital costs are amortized at 20% over 5 years, which are the prevailing commercial terms for this type of equipment.

Rented Equipment:

During the trial year, tractors were rented from ATCL to pull the equipment. For a commercial baling operation it may be cost-effective to purchase tractors.

Equipment Maintenance, Repair and Modifications:

The subcontractor, ATCL, in addition to supplying tractors and operators, maintained the baling equipment, made modifications recommended by the Ford-New Holland technical representative, and provided fuel for the tractors. Equipment maintenance and spare parts costs include those for spare parts, expendable items, and labor time for the mechanics. The actual charge out rate for the latter was $8.00/hr, which, although standard for ATCL, would not need to be paid by a private company with its own mechanics, and therefore is reduced to the standard price of ฿200/day.

Of the total value of spare parts and expendable items used during the trial year, $33,008 was provided with the original shipment of equipment, $8,361 came from ATCL's own stock, and $6,925 had to be ordered from the original equipment manufacturer in two separate shipments during the campaign. Since the costs for most of the equipment modifications were not segregated from those for maintenance and repair, they are not included as a separate category in Table 6.

Fuel:

The cost of fuel for the tractors was based on an estimate of the consumption per tractor-day of operation. Although fuel consumption varied depending on tractor model, ground conditions, and load, ATCL estimated that on average a tractor consumed 56 liters for an 8-hour day, and based on their cost of ฿7/liter, they charged $15.68 per tractor day of operation. The data from NAMC yields lower fuel costs of $0.38/t and $0.32/t for the round and square baling operations respectively (also based on a fuel price of ฿7/liter) — which indicates that tractor fuel economy is better than expected. NAMC data does not include fuel used when tractors moved from field to field.

Twine:

In the original shipment of equipment and parts, 400 balls of natural twine of approximately 1,700 meters each were included. In late January, this stock ran out and ATCL provided an additional 294 balls of synthetic twine (16 balls were left over at the end of the season) at approximately 1,200 meters each. The total cost of twine used was $15,006; $6,522 by the round balers and $8,484 by the square balers. The total twine consumed is estimated to be over 1 million meters, approximately 425,700 meters by the round balers and 587,900 meters by the square balers. Twine was consumed at an average rate of 156 m/t and 302 m/t by the round and square balers respectively. Consumption of twine by the square baler cannot be significantly reduced since it is a function of the dimensions of the bale. However, since the wrapping of round bales is controlled by the operator, there is much room for improvement. The average number of wraps during the trial year was 12.3 times, whereas the number of wraps necessary to secure the round bales is less.

Farmer Payments:

As part of its contribution to the trial year program, USAID paid an "honorarium" to farmers who allowed cane trash to be harvested from their properties. The program management, OCSB, and Nong Yai agreed to pay ฿50/rai ($12.25)/ha) after the bales were removed from the farmers' land. The general reaction of the farmers to this payment was positive; in fact some of them asked to participate in the program as a result of this incentive.

Labor:

Three categories of labor were used during the trial year: field labor (at a rate of ฿70($2.75)/day), tractor operators (at ฿400($15.69)/day — which included ฿200($7.84)/day for per diem costs), and truck drivers (at ฿150($5.88)/day). USAID covered the cost of the first two, and Nong Yai paid the salaries of the truck drivers. The latter is excluded from Table 6 which considers only baling costs. The payment for the tractor operators was much higher than market rate because of the structure of the contract with ATCL. The standard rate would have been about ฿150/day, with no per diem payments since tractor operators would be local. Therefore, a rate of ฿150($5.88)/day is used in Table 6 for tractor operator costs.

Because of frequent round baler accidents, additional field labor was assigned to the Bo Thong area to mark stumps and rocks. This resulted in a higher field labor cost for baling per tonne for the round balers than for the square balers. Total labor requirements remain significantly larger for square balers because of manual loading and transport.

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Program costs associated with square baling operations were more than 29% higher on a per tonne basis than those associated with round baling operations. (Table 6) To compare overall cost per tonne for cane field residue harvesting operations, bale collection and transportation costs must be included. Bale collection and transportation costs will be measured thoroughly during Phase II of the trial year and are discussed in greater detail in Section 2.3 below.

2.2.2.2 Trial Year Benefits

The work plan did not anticipate any pecuniary benefits from the research work conducted during the 1989-90 trial year other than those accruing to the local farmers who were paid for their participation and laborers who were employed. However, Nong Yai used the square baled cane trash they transported to the factory in their boilers to operate their refinery during the post-season period. Since no extended boiler tests were scheduled for Phase One of the trial year, there is no way to determine exactly how much the cane trash transported to the factory contributed to the post season refinery operations. However, use of this fuel did increase the amount of sugar refined by Nong Yai. Since Nong Yai is a cooperative, their farmers will realize 70% of any profits gained from these operations.[3]

2.2.3 In-Field Equipment Modifications

One purpose of the trial year was to see how "standard" hay baling equipment would fare under the conditions experienced with cane field residue baling in the Nong Yai region of Thailand. The conditions include:

- abrasive material — cane trash is similar to corn leaves in composition
- sandy, dusty soil with a high silica content — also highly abrasive to equipment
- deep furrows — up to 22 cm deep, which causes excessive wear to pick-up tines (if proper adjustments are not made) and more entrained dust in the trash
- generally hilly fields with rocks and tree stumps — especially in the Bo Thong region

The Ford New-Holland representative visited Nong Yai just before the crushing season and again in January 1990. He recommended several modifications to the equipment based on his observations of conditions and equipment performance. For the most part, the effects that these modifications had on baler performance were not quantifiable, however, some qualitative conclusions can be drawn from observation. Table 7 lists these recommended modifications along with the rationale for introducing them and an evaluation of their effectiveness.

2.3 Bale Collection and Transportation Performance

2.3.1 Bale Collection

Both the 1987 Trial Year Program Proposal, and the trial year work plan envisioned that once cane trash bales were formed, they would be moved from the field to an interim storage area. It was assumed that (1) trucks for transporting bales to the factory would be difficult to obtain and expensive during the crushing season, since they are generally used to haul cane during that period, and (2) storage space at the factory would be scarce. For these reasons, the plan was to wait until after the cane-crushing season before transporting the bales from the interim storage sites to the factory. The cane trash would be used as fuel once the bagasse stockpile ran out.

The work plan called for moving square bales to interim storage sites by loading them onto trailers towed by tractors. However, with a single trailer five laborers could only load and move about 400 bales per day — about one-third the number of bales that could be produced by *one* square baler. One reason for this, that was not fully anticipated, was that the storage sites were often as far as 1 or 2 kilometers from the fields. The initial attempt to collect square bales using a tractor-pulled trailer and five laborers resulted in a cost of $12.64/tonne. This figure reflects only a few days attempt at using this method, and is undoubtedly higher than would be expected with a better collection system. While investigating methods to solve this problem, Nong Yai agreed to provide trucks, a front end loader, and some laborers to collect the bales in the field and transport them directly to the factory.

One method that might increase productivity of bale collection in future square baling operations would be bale ejectors — one of the optional attachments available with the Ford New-Holland Model 326. This attachment ejects bales directly from the back end of the baler into a trailer also towed by the tractor. Although this is the common method for collecting baled hay and other forage, the Ford New-Holland technical representative felt that the deep furrows would prevent the bale ejector from accurately and consistently placing the bales in the towed trailer. Moreover, he felt that the abrasive quality of cane trash would soon render the bale ejector unusable.

At the Luisita Plantation, Central de Tarlac in the Philippines, which is currently the only other location with large-scale cane trash harvesting operations, they collect and stack bales in the field in piles of 25 to await transportation by truck to the factory. The bale consolidation operation at Luisita appears to facilitate loading operations. It must be noted that at that location, the lands are owned and controlled by the Luisita Plantation, whereas in Thailand there are many small holders. These Thai small holders were anxious to clear their fields immediately after harvest — particularly in the case of final ratoon fields. Therefore, bale consolidation in the fields, as is practiced at the Luisita Plantation, could not be implemented during these trials.

TABLE 7
IN-FIELD EQUIPMENT MODIFICATIONS

	MODIFICATION	RATIONALE	EVALUATION
1.	perforate the floor of the square baler feeding chamber with 200 holes, 1.2 cm in diameter spaced 4 cm apart	to allow entrained dust in the trash to fall out of the feeding chamber before entering the cutting chamber thereby prolonging the life of the knife and decreasing the ash content of the fuel	this was accomplished before the start of operations so no direct comparison is possible – however, lower than expected ash percentages in square bale samples indicate a degree of success
2.	drill new holes in the square baler pickup adjustment bracket to increase the clearance between the pickup mechanism and the ground	to account for the furrowed conditions which made the pickup gauge wheel almost ineffective in controlling the pickup clearance	this was accomplished after one month of operations – resulted in a reduction in downtime due to trash plugging the feeder area
3.	install an adjustable chain and bracket to the round baler pickup mechanism	to allow adjustment of the pickup mechanism independent of the pickup gauge wheel which was not able to stand up to the hard terrain	this was accomplished after one month of operations – resulted in a reduction in downtime due to trash plugging the feeder area
4.	hang a sheet metal shield from the bottom of the tractors pulling the round balers	to prevent cane trash from balling up under the tractors and wrapping the drive shaft on 4-wheel drive tractors (Note: square balers are pulled to one side of the tractor, not directly behind)	this was accomplished after one month of operations – the shield kept breaking, trash balling was not a severe problem, and 4-wheel drive was disconnected to eliminate drive shaft wrapping. Abandoned after 1 month
5.	adjusting the twine cutters on the round balers	to accommodate the plastic twine that was introduced when the original shipment of natural twine ran out	plastic twine was introduced after 40 days of operations – re-adjustments had to be made continually to ensure that the knives would cut properly. Recommend natural twine only
6.	moving the tines on the rakes one hole over in each row	to prevent tines from rubbing against the stripper bars and bending or breaking while operating in furrowed conditions	this was accomplished after two weeks of operations – although tine bending was still a problem, breakage was reduced
7.	installing a chain guard on the drive chain for the pickup mechanism on the square balers	to prevent pieces of cane trash and millable cane from derailing the chain and also to minimize the amount of dust abrading the chain	this modification was not introduced, and derailing was a significant problem

Round bale collection, which was accomplished throughout the campaign, was relatively simple. One to three bale movers were used to collect round bales from the field and move them to interim storage areas within 2 kilometers of the field from which they were taken. Data from the APM's daily logs and ATCL invoices for round bale collection operations show a cost of $4.81/tonne which would increase the overall real cost of round baling operations by over 23%.

The cost-effectiveness of bale collection operations in future bale harvesting campaigns will depend on (1) whether the factory intends to burn trash during the crushing season, (2) the cost and availability of land at or near the factory, and (3) the availability and cost of trucks during the crushing season. Bale collection, in and of itself, did little to facilitate the actual transportation of bales to the factory, while adding significantly to the cost.

Costs for storage will depend on the value of the land where bales are stored, costs needed to protect bales from fire and water damage, and dry matter losses associated with storage. Earlier tests sponsored by A.I.D. and carried out by HSPA[4] showed significant deterioration for square bales stored in the open (approximately 65% dry matter loss after one year). Deterioration for round bales was more modest but still significant (approximately 10% dry matter loss after one year).

Since the end of the 1989-90 cane-crushing season, Nong Yai used a trash/bagasse mixture in its boilers without experiencing significant problems. Approximately 1,500 tonnes of trash were mixed in with the factory's 20,000 tonnes of stockpiled bagasse, which only slightly lowered the fuel's moisture content — probably not enough to warrant significant boiler adjustments. Nong Yai's chief engineer has expressed some concern over using pure trash, given that the existing instrumentation in the factory makes exact boiler adjustments difficult.

For Nong Yai during the trial year, storing bales in the factory with bagasse was not a problem. First the area required for the year's bale collection was quite small, and second, Nong Yai has an extensive area available for bale storage. For other factories, this may not be the case. The decision of whether to transport bales directly to the factory or to store them in interim locations for later transport will depend, in part, on the availability of land at the factory. For an operation equal in scale to the trial year, Nong Yai would not use interim storage sites.

While it is true that trucks for bale transportation are more difficult to obtain in-season, they can be obtained, and there is little evidence that they are significantly more expensive than during the non-crushing season. However if large numbers of trucks are required for bale transportation involved in future, large-scale, commercial operations costs might rise.

One incentive to transport the bales directly from the field to the factory without interim storage is that some material is lost each time a bale is moved. This is exemplified by the difference in the estimated total quantity of square bales formed and the quantity received by Nong Yai according to their factory scales.

2.3.2 Bale Transportation

Although the trial year work plan did not include any provision to transport bales, when the factory began transporting square bales directly from the field to the factory, the research team from National Agricultural Machinery Center was asked to observe and record data for this operation.[5] The factory and the assistant program manager also kept daily records of man-hours for the field labor, trips per day for the trucks, approximate time and distance per trip, and tonnage received at the factory's scales.

Initially, the square bales were loaded onto the bucket of the front end loader by up to eight laborers. The bucket was then raised to the level of the truck and the bales were off-loaded and stacked in a truck (either one of four 6-wheel dump-trucks or a 10-wheel flat-bed truck) by an additional three or four laborers. The truck was driven to the factory where the bales were dumped in the bagasse storage area. Two laborers at the factory removed the twine from the bales to avoid problems with the factory's bagasse conveyor system.

Even after Nong Yai began providing labor and equipment, the bale transportation team could not keep up with the production of the square balers. To avoid friction with the farmers who needed to replant their fields, it was decided that each time the balers got more than 3 or 4 days ahead of the bale transportation team, the square balers would be temporarily halted until the bale transportation team could catch up. On the several occasions when the factory's equipment was required for other tasks at the factory, the bale transportation operation fell behind the square baling operations. And, as a result on three or four occasions, the baling had to be suspended until the bales could be removed from the fields.

In early February, the factory was able to commit at least three full-time dump trucks and drivers, and USAID agreed to provide at least 15 laborers. Once this plan was adopted there were no more serious bale transportation bottlenecks. Moreover, a different technique was used to load the trucks. Rather than loading bales onto the bucket of a front-end loader and then onto the truck, laborers threw them directly from the ground up to the truck. Also, the square balers were adjusted, to reduce the bale size and make the bales more manageable. The National Agricultural Machinery Center (NAMC) data shows a marked improvement in loading productivity after the modified bale loading technique was initiated. Using the front-end loader, the field laborers were able to load an average 360 kg/man-hr. When the new system was instituted and the bale size was reduced the loading figure jumped to 578 kg/man-hr.

The square bale transportation team moved 1,545 tonnes of square bales from the field to the factory over the course of the trial year.[6] Two different types of trucks were used to transport square bales; 6-wheeled dump trucks, carrying an average of 2.1 tonnes per load, and a 10-wheeled cane truck with the sides removed, carrying an average of 4.4 tonnes per load.

The data for the transportation cost figures was collected by the research team from NAMC, and is included along with transport cost projections over different distances in Appendix C, Section C.1. Square balers were operated within about 5 km of the factory, while round balers were operated about 25 km from the factory, so the actual transport costs cannot be compared without extrapolation. Data provided in Tables, 10, 11, and 12 in Appendix C show detailed costs for round bale transport, square bale transport in 6-wheeled dump trucks, and square bale transport in 10-wheeled cane trucks. The fixed costs were $3.11/tonne for the 6-wheeled truck and $4.27 for the 10-wheeled truck, or an average of $3.69/tonne. Variable costs average about $0.25/t-km.

The only data taken for transport of round bales was from a 5-day trial period. During the trial bales were moved from interim storage areas in the Bo Thong region to the factory. Only six truck-loads were transported during this period, weighing a total of 52 tonnes. Because it was a short trial and there was not enough time to achieve a steady-state performance, the data probably overestimates the costs of transporting round bales. Nevertheless, the data available yields a cost of $8.15/tonne for a one-way field-to-factory distance of 23.2 km. The fixed costs were $5.79/tonne and variable costs were approximately $0.10/t-km.

Figures 3 and 4 summarize the key data from these tables. Fixed costs of equipment and labor cover those portions of the operation that involve loading bales onto the truck in the field and unloading bales at the factory. Round bales are loaded using tractors with front-end loaders and have larger fixed costs for loading than the manually-loaded square bales. The costs of equipment, labor, and fuel associated with the actual transport from field to factory vary depending on the transport distance. For a given distance, transport costs for round bales were much lower than those for square bales because the average bulk density of round bales is 147 kg/m^3 compared with 100 kg/m^3 for the square bales. The greater density more than compensates for the greater void ratio present when round bales are loaded into a truck.

The factory later transported an additional 200 tonnes of round bales from the Nong Yai and Bo Thong regions to the factory. It was not possible to have the research team from NAMC conduct observations of these transportation operations, so no additional data are available.

Figure 3 compares the cost of transporting round and square bales a distance of 20 kilometers to the factory. Square bale transportation is further broken down to segregate bales transported by the 6-wheel (dump-) and 10-wheel (cane-) trucks. The transport category covers those costs associated with the field-to-factory trip. All other categories do not change with transport distances. To further illustrate, Figure 4 shows the cost per tonne projections for the round and square bale transportation over different distances. This graph includes all the fixed and variable costs shown in Figure 3.

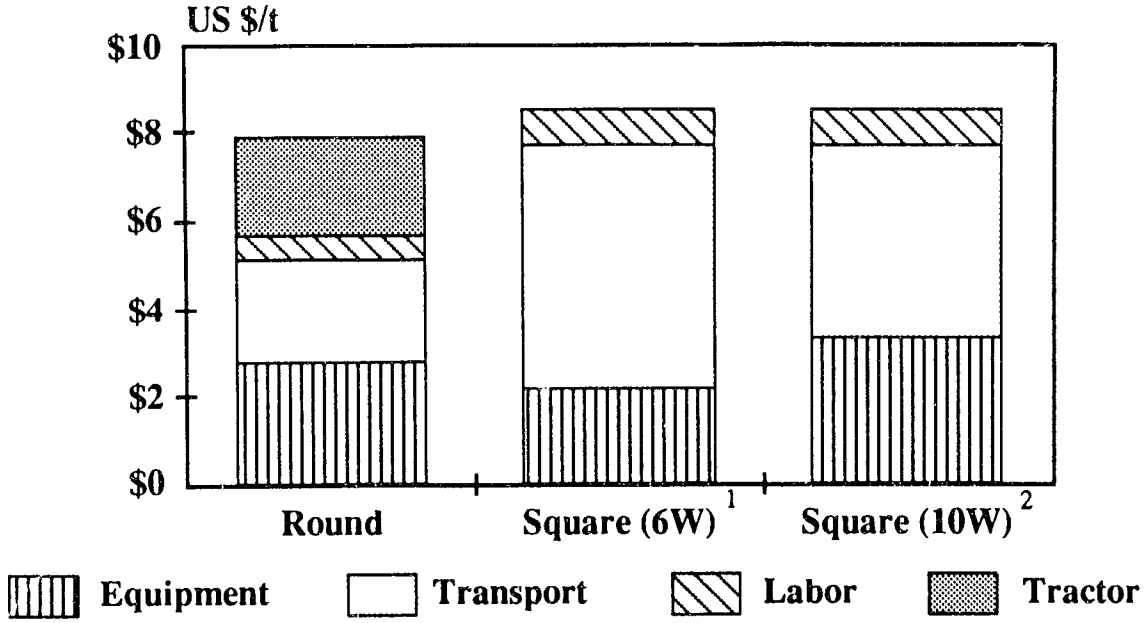
2.4 Lessons Learned

Several observations about the year's activities should be made in order to improve performance and cost effectiveness in future cane field reside collection activities. Much of the downtime was *avoidable* and should be eliminated. Avoidable downtime included: (1) bale transportation bottlenecks (for the square balers); (2) accidents and operator error; and (3) field scheduling problems. Managers of future trash baling efforts should:

- work closely with the factory's farm manager or cane quota men to coordinate the baling schedule with the harvesting schedule in order to minimize downtime due to field scheduling problems
- enlist the cooperation of the farm manager in selecting high quality fields, i.e., fields with fewer stumps and rocks, long straight furrows, thick even layers of trash, and no millable cane — to minimize the number of accidents, and ensure higher machine productivity
- keep a qualified mechanic standing by in case of mechanical breakdowns;
- lubricate baling equipment in accordance with operators manual for arid conditions (twice daily);
- schedule downtime (1 day per week) for routine maintenance and repairs
- provide a method to remove bales from the field promptly, whether or not the bales will be transported to the factory immediately

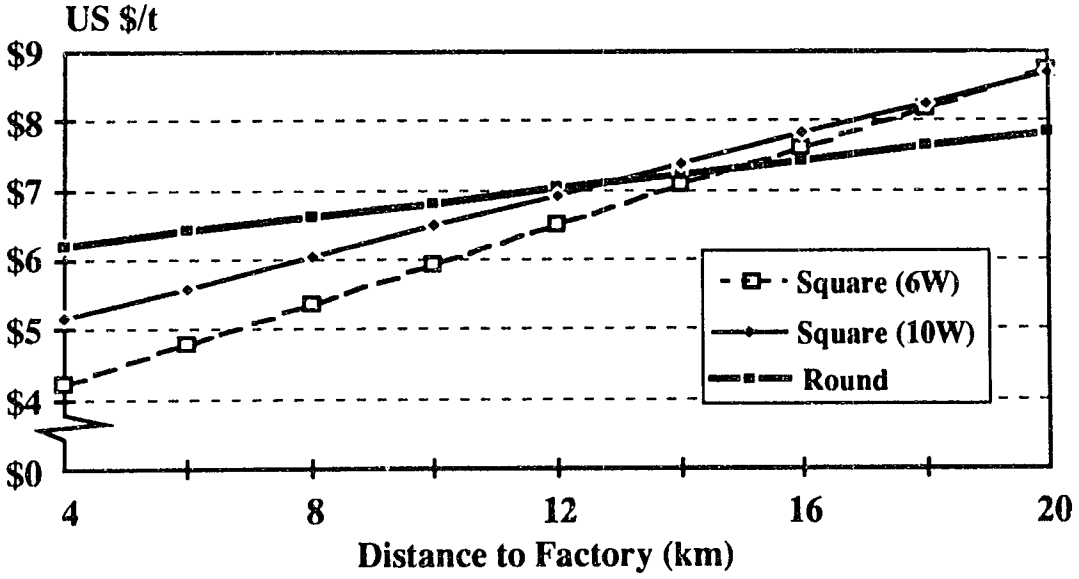
Figures 5 and 6 depict the upward trend of baling productivity over the trial year period, in terms of area covered and tonnes baled, respectively. These suggest further productivity increases in future commercially run operations. Figure 5 shows an increase of 21%, from 0.27 to 0.33 ha/hr, for the round baler and an increase of 115%, from 0.14 to 0.30 rai/hr, for the square baler. Figure 6 shows an increase of 48%, from 2.2 to 3.3 t/hr, for the round baler and an increase of 77%, from 1.6 to 2.9 t/hr, for square balers.

FIGURE 3
BALE TRANSPORTATION COST COMPARISON
(20 km field-to-factory distance)



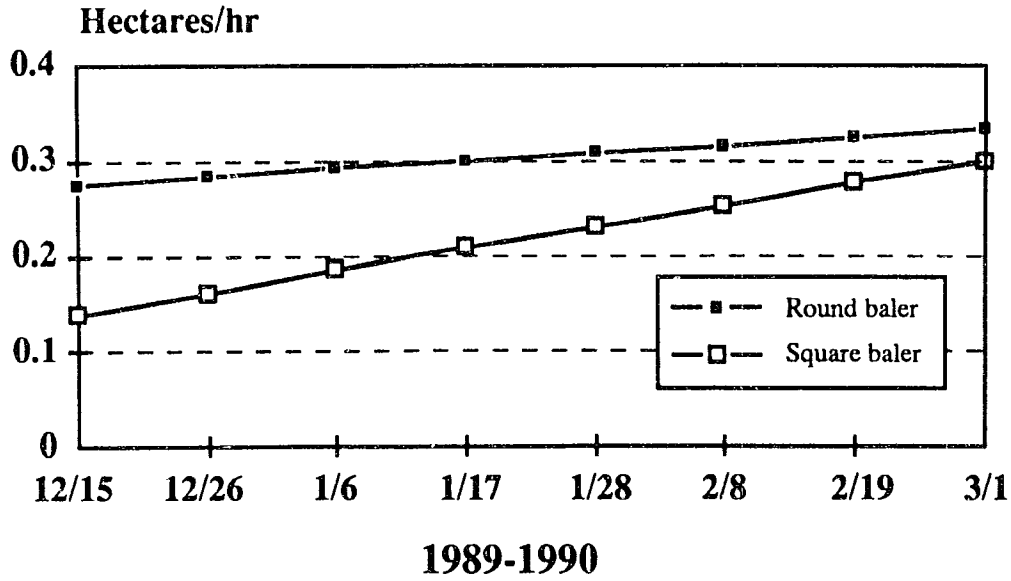
Source: Appendix Tables 10, 11, and 12 1 6-Wheel Truck 2 10-Wheel Truck

FIGURE 4
PROJECTED TRANSPORTATION COST:
ROUND VERSUS SQUARE BALES



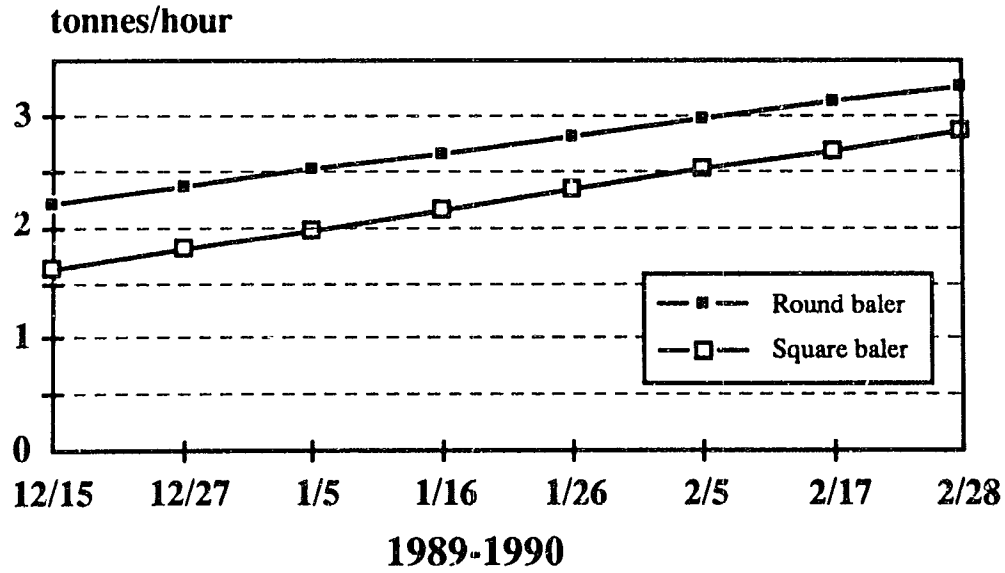
Source: Appendix Tables 10, 11, and 12

FIGURE 5
BALER PERFORMANCE OVER TIME [1]



[1] Represents a least-squares fit of APM's daily log data

FIGURE 6
BALER PERFORMANCE OVER TIME [1]



[1] Represents a least-squares fit of APM's daily log data

Notes

(1) The research plan is included in Appendix D.

(2) Unless otherwise noted, the data presented in this section was not derived from the research efforts of NAMC, OCSB, CLGC, or HSPA, but rather came from the daily logs compiled by the APM and from the monthly invoices from ATCL.

(3) Over 1,500 tonnes of cane trash were mixed in with the excess bagasse (about 20,000 tonnes), which together provided enough fuel to operate their refinery for 37½ days after the crushing season ended on March 15. Of the total 21,500 tonnes of 93:7 bagasse:trash fuel mixture left after that date, about 3,700 tonnes were left over to start the boilers at the beginning of the 1990-91 season. Thus, about 17,800 tonnes of mixed fuel were used to process 19,407 tonnes of raw sugar into 9,794 tonnes of plantation white sugar and 8,646 tonnes of refined sugar (with 967 tonnes lost in the refining process). All of the refined sugar is sold on the domestic market as part of Nong Yai's "quota." Most of the white sugar is sold on the international market.

Based on 50% mcwb, the factory requires about 20.5 tonnes of bagasse/hr to operate one of their 80 tonne boilers at 80% capacity to produce steam for the refinery and NYSF's nominal off-season power needs. In 1 hour they process about 21.5 tonnes of raw sugar into either plantation white or refined sugar. (This translates to 952 kg of bagasse/tonne of refined sugar.) By mixing the 20,000 tonnes of 50% mcwb bagasse with 1,500 tonnes of 12% mcwb trash they, in theory, produced 21,500 tonnes of 47.3% mcwb mixture. Since a 1 percent change in moisture is equivalent to a 2.3 percent change in calorific value, this change has the effect of increasing the calorific value of the material by 6.2%. Taking into consideration the estimated boiler efficiency (about 60%) using this 47.3% mcwb fuel lowers their fuel requirements by about 3.7%, so that they only required 19.7 tonnes of mixed fuel/hr to operate their 80 tonne boiler. (This translates to 916 kg of mixed fuel/tonne of refined sugar - a savings of 36 kg of fuel/tonne of refined sugar over bagasse alone.) Thus for refining operations since the end of the crushing season, the addition of 1,500 tonnes of trash effectively increased the fuel available by about 2,200 tonnes, which translates to about 2,400 tonnes of plantation white or refined sugar.

(4) Jakeway, L.A. and Santo, L.T. 1991. Results of Cane Residue Recovery Trials 1987-89, Final Report. Hawaiian Sugar Planters' Association, Honolulu, Hawaii, pp. 25-29.

(5) A summary of their data is included in Appendix C, Section C.1. Their complete analysis will be available in HSPA's Final Report.

(6) Approximately 20% of the square bales harvested were not transported to the factory due to losses in the field, mal-formed bales which were counted by the bale counter, accidental fires in the field, and losses from the truck during transport.

Chapter Three

FUTURE WORK

Several questions concerning the collection of sugarcane field residues should be answered in order to fully assess the potential of this biomass material as a boiler feedstock for energy production. These include:

- the cost of transporting round bales from the field to the factory
- the cost and technical feasibility of processing bales in preparation for use in the boiler
- the impact of trash removal on soil nutrient levels and other agronomic variables
- the impact of burning trash (both pure and mixed) in boilers
- the combustion properties of trash (both pure and mixed)
- the environmental impacts of burning trash
- the replicability of cane field residue collection operations

The MOU and Trial Year Work Plan anticipated that Phase Two of the trial year program would provide research data to answer some of these questions.

3.1 Phase II — Follow-on

The Nong Yai Sugar Factory has expressed an interest in obtaining baled trash in the 1990-91 season. They intend to use the cane trash along with their excess bagasse as a fuel both for sugar processing and for the production of excess power for sale to the grid. If they find it profitable to bale and process cane trash during the 1990-91 season, they may purchase their own baling equipment and continue the operation.

Table 8 compares baler performance under a scenario in which Nong Yai, or any commercial company, runs the cane baling operations. The projections included in this table are based on the guidelines listed in Section 2.4. The purpose here is to determine how many tonnes can be collected in the future under private management. In addition to eliminating bale transportation bottlenecks, accidents, and field scheduling problems, this table assumes conservative increases in productivity (ha/production hr and t/production hr) based on the trends shown in Figures 5 and 6. These productivity levels will only be reached if the guidelines listed in section 2-4 are followed. These increases are conservative because figures 5 and 6 are least-squares fits of the data obtained during the trial year, and do not show the true potential of the operations.[1]

Appendix C, Section C.3 provides the analysis of the per tonne costs under the future scenario, which is used in Table 8. With the increased production, the cost per tonne for raking and baling falls to $15.60 and $24.05 for the round and square baling operations, respectively. If transportation is included (for a 10 km field-to-factory distance), the respective total cost per tonne is $24.15 and $30.31.

It is possible to reduce the twine costs for the round baler by reducing the number of wraps per bale. By instructing the operators to wrap the bales merely five times, only about 63 meters of twine per tonne will be used, costing $1.16/tonne rather than the $2.39/tonne that it cost this year. This figure was factored into the per tonne calculations in Appendix C, Section C.3 and in Table 8.

Table 8 shows that over 11,200 tonnes of baled trash can be collected from 1,400 ha using this equipment. At the time of this writing, the National Energy Policy Office had not yet published the 300 MW solicitation for co-generated power. Since at least 10 months are required to design, procure, and install the equipment necessary to interconnect Nong Yai to the local Provincial Electric Authority grid, it is unlikely that they will be able to sell power during the 1990-91 crushing season unless necessary equipment is already available in Thailand.[2] Nevertheless, Nong Yai could profit from this operation by using cane trash to extend their refinery capabilities, and to provide power to NY Rubber, a rubber factory under Nong Yai Industries Co., Ltd. located less than 1 kilometer from the sugar factory. It should be noted that Nong Yai

BEST AVAILABLE

TABLE 8
BALER PERFORMANCE COMPARISON - FUTURE SCENARIO UNDER COMMERCIAL OPERATION

	Units	Round balers	Square balers
Total scheduled operating time:	hrs	2,580	2,580
Efficiency	percent	76	64
Production time:	hrs	1,961	1,651
Anticipated downtime:	hrs	619	929
Effective coverage:	ha/prod. hr	0.34	0.30
Effective productivity:	t/prod. hr	3.3	2.9
Area covered:	ha	667	494
Trash recovered:	t	6,471	4,788
Recovery rate:	t/ha	9.7	9.7

NOTES:

Total scheduled operating time: Based on 100 day season with one day per week for maintenance and repairs – or 86 operating days per season times 10 hours per day.

Overall Efficiency: The total scheduled operating time (10 hrs/day, 86 days/season) divided by the actual time baling, is based on the elimination of avoidable downtime as described in Section 2.2.1. Actual efficiency may be higher if preventative maintenance is adequately performed on the one non-production day per week.

Production time: The total scheduled operating time multiplied by the overall efficiency.

Anticipated downtime: The total in-field time less the production time. This reflects expected downtime due to unavoidable mechanical breakdowns, rain, fueling time, etc.

Effective coverage: Based on upward trends in area baled over the trial year, which showed an increase of 21% and 87% for the round and square balers respectively. See figure 2-5.

Effective productivity: Based on upward trends in tonnage baled over the trial year, which showed an increase of 48% and 77% for the round and square balers respectively. See figure 2-6.

Area covered: Trash recovered divided by recovery rate.

Trash recovered: Production time multiplied by the operating productivity.

Recovery rate: Operating productivity divided by the operating coverage.

Sugar Factory is a cooperative and that the farmers belonging to the cooperative receive 70% of any profits.

The factory intends to bring the bales into the factory during the season and mix them with the bagasse. During the trial year, Nong Yai produced a total of 482,400 tonnes of bagasse. Mixing that quantity of bagasse at 50% mcwb with 11,259 tonnes of trash at 12% mcwb will yield 493,659 tonnes of 49% mcwb mixed fuel (a 37.5:1 bagasse: trash mixture). In addition to increasing the total fuel available by 11,259 tonnes, this mixture will lower Nong Yai's fuel requirements by 1.4%, providing an effective

increase of 19,300 tonnes of 50% mcwb fuel. That amount of additional fuel used for refining sugar translates into an additional 20,400 tonnes of plantation white sugar.

Additionally, since the refinery process only requires low pressure steam, the trash can be used in the boilers to provide power for the needs of the near-by NY Rubber. The rubber factory runs during the sugar factory's off-season, and will require approximately 160 MWh/month of electrical power. The addition of 12,500 tonnes of trash will approximately double the number of post-season days Nong Yai can run its boilers. With the new 120 t/hr boiler currently being installed, the sugar factory will probably be able to run its boilers for 3 months beyond the end of the crushing season. Thus for 3 months, in addition to refining sugar, Nong Yai Sugar Factory could supply 500 MWh to NY Rubber, worth about $45,000 in avoided power purchases (at their current price of β2.3/kWh, which includes a demand charge).

3.2 Bale Processing

During the 1989-90 harvest season, Nong Yai constructed a bale shredding machine designed to process the large round bales. The machine tended to choke on the material during the initial test run of the shredder using round bales. Moreover, it was slow, processing only about 3 to 5 tonnes per hour. Several modifications have been recommended, and will probably be incorporated prior to the start of the next crushing season. However, it remains to be seen whether this design will be effective in processing large round bales. The factory has shown that it is possible to use square bales as a boiler fuel with no pre-processing other than removal of twine and mixing with the bagasse; however, the practicality and sustainability of this practice has not been proven. Square bales could be processed in the existing or modified bale shredding machine.

3.3 Program Replicability

Whether or not cane field residue collection operations similar to the trial year activities can be profitably conducted at other mills, both in Thailand and elsewhere in the world, depends on several key conditions.

1. The sale of privately generated electricity to the national grid must be legally permitted. In Thailand, although such laws have been enacted, there has been no formal solicitation to allow these sales to occur. Until such a solicitation is published, electricity produced by sugar mills cannot be sold to the national grid, and the profitability of cane residue collection operations will rely on increased refinery capacity and the transfer of electricity to adjacent industries owned by sugar factories.

2. Mill managers must realize they can profit by selling products other than sugar. Part of the rationale of the trial year program was to demonstrate to mill management that the generation of electricity for sale could be feasible and profitable.

3. Mills must be close enough to cane fields so that bale transportation costs are not excessive.

It will be less expensive to collect residues from cane fields that are flat with shallow furrows and few stumps or large rocks. Furthermore, the longer the tracts of land, the less turnaround time for the equipment and, other things being equal, the lower the per tonne costs.

3.4 Agronomic Study

During the trial year, preliminary research conducted by the Hawaiian Sugar Planters' Association (HSPA) into the agronomic impact of cane field residue collection activities showed no observable adverse effects of the trial year on cane production (in both planted fields and ratoon fields) nor on soil compaction. A more detailed analysis will be available in HSPA's third quarterly report to the Winrock/BEST Project. It must be noted, however, that the impact of removing cane trash from the field cannot be fully analyzed without studying the long-term effects on soil nutrition.

Winrock International has held discussions with Kasetsart University (Kamphaeng Saen Campus) to initiate a 5-year agronomic experiment. The purpose of this experiment is to study the effect on soil nutrients of the removal of cane residues from the field. Currently in Thailand, the normal practice is to burn the residues in the field after harvesting. Five years is the minimum amount of time required to determine the existence and extent of any depletion of soil nutrients. If this experiment is installed this year, first results should be available in 1996.

Notes

(1) Note that on the highest productivity day during the trial year, 5.57 and 4.87 tonnes/production hour were obtained by the round and square balers respectively - or over 2.2 times the average rate. Similarly, the best coverage rates were 4.29 and 4.00 rai/production hour for the round and square balers respectively - or over 2.3 times the average rates. These rates were obtained by the best operators on high quality fields.

(2) D. Hertzmark, et. al., *Interconnection of Sugar Mills to the Thailand Electric Power Grid: Issues and Prospects - DRAFT REPORT*, Office of Energy, U.S. Agency for International Development, January 1990, p. 3.

APPENDIXES

APPENDIX A

MEMORANDUM OF UNDERSTANDING
TRIAL YEAR, PHASE I

ELECTRICITY FROM SUGARCANE RESIDUES

Introduction

In 1986 the Ministry of Industry and the United States Agency for International Development (USAID), with the cooperation of the Electricity Generating Authority of Thailand (EGAT), worked with the Thai sugar industry to examine the costs and benefits of having the sugar industry generate and sell electricity produced from sugarcane residues to EGAT. The study published in September 1986 found this option attractive and described in detail the likely benefits to the nation, to the farmers, millers and EGAT.

Following a request from the Ministry of Industry, USAID in the summer of 1987 provided a team of experts to assist in the design of activities for a trial year to demonstrate the technical and commercial feasibility of the approach recommended. Nong Yai Sugar Company agreed to cooperate with the Ministry of Industry in sponsoring the trial.

Early in 1988 the participants agreed that it would be best to divide the trial year activities into two phases. Phase One, to be conducted during the 1988-9 harvest season, will determine the costs of collection, storage, and transport of cane tops and leaves and estimate the amounts that would be available as fuel. During Phase One the collected fuel will be test burned by the participating mill to determine combustion properties, but only for the mill's internal power requirements. Phase Two, to follow, will demonstrate the feasibility of steady, controllable generation of electricity by the sugar industry both during and outside the processing season. Division of the trial year into two phases will allow the mill to test the response of cane farmers and determine fuel quantities and combustion properties before committing itself to the capital costs required for power export. Participants agree to implement Phase Two following successful completion of Phase One.

Objectives

The purpose of this Memorandum of Understanding is to obtain the agreement of all parties that will be involved in Phase One of the trial year, before the commitment of further capital and management resources.

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The objective of Phase One is to determine the feasibility and costs of collection, storage, transport, and combustion of cane tops and leaves and to determine the quantity that may be available as fuel and the quality of the fuel.

It is expected that the Royal Thai Government will use the results of trial year activities to determine appropriate government policies with respect to generation and sale of electricity by the sugar industry.

Responsibilities

1. Nong Yai Sugar Factory

The Nong Yai Sugar Factory will harvest, store, and transport cane tops and leaves in sufficient quantities to establish the cost and technical feasibility of supplying this fuel for combustion, and will conduct tests of the combustion properties of the fuel in its boilers. The cost of this program will be paid by the Factory, excepting the provision of baling equipment and related technical assistance, which will be supplied by USAID. The Factory will identify and secure the cooperation of cane farmers who will participate in the trial year activities. The Factory will cooperate in the collection of data as described in the implementation plan. These activities will be carried out in cooperation with the technical specialists to be provided by the other participants in the trial year.

The mill will collaborate with representatives of USAID in the formulation of an operating plan for the implementation of Phase One of the trial year.

2. EGAT

EGAT will monitor the combustion tests at the Nong Yai Sugar Factory and will provide such technical advice as may be appropriate in assisting the mill staff in planning for power generation.

3. Ministry of Industry Office of the Cane and Sugar Board

The Ministry of Industry (MOI) will be the recipient of the agricultural machinery provided under grant funds by USAID and will assist in the collection of data and will assure that information obtained during Phase One is available for distribution to other interested sugar mills and sugar farmers in Thailand, publishing and disseminating information as seems appropriate.

The MOI will coordinate a tax waiver with the Department of Technical and Economic Cooperation (DTEC) and will set the terms for use of the agricultural machinery by the Nong Yai Sugar Factory. The MOI will retain ownership of the

agricultural machinery after the trial year and use it for Phase Two program, if any. It can also be used for subsequent demonstrations at other locations in Thailand.

4. USAID

USAID will provide funds for technical assistance and will procure the agricultural machinery to be used in the trial year. Technical assistance will include one full-time coordinator resident in Thailand during the trial year and short term specialists to assist in the design of field trials and systems to collect, store, process and burn cane tops and leaves, and to assist in other matters as necessary. The Hawaiian Sugar Planters' Association, acting as an agent for USAID, will work in collaboration with designated Thai institutions to collect and evaluate data on the program for harvesting cane tops and leaves.

USAID will collaborate with the Nong Yai mill in the formulation of an operating plan for the implementation of Phase One of the trial year.

5. DTEC

DTEC will coordinate with the MOI and USAID to assure that the requirements for a waiver of taxes on imported agricultural machinery are satisfied.

Agreement

The signatories of this Memorandum of Understanding agree to fulfill the responsibilities as defined above.

_____
Ministry of Industry

_____
Electricity Generating Authority of Thailand

_____
Nong Yai Sugar Factory

_____
Director
U.S. Agency for International Development

_____
Director General
Department of Technical and Economic Cooperation

APPENDIX B

TEST PROCEDURE FOR MONITORING, REPORTING, AND EVALUATING CANE RESIDUE RECOVERY*

* Reprinted from Fourth Quarterly Report on AID/TVA Cane/Energy Systems Assessment Program to U.S. Agency for International Development, Hawaiian Sugar Planters' Association, October 1988, Attachment 1.

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TEST PROCEDURE FOR MONITORING AND REPORTING CANE RESIDUE RECOVERY

Lee A. Jakeway
October 15, 1988

OBJECTIVES

The objectives of this study are to:

1. Assess the available cane residue resource base for a variety of field conditions.

2. Evaluate the productivity of the Cane Residue Recovery System (CRRS) and the economic feasibility of baling and transporting cane residue.

3. Evaluate the feasibility of storing bales of cane residue for deferred combustion and the effect of storage on fuel value.

4. Assess the agronomic effects of collecting and removing sugarcane residue from fields.

PROCEDURE

1. Locating Harvest Areas and Estimating Cane Yield

   a. A goal of working in two test areas per week at the commencement of the residue recovery campaign is established. One "green reaped" field and one conventionally harvested field (in close proximity to the green reaped field) will be designated in each test area. Green reaped and conventionally harvested fields will be compared later in a series of agronomic studies. It is anticipated that between 10 and 20 test areas will be designated (ten each for round and square balers) during the entire harvesting campaign.

   b. Fresh weight cane yield data will be obtained from the truck scale records already being maintained by the factory. If available, field maps of the test fields will be provided. (See Attachment A for an example of appropriate data collected for this procedure.)

2. Determination of Residue Resource Base

   a. Cane residue resource base will be determined immediately prior to the residue recovery operation in green reaped fields only. Rectangular harvest plots of approximately 20 m^2 (215 ft^2) will be used to determine the resource base. Once an appropriate size sample plot has been established, the plot size will be fixed throughout the study. Five plots per test field will be sampled to determine average cane residue yield. (See Attachment B for example of form required for data collection.)

b. A chopped representative subsample of approximately 1 kg (2.2 lbs) fresh weight will be obtained from each sample plot. Each sample will be analyzed immediately for moisture content and later for ash content. The sample will be tagged with all appropriate information as illustrated in Attachment C. The procedure for moisture determination is given in Attachment D.

Labor: 1 recorder, 3 samplers, one laboratory assistant.

Equipment:

Qty.	Description
1	Forage chopper and tractor.
1	Measuring tape and cord.
5	Burlap sacks for weighing collected residue.
1	Pull-type scale, 15 kg capacity, accurate to within 0.1 kg.
100	Polyethylene bags (5ℓ volumetric capacity).
100	Wires and tags for sample identification.
1	Balance scale (0.1 g accuracy).
1	Drying oven.

3. CRRS Performance Evaluation

a. The equipment required for the CRRS are a rake, baler and bale handler, and tractor power units to run these implements. The equipment will operate in numerous fields; therefore, travel time between fields must be monitored to assess system availability. A record of travel time between fields will be recorded using the form given in Attachment E.

b. For each individual implement utilized in the CRRS, a separate daily equipment activity log sheet will be maintained using a form similar to that given in Attachment F. Machine down time and explanations of down time will be part of recordkeeping. Equipment fuel and maintenance requirements will also be recorded. A repair record for all major equipment will be maintained using a form similar to that given in Attachment G. There will be an Equipment Data Recorder in the field at all times when the CRRS is operating to monitor its productivity. Bale production of balers will also be recorded as indicated in Attachment F.

c. Bale transportation to the storage site will be monitored to determine transportation costs. This will be performed when the HSPA Project Leader is present to observe operations. Typical loads will be followed from the field to the storage site.

Labor: 1 recorder, 1 assistant

Equipment: Clipboard, data forms, stop-watch

4. Residue Recovery Determination

After the CRRS has finished operating in a test field, field sampling will again be performed to assess residue recovery performance. Procedures and data collected will be exactly the same as described in Procedure 2 with the exception that moisture content need not be measured. The data form in Attachment B shall again be used for this Procedure.

Labor: Same as Procedure 2.

Equipment: Same as Procedure 2 with the exception of forage chopper, balance scales, and drying oven.

5. Determination of Baled Residue Physical Properties

a. A bale storage test will be conducted at a designated bale storage site where meteorological data can be collected. Pertinent weather data such as maximum/minimum temperature, rainfall, relative humidity, and daily average wind velocity will be collected at the designated storage area. Bales obtained from one field will be designated for the storage test. The storage intervals used for testing will be 0, 20, 50, 100, and 200 days after baling. Five bales will be sampled for each storage interval, giving a total of 25 bales for each storage treatment. The two storage treatments examined will be covered bales and uncovered bales. Round and square bales will be collected for the storage test. All bales will be weighed at the beginning of the test and immediately before sampling at the various storage intervals. The data form given in Attachment H will be used to record bale weights. Core samples of about 1 kg will be collected at each sampling period from bales to assess moisture content, ash, and calorific value. The total number of bales required for the storage test is 100. At the beginning of the storage test, bales will be tagged with appropriate information as illustrated in the example in Attachment I. The sample tag described in Attachment I shall be attached to the 1 kg sample which should be analyzed immediately for moisture content or frozen for analysis at a later time.

b. In addition to analyzing bales in storage, bales will be obtained from a field weekly to assess physical properties. It is anticipated that there will be differences in bale composition (and therefore fuel value) varying with field conditions. Therefore, this procedure should account for any differences due to field conditions. While the CRRS is operating, three bales will be sampled. A 1 kg sample will be obtained from each bale and tagged for later analysis. The information required on the tags for these samples is given in Attachment J. It is anticipated that bales shall be obtained from 20 fields during the entire harvest campaign, thus yielding a total of 60 bales maximum for this procedure. The samples shall be analyzed immediately for moisture content unless the samples can be frozen. Ash and calorific value can be determined at a later date using the dried sample used in determining moisture content.

Labor: 1 recorder, 2 assistants

Equipment:

Quantity	Description
1	Sling for lifting large round bales
1	1000 kg. capacity scales
2	Core sampler

6. Cane Residue Laboratory Analyses Summary

Table 1 summarizes the type and number of laboratory analyses that are to be performed in accordance with the previously described procedures. It is assumed that the total duration of the testing period will be approximately 3 months or about 100 campaign days allowing for a maximum of 20 separate test site data collections. Samples obtained from bales in storage are also included. Ash and calorific value can be determined from the same sample used to determine moisture content. Procedures for ash and calorific value determination are given in Attachment K.

Table 1. Summary of data collection sampling.

Sample type	No. of Samples Moisture content	Ash content	Calorific value
Pre-bale field residue[1]	100	100	
Round-bale field samples[2]	30	30	30
Square-bale field samples[2]	30	30	30
Round-bale storage samples[3]	50	50	50
Square-bale storage samples[3]	50	50	50
	260	260	160

[1] Based on 20 test sites.
[2] Based on 10 test sites each for round and square baler.
[3] Based on 50 collected samples.

Labor: 2 laboratory assistants

Equipment:

Quantity	Description
1	Muffle oven
1	Wiley mill
1	Adiabatic bomb calorimeter
1	Balance scale (0.0001 g accuracy)

7. Agronomic Assessment of Residue Removal

Fields originally designated in Procedure 1 will be evaluated for agronomic differences at a later date. The detailed procedure is given in the attached section titled "Test Procedure for Evaluating the Agronomic Impact of Sugarcane Residue Removal."

RESPONSIBILITIES

The following assignment of responsibilities is based on discussion which took place July 25-August 4, 1988, in Thailand, between the Hawaiian Sugar Planters' Association (HSPA) Experiment Station staff, the Ministry of Industry's Office of the Cane and Sugar Board (OCSB), Nong Yai Sugar Factory (NYSF), Kasetsart University's Farm Machinery Research Center (FMRC) and the Central Laboratory and Greenhouse Complex (CLGC), Kamphaengsaen Campus. The various research tasks called for in the procedures are described below by organization.

Ministry of Industry Office of Cane and Sugar Board (OCSB), Bang Phra Experiment Station

1. Collect field residue samples for residue recovery determination (Procedures 2 and 4).

2. Collect bale samples, both field and stored bales (Procedure 5).

3. Weigh bales collected for storage test (Procedure 5).

4. Determine moisture content for all field and bale samples and provide results to FMRC (Procedure 2).

5. Provide field and bale samples from the dried moisture content sample to the FMRC representative who in turn will turn over the samples to the CLGC for ash and calorific value determination (Procedure 6).

6. Assist in collection of agronomic data (Procedure 7).

7. Collect meteorological data from NYSF and provide data to FMRC representative (Procedure 5 and 7).

Nong Yai Sugar Factory (NYSF)

1. Identify and secure harvest fields for the CRRS to operate within. Also required are adjacent conventionally harvested fields designated for agronomic comparison. Yield data from these fields will be obtained (see Procedure 1).

2. Meteorological data will be collected at the bale storage test site and for designated harvest fields to aid in the agronomic evaluation (Procedure 5 and 7).

3. After sufficient residue has been collected, make provisions for preparing the residue to fuel boilers. At this time, HSPA will send a representative to document operations and perform measurements which are not described in this set of procedures.

Farm Machinery Research Center (FMRC), Kamphaengsaen Campus, Kasetsart University

1. Provide equipment necessary to process field residue samples, i.e., tractor and forage chopper (Procedure 2).

2. Provide one (1) Engineer/Technician and one (1) Driver/Worker to evaluate cane residue equipment performance (Procedure 3).

3. The Engineer/Technician will receive all data collected by OCSB and laboratory results from CLGC and in turn will provide summarized data to the HSPA project leader on a bi-weekly basis.

Central Laboratory and Greenhouse Complex (CLGC) Kamphaengsaen Campus, Kasetsart University

1. Perform all ash and calorific value analysis for residue samples collected by OCSB (Procedure 6).

2. Perform all plant and soil analyses that is required for the agronomic evaluation (Procedure 7).

Hawaiian Sugar Planters' Association (HSPA) Experiment Station

1. The HSPA project lead. · will be present at the initiation of the test procedure to instruct and certify that procedures are being followed properly.

2. HSPA will receive all data collected from the project and issue quarterly and final reports to USAID/TVA, summarizing results.

ATTACHMENT A

CANE FRESH WEIGHT YIELD DATA

Estate: _____ Variety: _____

Field No.: _____ Harvest date: _____

Weather condition during harvest: _____ Harvest area (ha): _____ (rai): _____

Crop age (months): _____ Row spacing (m): _____

Irrigated: _____

Unirrigated: _____

Truck scale
Load weights:
(tonnes)

Total weight: _____

Total yield: _____
(t/ha)

Comments: _____

_____

Supervisor name: _____ Date: _____

HSPA Form A-1

ATTACHMENT B

FIELD RESIDUE AMOUNT DETERMINATION

Circle appropriate field residue category:

Pre-Bale Post-Bale

Estate: _____ Variety: _____

Field No.: _____ Date sampled: _____

Weather condition during sampling: _____ Days after harvest: _____

Supervisor: _____

Plot No.	Plot dimensions	Residue Weights (kg) Gross wt.	Tare	Net wt.
1	_____	_____	_____	_____
2	_____	_____	_____	_____
3	_____	_____	_____	_____
4	_____	_____	_____	_____
5	_____	_____	_____	_____

HSPA Form A-2

ATTACHMENT C

EXAMPLE OF FIELD RESIDUE SAMPLE TAG

FIELD RESIDUE

Sample No. Estate

Variety Field No.

Date

Circle appropriate field residue category:

Pre-Bale Post-Bale

ATTACHMENT D

PROCEDURE FOR MOISTURE DETERMINATION

Moisture Determination

1. Zero balance.

2. Determine tare weight of sample pan.

3. Weigh out approximately 100 grams of sample.

4. Identify pan and sample by numbers.

5. Weigh the samples and sample pan together.

6. Recheck the scale to be sure it reads zero.

7. Place sample drying pan containing sample in oven and dry overnight at 85°C.

8. Weigh dried sample every 15 minutes until not more than 0.5 gram weight change is reached.

9. Calculate moisture content.

   Use original net subsample weight and subtract dry net subsample weight. Divide the difference of these two by the original net subsample weight, then multiply this amount by 100 to yield the % moisture of the subsample.

Example:	Original net subsample wt.	122.5
	Dry net subsample wt.	-113.2
	Difference	9.3
	Original net subsample	÷122.5
		.0759
		x100
	% moisture of subsample	7.59%

ATTACHMENT E

TRAVEL TIME FOR CRRS BETWEEN FIELDS

Depart field no.:_____ Departure time:_____

Arrive field no.:_____ Arrival time:_____

Supervisor:_____

Approximate distance between fields (km):_____

Comments:_____

_____

HSPA Form A-3

ATTACHMENT F

DAILY EQUIPMENT ACTIVITY LOG SHEET

Field No.:_____ Date:_____

Equipment:_____ Operator or Supervisor:_____

Time, start of work day:_____

Down time:	Time start and end	Explanation

Fuel and lubricant requirement:_____

No work available
and reasons for.

(hrs):_____

Meal breaks (min.):_____

Time, end of work day:_____

Estimated field area covered (ha):_____

Bales produced (for balers only)_____

HSPA Form A-4

ATTACHMENT G

REPAIR AND MAINTENANCE RECORD

Equipment description: _____

Date	Reason for repair	Repair Cost			Total
		Parts	Labor	Outside service	

HSPA Form A-5

ATTACHMENT H

STORED BALES WEIGHT DATA

Bale No.	Storage interval	Initial weight	Final weight	Weight loss

HSPA Form A-6

ATTACHMENT I

EXAMPLE O ALE STORAGE TAG

BALED RESIDUE

Initial Weight

Bale No.

Field Obtained From

Date Stored

Square or Round

Covered or Uncovered

ATTACHMENT J

EXAMPLE OF TAG INFORMATION REQUIRED

FOR FIELD BALE SAMPLES

FIELD BALES

Field No. Date Sampled

Round or Square

Bale No.

ATTACHMENT K

PROCEDURES FOR ASH AND CALORIFIC VALUE DETERMINATION

Ash Analysis

1. Remove crucible from dessicator and crucible identification number.

2. Weigh crucible to determine tare weight.

3. Place approximately 20 grams of oven-dry sample in crucible and reweigh for gross sample weight.

4. Place samples in hood and ignite over bunsen burner until ash samples appear white, brown, or gray in color.

5. Place in muffle oven at 600°C for 5 hours or overnight.

6. Place crucible containing ash in dessicator and allow it to cool.

7. Weigh ash and calculate carbonate ash content.

   To compute--divide net ash weight by the net sample weight; then, multiply this amount by 100 to yield the % ash (dry weight basis).

Example:	Net ash weight	3.8865
	Net sample weight	÷13.6934
		=.2838
		x100
	% of ash	28.3800

Calorific Value Determination

1. Grind dried sample in Wiley Mill to obtain uniform sample size for pelletizing.

2. Press at least two 1 gram pellets from each sample and place in dessicator until ready for combustion analysis. (Do not touch with fingers; use small forceps.)

3. Weigh all sample ignition cups for tare weights and record the identification number of the ignition cup. (Do not touch with fingers.) Weigh with Semimicro balancer.

4. Follow instructions for bomb calorimeter operation described in Attachment K-1.

5. If temperature does not change in 5 minutes after ignition, remove bomb and recharge with new sample.

ATTACHMENT K-1

ADIABATIC BOMB CALORIMETER OPERATION

1. Cut 10 centimeter length of fuse wire and join the electrodes of the bomb with the wire.

2. Weigh pelletized sample in sample ignition cup.

3. Close and charge the bomb with oxygen to 30 atmospheres.

4. Weigh out 2000 ±0.5 grams of distilled water in water bucket and ensure that water temperature is between 24° and 26°C.

5. Place bomb in water bucket and hook up electrodes for ignition.

6. Allow approximately 10 minutes for the automatic adiabatic bomb calorimeter to bring the water jacket temperature into equilibrium with the water bucket temperature.

7. Record the bucket temperature.

8. Ignite sample and note time elapsed after ignition.

9. Read the bucket temperature at one-minute intervals starting at about 6 minutes after firing, until the temperature reaches a stable maximum and remains constant for at least two minutes. Record the final temperature.

10. Disassemble bomb and measure remaining fuse wire.

11. Calculate calorific value.

APPENDIX C

COST BREAKDOWNS FOR TRIAL YEAR AND ESTIMATES FOR FUTURE ACTIVITIES

C.1: Cost Breakdown For Trial Year: Actual

This section of Appendix C presents the actual costs for the Cane Energy Trial Year Program for the 1989-90 cane crushing season at the Nong Yai Sugar Factory. For comparison purposes, costs are divided between those associated with square baling operations and those associated with round baling operations. The variable costs associated with raking operations are divided between rakes forming windrows for the round and square balers respectively. Per tonne costs are based on:

Round Bales	Square Bales	
2,731.0 t	1,945.0 t	for trash raking and baling
2,731.0 t	122.4 t	for bale collection
52.3 t	1,546.1 t	for bale transportation

Costs not listed in this section include those associated with the activities in the 1988-89 trial year, those involved with program management, technical specialists and the research activities under the direction of HSPA.

It should be noted that some of the costs in this section are higher than would be realized in any subsequent cane trash baling operation, and some represent one-time costs associated with the "learning process." These include the rate for mechanics, the cost of the locally manufactured trailer, the cost of imported bale movers and front end loaders, and the full cost of operations during times when the equipment was idle for reasons which should be avoidable in the future (such as bale transportation bottlenecks, field scheduling problems, and accidents). Section C.2 analyzes the real or *rationalized* costs of the trial year by eliminating these avoidable costs.

C.1.1 Capital Equipment

Capital equipment was procured by USAID in the United States and shipped to Thailand - arriving at Nong Yai at the end of February, 1989. One of the signatories of the Memorandum of Understanding, the Department of Economic and Technical Cooperation, arranged the importation of this equipment free of duty. Capital costs shown in Appendix Table 1 are amortized at 20% over 5 years.

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APPENDIX TABLE 1
CAPITAL EQUIPMENT: ACTUAL COSTS

Qty	Equipment Type	Unit Cost (US $)	Total Cost (US $)	Amortized Cost (US $)	Cost per tonne (US$/t)
	Round Balers:				
3.0	Rakes	$4,495.00	$13,485.00	$4,509.11	$1.65
3.0	Balers	$19,745.50	$59,236.50	$19,807.48	$7.25
1.0	Bale Movers	$1,525.10	$1,525.10	$509.96	$0.43
2.0	Bale Movers (local)	$1,000.00	$2,000.00	$668.76	
	Round Bale Transport:				
2.0	Front-End Loaders	$11,146.00	$22,292.00	$7,453.99	$2.73
	Square Balers:				
3.0	Rakes	$4,495.00	$13,485.00	$4,509.11	$2.32
3.0	Balers	$15,362.10	$46,086.30	$15,410.32	$7.92
1.0	Trailer (local)	$168.63	$168.63	$56.38	$0.46
		Total Round Baler:	**$76,246.60**	**$25,495.31**	**$9.33**
		Total Round Bale Transport:	**22,292.00**	**7,453.99**	**$2.73**
		Total Square Baler:	**$59,739.93**	**$19,975.81**	**$10.70**
		Total:	**$158,278.53**	**$52,925.11**	
		Average:			**$11.31**

NOTES

Two of the three bale movers were designed and manufactured locally in Thailand, and the trailer for collecting square bales was procured locally.

The capital cost per tonne for the bale movers and front end loaders are derived from Appendix Table 9 and Appendix Table 10, and thus reflect data collected by NAMC.

C.1.2 Rented Equipment

Tractors were rented from Anglo-Thai Company, Limited at a fixed rate of $40.00/tractor/8-hr day. The tractors used for the trial year activities included Ford Models 5000, 6000, and 6610. The number of unit-days shown in Appendix Table 2 reflects actual days of operation for each type of machine. Out of 457 unit-days worked (associated with raking and baling equipment), the round balers worked 177 unit-days, rakes supporting them worked 81, square balers worked 137, and rakes supporting them worked 62.

APPENDIX TABLE 2
RENTED EQUIPMENT: ACTUAL COSTS

Equipment Type	Unit cost (US $/day)	Number of unit-days per season	Cost per season (US $)	Cost per tonne (US $/t)
Tractors pulling:				
Rakes for RB	$40.00	81.0	$3,240.00	$1.19
Round Balers	$40.00	177.0	$7,080.00	$2.59
Bale movers (collection)	$40.00	167.0	$6,680.00	$2.45
Bale movers (transport)	$40.00	15.0	$600.00	$1.63*
Rakes for SB	$40.00	62.0	$2,480.00	$1.28
Square Balers	$40.00	137.0	$5,480.00	$2.82
SB trailer collection	$40.00	18.0	$720.00	$5.88†
		Total Round Baler:	**$17,600.00**	**$7.86**
		Total Square Baler:	**$8,680.00**	**$9.97**
		Total:	**$26,280.00**	
		Average:		**$8.74‡**

* The rental cost per tonne for the bale movers involved in transportation is derived from Appendix Table 10, and thus reflects data collected by NAMC.

† The rental cost per tonne for the tractor pulling the trailer involved in square bale collection is based on 122.4 tonnes collected.

‡ The average is based on a projected total rental cost of $40,864.87 divided by the total tonnage baled. The projected total rental cost includes projected annual costs for tractors pulling round bale movers involved in transport and those pulling the square bale collection trailer. Actual costs provided in the table reflect the period for which data was kept.

C.1.3 Maintenance and Repairs

Not all the spare parts in the original shipment were used. Therefore, those parts not used out of the shipment are not reflected in Appendix Table 3. Large spare parts left over were simply counted and their value was subtracted from the invoices of the original shipment. For the miscellaneous and small spare parts included in the original shipment, it was assumed that 40% of them were used during the trial year. The total cost of fluids ($579.60) and miscellaneous parts ($357.40) are split between round and square balers according to the number of unit-days worked. Spare parts and labor costs for rakes are split between those supporting the round and square balers according to the number of unit-days each worked.

APPENDIX TABLE 3
MAINTENANCE AND REPAIRS: ACTUAL COSTS

Description	Cost per season (US $)	Cost per tonne (US $/t)
Round Balers:		
Spare parts included in original shipment	$4,411.98	$1.62
Spare parts in 2nd shipment	$1,206.56	$0.44
Spare parts in 3rd shipment	$1,479.00	$0.54
OEM spare parts provided by ATCL	$488.00	$0.18
Miscellaneous parts provided by ATCL	$138.42	$0.05
Lubricating grease & hydraulic oil	$224.48	$0.08
Repair labor	$744.00	$0.27
Modifications	$192.00	$0.07
Subtotal round balers:	$8,884.44	$3.25
Rakes supporting round balers:		
Spare parts included in original shipment	$2,931.39	$1.07
Spare parts in 3rd shipment	$305.87	$0.11
Miscellaneous parts provided by ATCL	$63.35	$0.02
Lubricating grease & hydraulic oil	$102.73	$0.04
Repair labor	$9.06	$0.00
Subtotal round baler rakes:	$3,412.40	$1.25
Square Balers:		
Spare parts included in original shipment	$3,668.94	$1.89
Spare parts in 2nd shipment	$4,638.64	$2.38
Spare parts in 3rd shipment	$948.00	$0.49
OEM spare parts provided by ATCL	$468.00	$0.24
Miscellaneous parts provided by ATCL	$112.54	$0.06
Lubricating grease & hydraulic oil	$173.75	$0.09
Repair labor	$64.00	$0.03
Modifications	$120.00	$0.06
Subtotal square balers:	$10,193.87	$5.24
Rakes supporting square balers:		
Spare parts included in original shipment	$2,243.78	$1.15
Spare parts in 3rd shipment	$234.13	$0.12
Miscellaneous parts provided by ATCL	$48.49	$0.02
Lubricating grease & hydraulic oil	$78.63	$0.04
Repair labor	$6.94	$0.00
Subtotal square baler rakes:	$2,611.97	$1.34
Total round balers:	**$12,296.84**	**$4.50**
Total square balers:	**$12,805.84**	**$6.58**
Total:	**$25,102.68**	
Average:		**$5.37***

* The average is based on the total cost of maintenance, repairs, and modifications divided by the total tonnage baled by both round and square balers.

C.1.4 Twine

The cost of twine for the bales is shown in Appendix Table 4. Included also are projections for future round baling efforts depending on the number of wraps per bale.

APPENDIX TABLE 4
ACTUAL TWINE USAGE AND COSTS

	Round balers	Square balers	Total/ Average
TRIAL YEAR COSTS			
Twine in original shipment (m):	340,000	340,000	680,000
Cost of orig. ship. ($):	$4,950	$3,940	$8,890
Unit cost of orig. ship. ($/1,000 m):	$14.56	$11.59	$13.07
ATCL Twine (m):	85,719	247,881	333,600
Cost of ATCL twine ($):	$1,571.51	$4,544.49	$6,116.00
Unit cost of ATCL twine ($/1,000 m):	$18.33	$18.33	$18.33
Avg. bale dimensions (cm):	150.0	40x45x81.4	NA
Avg. bale weight (kg):	371	16.07	NA
Tonnes collected (t):	2,731	1,945	4,676
Twine per wrap (m):	4.71	2.43	NA
No. wraps per bale:	12.27	2.00	NA
Twine per bale (m):	57.83	4.86	NA
Twine per Tonne trash (m/t):	155.88	302.25	229.07
Total twine use (m):	425,719	587,881	1,013,600
Total cost ($):	**$6,521.51**	**$8,484.49**	**$15,006.00**
Average unit cost ($/1,000 m):	**$15.32**	**$14.43**	**$14.80**
Avg cost per Tonne trash ($/t):	**$2.39**	**$4.36**	**$3.21**
COST PROJECTION			
ATCL twine unit cost ($/1,000 m):	$18.33	$18.33	
Twine per tonne of trash - 12 wraps (m/t):	152.42	NA	
Cost per tonne of trash - 12 wraps ($/t):	$2.79	NA	
Twine per tonne of trash - 8 wraps (m/t):	101.61	NA	
Cost per tonne of trash - 8 wraps ($/t):	$1.86	NA	
Twine per tonne of trash - 6 wraps (m/t):	76.21	NA	
Cost per tonne of trash - 6 wraps ($/t):	$1.40	NA	
Twine per tonne of trash - 5 wraps (m/t):	63.51	NA	
Cost per tonne of trash - 5 wraps ($/t):	$1.16	NA	
Twine per tonne of trash - 2 wraps (m/t):	NA	302.25	
Cost per tonne of trash - 2 wraps ($/t):	NA	$5.54	

C.1.5 Fuel

The cost of fuel for the tractors shown in Appendix Table 5 is based on an estimate of the consumption per tractor-day of operation. The figure of $15.68/unit-day used below is ATCL's estimate based on an average consumption of 7 liters/hour and $β7/liter. The actual fuel use was significantly less, as discussed on page 20.

APPENDIX TABLE 5
FUEL: ACTUAL COSTS

Equipment Type	Unit cost (US $/day)	Number of unit-days per season	Cost per season (US $)	Cost per tonne (US $/t)
Tractors pulling:				
Rakes for RB	$15.68	81.0	$1,270.08	$0.47
Round Balers	$15.68	177.0	$2,775.36	$1.02
RB movers collection	$15.68	167.0	$2,618.56	$0.96
RB movers transport	$15.68	15.0	$235.20	$0.64*
Rakes for SB	$15.68	62.0	$972.16	$0.50
Square Balers	$15.68	137.0	$2,148.16	$1.10
SB trailer collection	$15.68	18.0	$282.24	$2.31†
		Total Round Baler:	**$6,899.20**	**$3.08**
		Total Square Baler:	**$3,402.56**	**$3.91**
		Total:	**$10,301.76**	
		Average:		**$3.43‡**

* The fuel cost per tonne for the round bale movers involved in transportation is derived from Appendix Table 10 and thus reflects data collected by NAMC.

† The fuel cost per tonne for the tractors pulling the trailer used in square bale collection is based on 122.4 tonnes collected.

‡ The average is based on a projected total fuel cost of $16,020.15 divided by the total tonnage baled. The projected total fuel cost includes projected annual costs for the tractors pulling round bale movers involved in transport and those pulling the square bale collection trailer.

C.1.6 Labor

Labor, as shown in Appendix Table 6, is divided into two categories, tractor operators and laborers. Tractor operators were supplied by ATCL at a rate of $8.00/person-day ($1/hr), however, $8.00/person-day was also paid to cover per diem costs for

operators. Therefore the total charge-out rate paid to ATCL for tractor operators was $16.00/person-day. Laborers were paid directly at a rate of β70($2.75)/person-day.

APPENDIX TABLE 6
LABOR: ACTUAL COSTS

Labor Category	Unit cost (US $/day)	Number of unit-days per season	Cost per season (US $)	Cost per tonne (US $/t)
Round Balers:				
Op RB rakes	$16.00	81.0	$1,296.00	$0.47
Op RB	$16.00	177.0	$2,832.00	$1.04
Lab RB*	$2.75	154.0	$423.50	$0.16
OP RB collection	$16.00	167.0	$2,672.00	$0.98
OP RB transport	$16.00	15.0	$240.00	$0.65†
Square Balers:				
Op SB rakes	$16.00	62.0	$992.00	$0.51
Op SB	$16.00	137.0	$2,192.00	$1.13
Lab SB‡	$2.75	77.0	$211.75	$0.11
OP SB collection	$16.00	18.0	$288.00	$2.35♠
Lab SB collection	$2.75	90.0	$247.50	$2.02♠
Lab SB transport♦	$2.75	722.4	$1,986.60	$1.28
	Total Round Baler:		**$7,463.50**	**$2.65**
	Total Square Baler:		**$5,917.85**	**$7.41**
	Total:		**$13,381.35**	
	Average:			**$5.01♣**

* The number of laborers supporting round baling operations varied between 1 and 4.

† The operator cost per tonne for round bale transport is derived from Appendix Table 10 and thus reflects data collected by NAMC.

‡ The number of laborers supporting square baling operations varied between 1 and 3.

♠ The labor and operator cost per tonne for square bale collection is based on 122.4 tonnes collected.

♦ The number of laborers supporting square bale transportation operations varied between 9 and 16.

♣ The average is based on a projected total labor cost of $23,413.36 divided by the total tonnage baled. The projected total labor cost includes projected annual costs for round bale transport operators and square bale collection and transport operators and laborers.

C.1.7 Farmer Payments (Appendix Table 7)

APPENDIX TABLE 7
FARMER PAYMENTS: ACTUAL COSTS

Baling System	Unit cost (US $/ha)	Expected coverage (ha)	Cost per season (US $)	Cost per tonne ($/t)
Round Balers	$12.25	316	$3,874.51	$1.42
Square Balers	$12.25	194	$2,372.55	$1.22
		Total:	$6,247.06	
		Average:		$1.34*

* The average is based on the total farmer payment cost of $6,247.06 divided by the total tonnage baled.

C.1.8 Cost by Operation Comparison: Actual

In this section of Appendix C, costs for the different operations associated with cane field residue collection are segregated and calculated on a per tonne basis. Capital costs are amortized at 20% over 5 years (prevailing commercial terms).

C.1.8.1 Raking and baling operations (Appendix Table 8)

C.1.8.2 Bale collection operations

The costs shown in Appendix Table 9 are associated with the collection of round and square bales to interim storage locations in areas close to the harvest fields. See Section 2.3.1, pages 23-26 for a further discussion.

C.1.8.3 Bale transportation operations

Round bale transportation

The round bale transportation figures in Appendix Table 10 are estimates based on NAMC's observation of 6 trips from the Bo Thong area to the factory. The last column represents the actual data taken by NAMC. The rest of the columns are projections based on field-to-factory distances of between 4 and 20 km. Included in this cost estimate are three rented tractors (two with front-end loaders and one with bale mover attached), tractor operators, tractor fuel, the factory's flat-bed truck (assumed opportunity cost of 10 wheel truck is ฿2,500($98.04)/day, including operator

APPENDIX TABLE 8
RAKING AND BALING OPERATIONS: ACTUAL COSTS

Description	Unit cost (US $/day)	Number of units	Cost per season (US $)	Cost per tonne ($/t)
Round balers:				
Capital equipment	$6,602.49	3.0	$19,807.48	$7.25
Tractor rental	$40.00	177.0	$7,080.00	$2.59
Fuel	$15.68	177.0	$2,775.36	$1.02
Operator	$16.00	177.0	$2,832.00	$1.04
Maintenance, repair, modifications			$8,884.44	$3.25
Twine			$6,521.51	$2.39
Labor	$2.75	154.0	$423.50	$0.16
Farmer payments	$1.96	1,976.0	$3,874.51	$1.42
Rake supporting round balers:				
Capital equipment	$1,503.04	3.0	$4,509.11	$1.65
Tractor rental	$40.00	81.0	$3,240.00	$1.19
Fuel	$15.68	81.0	$1,270.08	$0.47
Operator	$16.00	81.0	$1,296.00	$0.47
Maintenance, repair, modifications			$3,412.40	$1.25
Total round baler harvesting costs:			**$65,926.39**	**$24.15**
Square balers:				
Capital equipment	$5,136.77	3.0	$15,410.32	$7.92
Tractor rental	$40.00	137.0	$5,480.00	$2.82
Fuel	$15.68	137.0	$2,148.16	$1.10
Operator	$16.00	137.0	$2,192.00	$1.13
Maintenance, repair, modifications			$10,193.87	$5.24
Twine			$8,484.49	$4.36
Labor	$2.75	77.0	$211.37	$0.11
Farmer payments	$1.96	1,210.0	$2,372.55	$1.22
Rake supporting square balers:				
Capital equipment	$1,503.04	3.0	$4,509.11	$2.32
Tractor rental	$40.00	62.0	$2,480.00	$1.28
Fuel	$15.68	62.0	$972.16	$0.50
Operator	$16.00	62.0	$992.00	$0.51
Maintenance, repair, modifications			$2,611.97	$1.34
Total square baler harvesting costs:			**$58,058.38**	**$29.85**

APPENDIX TABLE 9
BALE COLLECTION OPERATIONS: ACTUAL COSTS

Description	Unit cost (US $/day)	Number of units	Cost per season (US $)	Cost per tonne ($/t)
Round bale collection				
Capital equipment		3.0	$1,178.72	$0.43
Tractor rental	$40.00	167.0	$6,680.00	$2.45
Fuel	$15.68	167.0	$2,618.56	$0.96
Operator	$16.00	167.0	$2,672.00	$0.98
Total round bale collection costs:			**$13,149.28**	**$4.81**
*Square bale collection**				
Capital equipment	$3.38	3.0	$10.15	$0.08
Tractor rental	$40.00	18.0	$720.00	$5.88
Fuel	$15.68	18.0	$282.24	$2.31
Operator	$16.00	18.0	$288.00	$2.35
Labor	$2.75	90.0	$247.06	$2.02
Total square bale collection costs:			**$1,547.45**	**$12.64**

* The square bale collection figures are based on 18 days of operations during the trial year. The operations consisted of using a tractor hauled trailer with 5 laborers loading it in the field and unloading it at an interim storage area. This was a stop-gap operation necessary when Nong Yai vehicles were unavailable. The estimated total tonnes of bales collected during this period is estimated at 400 bales/day x 18 days x .017 tonnes/bale = 122.4 tonnes. Amortized capital cost for the trailer is factored at 18 days ÷ 100 days/year.

and fuel). The amortized capital cost for the front end loaders is divided by the assumed number of working hours (8 x 100) per cane crushing season and factored by the numbers of in-field hours.

Square bale transportation

The square bale transportation figures in Appendix Tables 11 and 12 are estimates based on NAMC's observation of 75 truck loads of bales (9 flat-bed loads and 66 dump-truck loads). As discussed in the body of this report, the factory provided transportation trucks and operators to move the bales directly from the field to the factory. Although there is no direct cost for the trucks, the opportunity cost for providing them is assumed to be the prevailing rental cost in that area for these types

of trucks. Two types of trucks were provided by the factory; a 10-wheel, flat-bed truck (which would rent for ß2,000($78.43)/day, including operator and fuel), and 5, 6-wheel dump trucks (which would rent for ß1,500/day each, including operator and fuel). Appendix Table 11 shows projections for the 6-wheel dump trucks and Appendix Table 12 for the 10-wheel flat-bed.

The factory kept exact records of the number of trips and the tonnage transported. The dump trucks made 572 trips, transporting a total of 1,053.25 tonnes; and the flat-bed trucks made 89 trips, transporting a total of 492.8 tonnes. The NAMC data collection team observed this operation and determined averages for the in-field time, round-trip time, and field-to-factory distance. USAID covered the cost of the in-field labor for this operation, so exact figures are available for this part. For both Appendix Tables 11 and 12 the first data columns are actual NAMC figures for the 6 wheel dump truck and 10 wheel flat-bed truck respectively. The rest of the data columns show cost projections based on field-to-factory distances of 4 to 20 km.

APPENDIX TABLE 10
ROUND BALE TRANSPORTATION COST PROJECTIONS

Field-to-factory distance:	4km	6km	8km	10km	12km	14km	16km	18km	20km	actual avg
Transport time, field-factory-field (h):	0.54	0.68	0.83	0.97	1.12	1.26	1.41	1.55	1.70	1.93
Transit time, on the road (h):	0.29	0.43	0.58	0.72	0.87	1.01	1.16	1.30	1.45	1.68
In-factory time (h):	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
In-field time (h):	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
No. bales loaded:	23.50	23.50	23.50	23.50	23.50	23.50	23.50	23.50	23.50	23.50
Average bale weight (kg):	371.00	371.00	371.00	371.00	371.00	371.00	371.00	371.00	371.00	371.00
Loaded weight (t):	8.72	8.72	8.72	8.72	8.72	8.72	8.72	8.72	8.72	8.72
Loaded out rate (t/h):	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18	9.18
Truck fuel consumption (l/load):	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.59
Tractor fuel consumption (l/load):	8.42	8.42	8.42	8.42	8.42	8.42	8.42	8.42	8.42	8.42
Distance to factory (km):	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00	23.17
Trip speed (kph):	27.66	27.66	27.66	27.66	27.66	27.66	27.66	27.66	27.66	27.66
Operator cost/load (@$2.00/h):	$5.70	$5.70	$5.70	$5.70	$5.70	$5.70	$5.70	$5.70	$5.70	$5.70
Truck cost/day (incl op&fuel):	$98.04	$98.04	$98.04	$98.04	$98.04	$98.04	$98.04	$98.04	$98.04	$98.04
Tractor cost/day (@$40/day):	$120.00	$120.00	$120.00	$120.00	$120.00	$120.00	$120.00	$120.00	$120.00	$120.00
Tractor fuel cost/load (@$15.68/day):	$5.59	$5.59	$5.59	$5.59	$5.59	$5.59	$5.59	$5.59	$5.59	$5.59
capital costs (bale movers & lodrs)/load:	$10.25	$10.25	$10.25	$10.25	$10.25	$10.25	$10.25	$10.25	$10.25	$10.25
Tractor cost/load (3 each):	$14.25	$14.25	$14.25	$14.25	$14.25	$14.25	$14.25	$14.25	$14.25	$14.25
Truck cost/load:	$18.25	$20.02	$21.79	$23.57	$25.34	$27.11	$28.88	$30.65	$32.43	$35.24
Capital in-field & Factory cost/tonne:	$2.86	$2.86	$2.86	$2.86	$2.86	$2.86	$2.86	$2.86	$2.86	$2.86
Tractor rent & Fuel:	$2.28	$2.28	$2.28	$2.28	$2.28	$2.28	$2.28	$2.28	$2.28	$2.28
Transport cost/tonne:	$0.41	$0.61	$0.81	$1.02	$1.22	$1.42	$1.63	$1.83	$2.03	$2.35
Labor cost/tonne:	$0.65	$0.65	$0.65	$0.65	$0.65	$0.65	$0.65	$0.65	$0.65	$0.65
Total cost/load:	$54.04	$55.81	$57.59	$59.36	$61.13	$62.90	$64.67	$66.45	$68.22	$71.03
Distance to factory (km):	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00	23.17
Cost/tonne:	$6.20	$6.40	$6.60	$6.81	$7.01	$7.21	$7.42	$7.62	$7.82	$8.15

APPENDIX TABLE 11
SQUARE BALE TRANSPORT COST PROJECTIONS (6-WHEEL TRUCKS)

Field-to-factory distance (km):	actual avg.	4km	6km	8km	10km	12km	14km	16km	18km	20km
No of men in-field:	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73	10.73
In-field time (h):	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
transport time, field-to-factory(h):	0.45	0.45	0.61	0.77	0.93	1.09	1.25	1.41	1.57	1.73
transit time, on the road (h):	0.32	0.32	0.48	0.64	0.80	0.96	1.12	1.28	1.44	1.60
In-factory time (h):	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
No. bales loaded:	145.00	145.00	145.00	145.00	145.00	145.00	145.00	145.00	145.00	145.00
Bale weight (kg):	14.44	14.44	14.44	14.44	14.44	14.44	14.44	14.44	14.44	14.44
Tonnes per load:	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.09
Loaded out rate (t/h):	4.81	4.81	4.81	4.81	4.81	4.81	4.81	4.81	4.81	4.81
Km. to factory:	4.05	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00
Off-loading rate (t/h):	15.70	15.70	15.70	15.70	15.70	15.70	15.70	15.70	15.70	15.70
Trip Speed (kph):	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Man-hr/load:	5.36	5.36	5.36	5.36	5.36	5.36	5.36	5.36	5.36	5.36
In-field labor efficiency (t/man-hr):	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
Round Trip fuel consumption (l):	1.35	1.33	2.00	2.67	3.33	4.00	4.67	5.33	6.00	6.67
Labor cost/load (@ $0.34/hr):	$1.84	$1.84	$1.84	$1.84	$1.84	$1.84	$1.84	$1.84	$1.84	$1.84
Truck cost/day (incl op&fuel):	$58.82	$58.82	$58.82	$58.82	$58.82	$58.82	$58.82	$58.82	$58.82	$58.82
Capital in-field & Factory cost/tonne:	$2.23	$2.23	$2.23	$2.23	$2.23	$2.23	$2.23	$2.23	$2.23	$2.23
Transport cost/tonne:	$1.12	$1.12	$1.69	$2.25	$2.81	$3.37	$3.94	$4.50	$5.06	$5.62
Labor cost/tonne:	$0.88	$0.88	$0.88	$0.88	$0.88	$0.88	$0.88	$0.88	$0.88	$0.88
Equipment cost/load:	$7.01	$7.01	$8.19	$9.37	$10.54	$11.72	$12.90	$14.07	$15.25	$16.43
Total cost/load:	$8.85	$8.85	$10.03	$11.21	$12.38	$13.56	$14.74	$15.91	$17.09	$18.27
Km. to factory:	4.05	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00
Cost/tonne:	$4.23	$4.23	$4.79	$5.36	$5.92	$6.48	$7.04	$7.60	$8.17	$8.73

APPENDIX TABLE 12
SQUARE BALE TRANSPORT COST PROJECTIONS (10-WHEEL TRUCK)

Field-to-factory distance (km):	actual avg.	4km	6km	8km	10km	12km	14km	16 km	18km	20km
No of men in-field:	11.33	11.33	11.33	11.33	11.33	11.33	11.33	11.33	11.33	11.33
In-field time (h):	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
transport time, field-to-factory(h):	0.98	0.57	0.73	0.89	1.05	1.21	1.37	1.53	1.69	1.85
transit time, on the road (h):	0.44	0.32	0.48	0.64	0.80	0.96	1.12	1.28	1.44	1.60
In-factory time (h):	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
No. bales loaded:	301.00	301.00	301.00	301.00	301.00	301.00	301.00	301.00	301.00	301.00
Bale weight (kg):	14.77	14.77	14.77	14.77	14.77	14.77	14.77	14.77	14.77	14.77
Tonnes per load:	4.44	4.44	4.44	4.44	4.44	4.44	4.44	4.44	4.44	4.44
Loaded out rate (t/h):	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83	4.83
Km. to factory:	5.52	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00
Off-loading rate (t/h):	17.78	17.78	17.78	17.78	17.78	17.78	17.78	17.78	17.78	17.78
Trip Speed (kph):	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Man-hr/load:	11.30	11.30	11.30	11.30	11.30	11.30	11.30	11.30	11.30	11.30
In-field labor efficiency (t/man-hr):	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
Round Trip fuel consumption (l):	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76	2.76
Labor cost/load (@ $0.34/hr):	$3.88	$3.88	$3.88	$3.88	$3.88	$3.88	$3.88	$3.88	$3.88	$3.88
Truck cost/day (incl op&fuel):	$98.04	$98.04	$98.04	$98.04	$98.04	$98.04	$98.04	$98.04	$98.04	$98.04
Cap. in-field & Factory cost/tonne	$3.40	$3.40	$3.40	$3.40	$3.40	$3.40	$3.40	$3.40	$3.40	$3.40
Transport cost/tonne	$1.22	$0.88	$1.32	$1.76	$2.21	$2.65	$3.09	$3.53	$3.97	$4.41
Labor cost/tonne	$0.87	$0.87	$0.87	$0.87	$0.87	$0.87	$0.87	$0.87	$0.87	$0.87
Equipment cost/load:	$24.07	$19.04	$21.00	$22.96	$24.92	$26.88	$28.84	$30.81	$32.77	$34.73
Total cost/load:	$27.95	$22.92	$24.88	$26.84	$28.80	$30.76	$32.72	$34.68	$36.64	$38.60
Km. to factory:	5.52	4.00	6.00	8.00	10.00	12.00	14.00	16.00	18.00	20.00
Cost/tonne:	$5.49	$5.16	$5.60	$6.04	$6.48	$6.92	$7.36	$7.80	$8.24	$8.69

APPENDIX TABLE 13
SUMMARY OF ACTUAL COSTS

ACTUAL TRANSPORTATION COSTS
(from Appendix Tables 10, 11, and 12)

	Season cost	Cost per tonne
Round Baler:	$8,529.19	$8.15
Square Baler:	$1,986.60	$5.70
Total:	$10,515.79	
Average:		$6.93

TOTAL ACTUAL COSTS

	Season cost	Cost per tonne
Round Baler:	$87,604.87	$37.10
Square Baler:	$61,592.87	$48.20
Total:	$149,197.74	
Average:		$42.65

TOTAL ACTUAL COSTS EXCLUDING BALE COLLECTION

	Season cost	Cost per tonne
Round Baler:	$74,455.59	$32.29
Square Baler:	$60,044.98	$35.55
Total:	$134,500.57	
Average:		$33.92

C.2 Cost Breakdown for Trial Year: Rationalized

In this section of Appendix C, the per tonne costs for raking and baling operations are analyzed under a realistic scenario in which all of the *avoidable* downtime for the equipment is eliminated. The purpose here is to determine the cost/tonne for cane residue collection activities with no bale transportation bottlenecks, accidents, or field scheduling problems. The general method used to obtain the following data involves reducing the number of hours charged to equipment rental, capital costs, and labor by the number of unit-hours of avoidable downtime. The per tonne costs are based on 2,731 tonnes harvested by the round balers and 1,945 tonnes harvested by the square balers. The figures below are included in Table 6, page 19.

C.2.1 Capital Equipment

Capital equipment costs in Appendix Table 14 are amortized as before, then factored by the number of real unit-hours worked (defined as the in-field scheduled unit-hrs less the number of unit-hrs of avoidable downtime) ÷ the in-field scheduled unit-hrs worked. [For example, the round balers actually worked 1,881 unit-hrs, however 426 hrs were avoidable downtime, therefore the factor would be (1,881 — 426) ÷ 1,881 = 0.77.]

APPENDIX TABLE 14
CAPITAL EQUIPMENT: RATIONALIZED COSTS

Equipment type	Amortized cost 5 yrs @ 20% (US $)	Scheduled Operating time (unit-hrs)	Avoidable downtime (unit-hrs)	Factor	Factored cost (US$)	Cost per Tonne (US $/t)
Rake for RB	$2,254.56	648.00	0.00	1.00	$2,254.56	$0.83
Round baler	$19,807.48	1,881.00	426.00	0.77	$15,321.58	$5.61
Rake for SB	$2,254.56	496.00	0.00	1.00	$2,254.56	$1.16
Square Baler	$15,410.32	1,869.00	494.00	0.74	$11,337.18	$5.83
			Total Round Baler:		$17,576.14	$6.44
			Total Square Baler:		$13,591.74	$6.99
			Total:		$31,167.88	
			Average:			$6.67

C.2.2 Rented Equipment

The costs for rented equipment in this section are treated the same as in C.1.2 except that the unit-days of avoidable downtime are reduced.

APPENDIX TABLE 15
RENTED EQUIPMENT: RATIONALIZED COSTS

Tractors pulling	Unit cost (US $/hr)	In-field production time (unit-hrs)	Factored cost (US $)	Cost per tonne (US $/t)
Rakes for RB	$5.00	648.00	$3,240.00	$1.19
Round balers	$5.00	1,455.00	$7,275.00	$2.66
Rakes for SB	$5.00	496.00	$2,480.00	$1.28
Square balers	$5.00	1,375.00	$6,875.00	$3.53
	Total Round Baler:		$10,515.00	$3.85
	Total Square Baler:		$9,355.00	$4.81
		Total:	$19,870.00	
		Average:		$4.25

C.2.3 Maintenance and Repairs

The costs of maintenance and repairs on the equipment remain basically the same, except the charge out rate for the mechanics is reduced to $ 200/day which is a more standard rate for this category of labor. Thus the cost of repair labor for the round balers and rakes supporting the round balers is reduced from $753.06 to $92.16, and the cost of repair labor for the square balers and rakes supporting them is reduced from $70.94 to $8.82.

The overall cost of maintenance and repairs was thus $11,636.07 and $12,743.59 for the round and square balers respectively, or on a per tonne basis $4.26 and $6.55 for the round and square balers, respectively.

C.2.5 Twine

Twine costs in this section are treated the same as in Appendix Table 4, thus for the round bales, twine was $6,521.51 total or $2.39/tonne, and for the square balers, twine was $8,484.49 total or $4.36/tonne.

C.2.4 Fuel

The costs for fuel in Appendix Table 16 are treated the same as in C.1.5, except that the unit days of avoidable downtime are reduced.

APPENDIX TABLE 16
FUEL: RATIONALIZED COSTS

Tractors pulling	Unit cost (US $/hr)	In-field production time (unit-hrs)	Factored cost (US $)	Cost per tonne (US $/t)
Rakes for RB	$1.96	648.00	$1,270.08	$0.47
Round balers	$1.96	1,455.00	$2,851.80	$1.04
Rakes for SB	$1.96	496.00	$972.16	$0.50
Square balers	$1.96	1,375.00	$2,695.00	$1.39
	Total Round Baler:		$4,121.88	$1.51
	Total Square Baler:		$3,667.16	$1.89
		Total:	$7,789.04	
		Average:		$1.67

C.2.6 Labor

The costs for labor in this section are treated the same as in C.1.6, except the unit-days of avoidable downtime are reduced.

APPENDIX TABLE 17
LABOR: RATIONALIZED COSTS

Labor category	Unit cost (US $/hr)	In-field production time (unit hrs)	Factored cost (US $)	Cost per tonne (US $/t)
Round balers				
Rake operators	$0.74	648.00	$476.28	$0.17
Baler operators	$0.74	1,455.00	$1,069.43	$0.39
Baler laborers	$0.34	806.00	$277.06	$0.10
Square balers				
Rake operators	$0.74	496.00	$364.56	$0.19
Baler operators	$0.74	1,375.00	$1,010.63	$0.52
Baler laborers	$0.34	122.00	$41.94	$0.02
	Total Round Baler:		$1,822.77	$0.67
	Total Square Baler:		$1,417.12	$0.73
		Total:	$3,239.89	
		Average:		$0.69

BEST AVAILABLE

C.2.7 Farmer Payments

The costs for farmer payments in this section are treated the same as in C.1.7. Thus, the per tonne cost for farmer payments are $1.42 and $1.22 for the round and square balers, respectively.

APPENDIX TABLE 18
SUMMARY OF RATIONALIZED BALING COSTS

	Season cost	Cost per tonne
Round baler		
Capital equipment:	$17,576.14	$6.44
Rented equipment:	$10,515.00	$3.85
Maintenance & Repairs:	$11,636.07	$4.26
Fuel costs:	$4,121.88	$1.51
Twine costs:	$6,521.51	$2.3[illegible]
Labor costs:	$1,822.77	$0.67
Farmer payments:	$3,874.51	$1.42
Total:	$56,067.87	
Average:		$20.53
Square baler		
Capital equipment:	$13,591.74	$6.99
Rented equipment:	$9,355.00	$4.81
Maintenance & Repairs:	$12,743.59	$6.55
Fuel costs:	$3,667.16	$1.89
Twine costs:	$8,484.49	$4.36
Labor costs:	$1,417.12	$0.73
Farmer payments:	$2,372.55	$1.22
Total:	$51,631.66	
Average:		$26.55

C.3 Cost per Tonne - Future Scenario: Under Private Management

In this scenario, estimates of the costs per tonne of collection, transportation, and processing of cane field residues for use as a boiler fuel will be analyzed under the assumption that a privately owned and operated company in Thailand will be running the operation. Cost estimates are based on the experience gained during the trial year program at the Nong Yai Sugar Factory and are subject to change for other locations. Other assumptions include:

1. 100-day season, 10 hours/day.
2. One day/week for maintenance and repairs, or 86 operating days/season.
3. All avoidable downtime is eliminated (see Section C.2).
4. Round baler twine consumption is reduced to 63.48 m/t.
5. A conservative increase in tonnes baled per hour of 48% and 77% for the round and square balers respectively, based on NYSF selecting high quality fields and using experienced operators.[1]

Under these assumptions, it is expected that the round balers will produce 3.3 tonnes/production hour x 10 hours/day x 3 machines x 86 operating days x 76% operating efficiencies = 6,471 tonnes, and that the square balers will produce 2.81 tonnes/production hour x 10 hours/day x 3 machines x 86 operating days x 64% operating efficiency = 4,788 tonnes.

C.3.1 Capital Equipment

Some of the capital equipment for any privately run operations will have to be imported into Thailand, and therefore costs for imported equipment shown in Appendix Table 19 reflect importation duties, taxes and profit for shipping agent. The rake and baler models are the same used during the trial year, however, bale movers and front-end hydraulic loaders can be purchased locally at a lower price.

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[1] Note that on the highest productivity day during the trial year, 5.57 and 4.87 tonnes/production hour were obtained by the round and square balers respectively - or over 2.2 times the average rate. Similarly, the best coverage rates were 0.69 and 0.64 ha/production hour for the round and square balers respectively, or over 2.3 times the average rates. These rates were obtained by the best operators on high quality fields.

APPENDIX TABLE 19
CAPITAL EQUIPMENT: PROJECTED COSTS

Qty	Equipment Type	Unit Cost (US $)	Total Cost (US $)	Amortized Cost (US $)	Cost per tonne (US$/t)
Round Balers:					
2.0	Rakes	$7,253.72	$14,507.44	$4,850.99	0.75
3.0	Balers	$31,863.94	$95,591.82	$31,963.96	$4.94
3.0	Bale Movers	$1,000.00	$3,000.00	$1,003.14	$0.16
2.0	Front-End Loaders	$2,823.53	$5,647.06	$1,888.26	$0.29
Square Balers:					
2.0	Rakes	$7,253.72	$14,507.44	$4,850.99	$1.01
3.0	Balers	$24,790.31	$74,370.93	$24,868.13	$5.19
	Total Round Baler:		$118,746.32	$39,706.36	$6.14
	Total Square Baler:		$88,878.37	$29,719.12	$6.21
	Total:		$207,624.69	$69,425.48	
	Average:				$6.17

C.3.2 Rented Equipment

In addition to renting tractors, trucks for transporting bales will have to be hired. Based on this year's experience the following trucks will have to be committed for the entire crushing season to bale transportation; 3 dump trucks for square bale transportation and 3 flat-bed trucks for round bale transportation. Costs for these trucks are based on current rental prices (including driver and fuel), at β1,500 ($58.82)/day and β2,500($98.04)/day for the dump trucks and flat-bed trucks respectively. (Appendix Table 20)

C.3.3 Maintenance and Repairs

The same cost per tonne for maintenance and repairs used in Section C.2.3 are used in Appendix Table 21.

C.3.4 Twine

The twine costs in Appendix Table 22 are different because the plastic twine that is available in Thailand is more expensive than the twine imported for the trial year.

APPENDIX TABLE 20
RENTED EQUIPMENT: PROJECTED COSTS

Equipment Type	Unit cost (US $/day) (unit-day)	Number of unit-days per season	Cost per season (US $)	Cost per tonne (US $/t)
Tractors pulling:				
Rakes for RB	$40.00	100	$4,000.00	$0.62
Round Balers	$40.00	300	$12,000.00	$1.85
Bale movers	$40.00	300	$12,000.00	$1.85
Rakes for SB	$40.00	100	$4,000.00	$0.84
Square Balers	$40.00	300	$12,000.00	$2.51
Trucks:				
Flat-bed (10W)	$98.04	300	$29,412.00	$4.55
Dump (6W)	$58.82	300	$17,646.00	$3.69
		Total Round Baler:	$57,412.00	$8.87
		Total Square Baler:	$33,646.00	$7.03
		Total:	$91,058.00	
		Average:		$8.09

APPENDIX TABLE 21
MAINTENANCE AND REPAIR: PROJECTED COSTS

Equipment Type	Cost per season (US $)	Cost per tonne (US $/t)
Round Balers & Rakes:	$20,400.40	$4.26
Square Balers & Rakes:	$31,370.86	$6.55
Total:	$51,771.26	
Average:		$4.60

APPENDIX TABLE 22
TWINE: PROJECTED COSTS

Bale Type	Cost per season (US $)	Cost per tonne (US $/t)
Round Bales:	$8,148.00	$1.26
Square Bales	$32,550.53	$6.80
Total:	$40,698.53	
Average:		$3.61

C.3.4 Fuel

Fuel assumptions for the tractors in Appendix Table 23 differ from previous sections. Fuel will be supplied by the factory, at a cost of β6.5/l ($0.255/l). Using ATCL's assumption of 7 l/hr x 10 hr/day x β6.5/l = β455/day per tractor or $17.84/day per tractor. The number of operating days must be modified by the expected unavoidable downtime (17.68% and 26.38% for the round and square balers respectively). Thus one tractor pulling a round baler would only use fuel on 71 days, and a tractor pulling a square baler would use fuel for 63 days. Calculations for the rakes and round bale-moving equipment are based on their being in use all 86 operating days. Transportation fuel costs are included in the hireage rate.

APPENDIX TABLE 23
FUEL: PROJECTED COSTS

Equipment Type	Unit cost (US $/day)	Number of unit-days per season	Cost per season (US $)	Cost per tonne (US $/t)
Tractors pulling:				
Rakes for RB	$17.84	86	$1,534.03	$0.24
Round Balers	$17.84	213	$3,799.39	$0.59
Bale movers	$17.84	258	$4,602.08	$0.71
Rakes for SB	$17.84	86	$1,534.03	$0.32
Square Balers	$17.84	189	$3,371.29	$0.70
	Total Round Baler:		$9,935.49	$1.54
	Total Square Baler:		$4,905.31	$1.02
		Total:	$14,840.80	
		Average:		$1.32

C.3.5 Labor

Labor costs shown in Appendix Table 24 are divided into two categories, tractor operators and laborers. Tractor operators would be supplied by the factory at a rate of β120($4.71)/person-day. They will be paid for the full 86 operating days/season. Laborers will be paid at a rate of β70($2.75)/person-day. It is assumed that 2 laborers will assist the round balers, 2 will assist the square balers, and 16 laborers will be on the square bale transportation team (for the full 100 days/season). Transportation truck drivers are included in with the truck rental rate.

APPENDIX TABLE 24
LABOR: PROJECTED COSTS

Labor Category	Unit cost (US $/day)	Number of unit-days per season	Cost per season (US $)	Cost per tonne (US $/t)
Round Balers:				
Op RB rakes	$5.88	86	$505.88	$0.08
Op RB	$5.88	258	$1,517.65	$0.23
Lab RB	$2.75	172	$473.00	$0.07
OP RB transport	$5.88	258	$1,517.65	$0.23
Square Balers:				
Op SB rakes	$5.88	86	$505.88	$0.11
Op SB	$5.88	258	$1,517.65	$0.32
Lab SB	$2.75	172	$473.00	$0.10
Lab SB transport	$2.75	1,600	$4,400.00	$0.92
		Total Round Baler:	$4,014.18	$0.62
		Total Square Baler:	$6,896.53	$1.44
		Total:	$10,910.71	
		Average:		$0.97

C.3.6 Farmer Payments

From Table 8, the round baler is expected to cover 667 ha/season and the square baler 494 ha/season.

APPENDIX TABLE 25
FARMER PAYMENTS: PROJECTED COSTS

Baling System	Unit cost (US $/ha)	Expected coverage (t/ha)	Cost per tonne (US $/t)	season coverage (ha)	Cost per season ($/t)
Round balers	$12.25	9.7	$1.42	667	$8,175.41
Square balers	$12.25	9.7	$1.22	494	$6,049.12
Totals:				1,161	$14,224.53
Averages:		9.7	$1.32		

APPENDIX TABLE 26
SUMMARY OF PROJECTED COSTS

TOTAL SCENARIO BALING COSTS

	Season Cost	Cost per tonne
Round Baler:	$109,190.51	$15.60
Square Baler:	$128,521.84	$24.05
Total:	$237,712.35	
Average:		$19.26

TOTAL SCENARIO TRANSPORT COSTS

	Season Cost	Cost per tonne
Round Baler:	$50,423.12	$7.79
Square Baler:	$22,046.00	$4.60
Total:	$72,469.12	
Average:		$6.44

TOTAL SCENARIO COSTS

	Season Cost	Cost per tonne
Round Baler:	$156,245.91	$24.15
Square Baler:	$145,137.48	$30.31
Total:	$301,383.38	
Average:		$26.77

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The Office of Energy

The Agency for International Development's Office of Energy plays an increasingly important role in providing innovative approaches to solving the continuing energy crisis in developing countries. Three problems drive the Office's assistance programs: high rates of energy and economic growth accompanied by a lack of energy, especially power in rural areas; severe financial problems, including a lack of investment capital, especially in the electricity sector; and growing energy-related environmental threats, including global climate change, acid rain, and urban air pollution.

To address these problems, the Office of Energy leverages financial resources of multilateral development banks such as The World Bank and the Inter-American Development Bank, the private sector, and bilateral donors to increase energy efficiency and expand energy supplies, enhance the role of private power, and implement novel approaches through research, adaptation, and innovation. These approaches include improving power sector investment planning ("least-cost" planning) and encouraging the application of cleaner technologies that use both conventional fossil fuels and renewable energy sources. Promotion of greater private sector participation in the power sector and a wide-ranging training program also help to build the institutional infrastructure necessary to sustain cost-effective, reliable, and environmentally-sound energy systems integral to broad-based economic growth.

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Office of Energy
Bureau for Science and Technology
U.S. Agency for International Development
Room 508, SA-18
Washington, D.C. 20523-1810
Tel: (703) 875-4052