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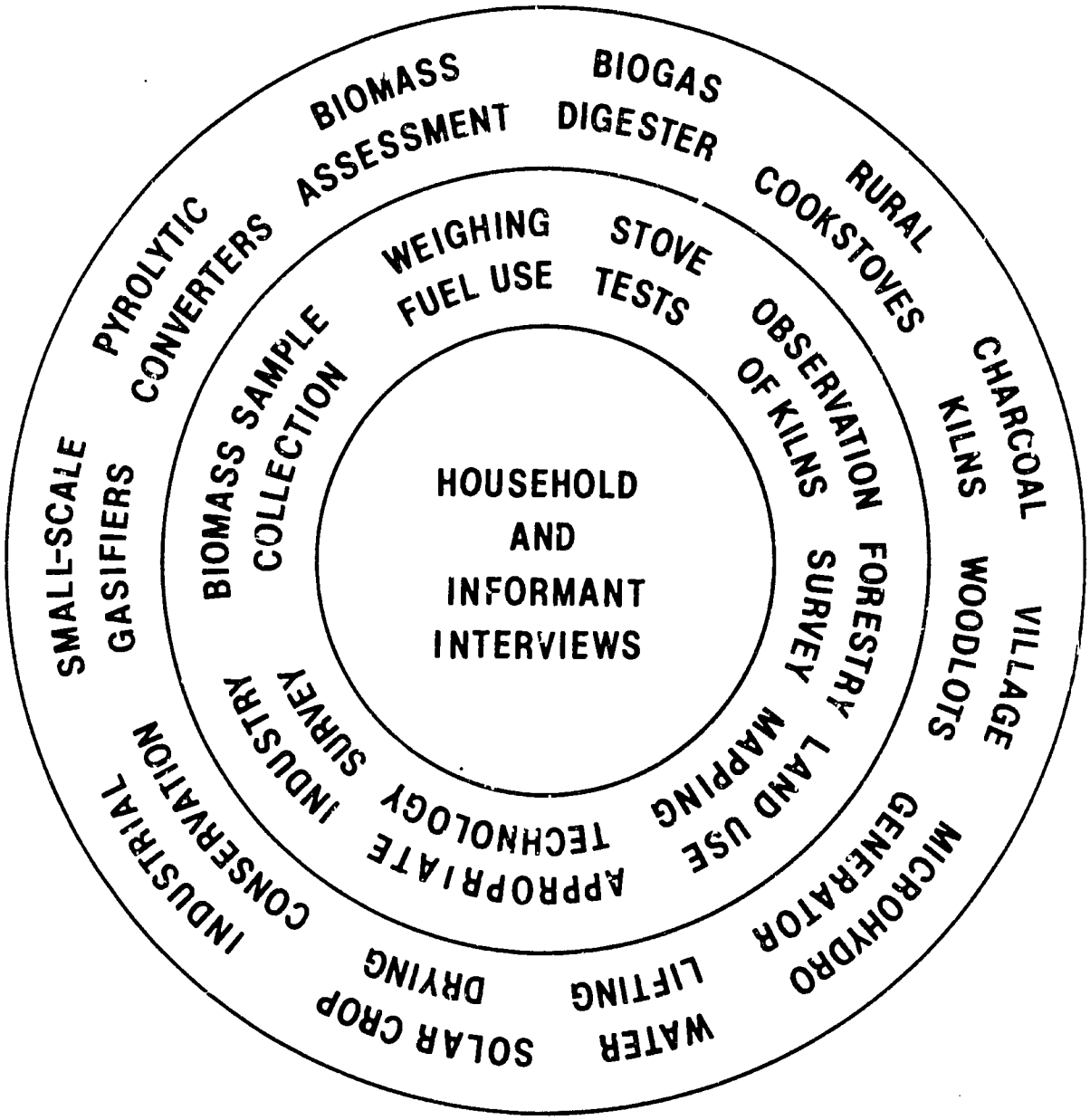

BIOMASS SAMPLES

META SYSTEMS INC THAI GROUP

PN AAQ 269

FEBRUARY 1982

BIOMASS SAMPLES: COLLECTION AND ANALYSIS

BUAPHAN PUKTING

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Acknowledgement

This series of reports was produced through the joint efforts of professors and students from four of Thailand's leading universities, Chulalongkorn University Social Research Institute, Chiangmai University Center for Social Sciences, Khon Kaen University Faculty of Agricultural Economics, and Kassetsart University Faculty of Forestry and research personnel from Meta Systems, Inc. Together they were responsible for the design, execution and analysis of the baseline survey.

The methodology for the biomass survey was developed by Dr. Kassem Chunkao, Dr. Choompol Ngampongsai and Dr. Snit Aksornkae of Kassetsart University. They also participated in the training of survey personnel, the analysis of the data, and the review of the final report. Without their participation this effort could not have been made.

This report was written by Buaphan Pukting and John Arnold. The graphics were drawn by Jakrit Charoenpant. The text was typed by Watcharee Chalorkunwat. The dedication, patience, long hours and unflagging sense of humor of all participants is gratefully acknowledged.

Authors Warning

The results presented herein are meant for use by researchers working on the Renewable Non-Conventional Energy Project. Approval should be obtained from U.S. Agency for International Development, Bangkok (Rod MacDonald) or Asia Bureau, Washington (Robert Ichord) before quoting any part of this report.

Because I know that time is always time
And place is always and only place
And what is actual is actual only for one time
And only for one place
I rejoice that things are as they are and
I renounce the blessed face
And renounce the voice
Because I cannot hope to turn again
Consequently I rejoice, having to construct something
Upon which to rejoice

T.S. Eliot

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Errata Sheet

LIST OF CHANGWAT OF THAILAND

In this report a variety of spellings have been used for the survey Changwat and village. The correct spelling and some of the variants are shown below.

Changwat

Buri Ram: Buriram, Burirum

Chanthaburi: Chantaburi

Chiang Mai: Chiangmai, Chaing Mai, Cheing Mai

Chon Buri: Chonburi

Kamphaeng Phet: Kampangphet, Kampaengpet, Kamphangphet, Kampangphet

Khon Kaen

Lampang

Nakhon Ratchisima: Korat

Nan

Phetchaburi: Petburi, Petchbura, Petchaburi

Roi et: Roi-et, Roi-Et

Si Sa Ket: Srisaket, Sisaket

Udon Thani: Udorn Thani, Udornthani

Villages

Bang Rahong: Bangrahong

Maikan Sangkan: Mailand Sangan

Pa Bhu: Pabhu

Wang Chapou: Wangchapoo

Klong Bon: Klongbon

Nong Wangyao: Nongvangyao

Pa Woe: Paver, Pawer

Pa Han: Pahan

Pa Nai: Panai

Si Chiengmai: Srichiengmai, Srichaiangmai

San Pa Tong: San Pa Toung

Samkhasantisuk: Sam Kha San Tisuk

Mai Ho Phra: Mae Ho Pra

Nong Buaeng: Nongbuadeang

OTHER TERMS

Household - Related individuals living in a house and eating together

House compound - Area around the house which is owned by members of the household and is often demarcated by a fence

Head of household - Male or female leader of the members of the household, usually the owner of the house

Head of village - Phuyaiban

Head of sub-district - Kamnan

Village - Muban

District - Amphoe

Province - Changwat

Errata Sheet (continued)

Phase I - Survey in Petchaburi, Korat, Srisaket, Kampangphet, and Lampang

Phase II - Survey in Songkla, Chantaburi, Roe-et, Udorn Thani, and Chiang Mai

Phase III - Survey in Nan, Burirum, and Chiang Mai

Delivered heat - The amount of energy content in the fuel burned

Captured heat - In cooking the amount of heat which is transferred to the cooking vessel

Moisture content - On a wet basis, weight of water as percentage of total sample weight

Heat or energy content - The high heat content of a substance at 0% moisture as measured in a bomb calorimeter

1 Unit of electricity - 1 kilowatt-hour, a billing unit used by the Provincial Electric Authority

6 1/4 rai = 2 1/2 acres = 1 hectare

jar lamp - small wick lamps

wick lamp - chimney or hurricane lamps

Rice Products - Straw residue in field,
- Stalk residue from threshing,
- Husk shell residue from milling
- Bran edible residue from milling

NEA - National Energy Administration of Thailand

NSO - National Statistics Organizationof Thailand

PEA - Provincial Electricity Authority

1. Introduction

This report has been prepared to provide background information and research findings on the characteristics and uses of biomass fuels in the rural areas of Thailand for use by the participants in the project, especially those involved in the biomass survey.

The collection and analysis of biomass samples in the baseline survey had three goals. The first was to provide basic data on the potential of wood, charcoal and other biomass fuels as sources of energy. The second was to provide preliminary data which could serve as a basis for planning the project component on biomass assessment. The third was to determine the extent to which non-scientific personnel working on a larger survey effort could collect meaningful data on the production and fuel potential of various species of biomass.

In addressing these goals this report attempts to identify the following;

- the key factors affecting the quantity of biomass produced per unit area or per unit crop produced
- the moisture and energy content for various types of biomass residues
- the major methodological problems in collecting and analyzing a large number of biomass samples

Because of technical problems in the collection and preservation of the biomass species in the field, the procedures for the collection of biomass were modified after the first phase of the survey and the survey personnel were given further instruction in these procedures. In addition, forestry students were recruited to provide technical assistance to each survey team especially in the measurement of woodland resources and the mapping of land use.

The biomass samples were analyzed to determine average values for the moisture content and heat value of the various types and species of biomass and, where possible, the level of production of this biomass per unit resource. Since the data showed considerable variation, related environmental factors were analyzed to determine how they affected the level of production and the moisture and heat content of the different types of biomass. Where suitable explanatory variables were not available, attempts were made to use simple probability distributions to present the results.

2. Methodology

2.1 Animal Dung Measurements

The information on the production of animal dung was the most difficult to collect of all types of biomass. The energy content of the dung produced per animal was determined by measuring the number of feces produced per day, the weight of a typical fece, the percentage of dry matter in the typical fece, and the energy content in the dry matter. The number of feces produced per day was counted by a villager who had responsibility for the animal and who was hired by the survey personnel for one day's observation. While this method worked well with cows and buffaloes which were grazing, it was not applicable for pigs which are generally kept penned beneath the house. For pigs, a day's production of feces was collected from the pen. The fece collected for each animal was placed in a plastic bag and weighed.

From this fece a sample of approximately 100 grams was taken for determination of moisture and energy content. The information on moisture content was used to estimate the amount of dry matter in the sample fece. No attempt was made to estimate the average moisture content of fresh dung, since the sample could not be collected immediately after discharge.

The preservation of the dung samples during the time between collection in the field and return to the laboratory created problems. A large percentage of the samples taken in phase I of the survey were lost due to deterioration in their containers from liquification and insect damage. In the second phase the samples were air dried following the initial weighing and the problem of deterioration was considerably reduced. A total of 138 samples were analyzed out of a total collection of some 250 samples. Data was also collected on the age, sex, location and size of the animals from which the samples were obtained.

2.2 Field Residue Measurements

The selection of field residues for examination as energy sources was made based on on-going harvesting activities in the survey areas. Samples were taken of the residues left following the harvest (or simulated harvest). For crops that had been harvested within a two week period prior to collection or would be harvested within two weeks of collection the production of residues was measured by counting the number of plants in a fixed area and weighing the unharvested part of a few of the plants to determine an average weight. The height of the residue was also recorded. Samples of the unharvested residues were then collected and brought back from the field for moisture and energy content analysis. The problems of preserving the samples were similar to those experienced with the dung samples. This limited the sample size tested in the first phase. In the second phase new procedures for collection were established but the timing of the survey activity limited the crops which could be surveyed. A total of about 100 samples of field residues were collected and analyzed for moisture content. Another 130 samples were collected not as field residues but as other plant species.

2.3 Wood and Charcoal Measurements

Three types of wood were collected; the wood used in stove efficiency tests, the wood used in charcoal-making efficiency tests, and other wood commonly used in the villages as a fuel. For the stove and charcoal tests the total quantity of wood used was measured and a sample of about 100 grams was collected and brought back for moisture and energy content analysis. The other wood samples were collected from the market or, more frequently, from recently cut or standing trees. These samples tended to have a higher moisture content, as discussed in section 3.3. The sample collection and testing procedures were the same as for the stove and charcoal-making fuels.

Charcoal samples were collected in a manner similar to the wood samples. The three types of samples were also stove test fuels, charcoal-making fuels and other species of charcoal obtained in the market place.

2.4 Sample Testing

The biomass samples were brought back to Bangkok and reweighed. They were then transferred to paper bags and placed in drying ovens for 36 hours at 105°C. They were weighed after drying to determine the additional loss in moisture. The losses of moisture in transportation from the field and in the drying ovens were added together and compared with the original weight of the sample recorded in the field to determine the moisture content (on a wet basis).

The information on moisture content was combined with screening data on species and source and a subset was selected for testing in the bombe calorimeter. The bombe calorimeter measured the heat of combustion at constant volume. The value measured was the high heat value, i.e., the steam was condensed. The samples to be tested in the calorimeters were processed in batches of twenty to forty. They were first ground into granular form then placed in a drying oven. Afterwards they were placed in plastic bags or containers and stored in a partial vacuum until being tested in the calorimeters. As there was no desiccant the containers, it is assumed that the moisture content of the samples increased while in the containers. While there is no data on how much moisture was absorbed from the air in the storage containers, the storage period in granular form averaged about 4 days. It is estimated that the moisture might have added 1 or 2% to the weight of the sample.* This would imply a + 1.5% correction factor for the calorific values.

Three bombes were used for this analysis and a composite sample was run through all three to determine the consistency of measurement. For each sample two tests were made and the average calorific value computed. The calorimeters were operated using standard ASTM D 240 with thermometers having an accuracy of .01 F.

Of the approximately 1240 samples collected in the field, 1000 were analyzed for moisture content and 155 were analyzed for energy content.

3. Analysis of Results

3.1 Animal Dung Energy Production

The quantity of dry matter produced by each species, buffalo, cow and pig varied considerably. For purposes of this analysis a subset of the collected data has been used. Exceptionally large or small measurements reflecting probable errors in data recording and sample processing were excluded. About 12% of the buffalo samples and 9% of the cow samples were eliminated in this way. For the pigs about 35% of the sample was eliminated because of various measurement errors.

The average dry weight produced per day for buffaloes was 5.8 kilograms for adults and 2.5 kilograms for non-adults. The number of

*for additional discussion see note at end of text

feces produced daily averaged 5.6 for adults and 4.7 for non-adults. The variance on all of these numbers was considerable. The coefficients of variation for the dry matter production was .44 and .55 for the adult and non-adult buffaloes, respectively. Daily dry matter production for cows averaged 2.2 kilograms for adults and 1.7 kilograms for non-adults with an average fece production of 5.9 and 6.1 for adults and non-adults, respectively. Again the coefficient of variation for dry matter production was quite high, .59 and .43 for adults and non-adults, respectively.

For both buffaloes and cows the sample size was about 60, however for pigs the sample size was only 15 due to collection problems. The average recorded daily dry matter production for pigs was .56 kilograms for adults and .48 kilograms for non-adults. The coefficient of variation was .65 for adults and .42 for non-adults respectively. The number of feces could not be determined because of the method of collection as described in section 2.1. Details of the dry matter production statistics are presented in table 1.

Four variables were examined in order to explain the considerable variance in amount of dry matter produced by each species. The first variable, age, has already been discussed. The other three were sex, location and size of the animals. The difference between male and female production is summarized in table 1. The differences between the averages for each sex is considerably less than the standard deviation for each species except pigs. For the pigs only one sample was available for the male versus six for the female. The available data indicates that sex has very little influence on the level of production.

Regional variation also appears to have little impact, although the sample size was too small to draw any firm conclusions. The data presented in table 2 which includes the full sample, shows that over one-third of the cells have no value and another 13% are limited to a single measurement. While the data appears to indicate that buffaloes in Chantaburi and Udorn Thani are more productive, the cows do not show a similar trend. It is clear that variables such as the method of tending the animals, the season, and the availability of natural fodder affect the volume of dry matter produced, but it was not possible to analyze these with such a small sample. Judging from the data in table 2 it is also not possible to aggregate these variables into a regional variable.

The most obvious variable against which dung production might be expected to vary is the size of the animal, therefore estimates were made of the height and weight of each animal. Since only the former was directly measurable*, it was used for comparison with the quantity of dung produced. The attempt to establish a relationship proved futile as can be observed in the three graphs, figures 1-3. Neither exponential nor linear relationships could be established between dry matter production and height for any of the species.

All attempts to explain the variance in dry weight dung production were unsuccessful probably for the following reasons:

*given the equipment and time constraints of the enumerators only rough guesses of weight could be made

Table 1

DUNG PRODUCTION STATISTICS

(kg oven-dry weight per animal-day)

ANIMAL	AGE	SEX	AVERAGE	STANDARD* DEVIATION(%)	SAMPLE SIZE
Buffalo	Adult	Male	6.2	2.54	19
		Female	5.4	2.52	21
		All	5.8	2.56 (.44)	40
	Young	Male	2.5	1.53	13
		Female	2.5	1.21	13
		All	2.5	1.38 (.55)	26
Cow	Adult	Male	2.3	1.55	16
		Female	2.1	0.98	17
		All	2.2	1.30 (.59)	33
	Young	Male	1.8	1.19	14
		Female	1.6	0.93	10
		All	1.7	1.10 (.65)	24
Pig	Adult	Male	0.96	-	1
		Female	0.49	0.19	6
		All	0.56	0.24 (.43)	7
	Young	Male	0.51	0.26	3
		Female	0.47	0.15	5
		All	0.48	0.20 (.42)	8

* number in parentheses is coefficient of variation

Table 2

REGIONAL VARIATION IN DUNG WEIGHT

(kg oven-dry matter per animal-day)

AREA	BUFFALO		COW		PIG	
	Adult	Young	Adult	Young	Adult	Young
Petchburi	-	-	0.79 (3)	1.75 (1)	-	0.16 (1)
Korat	-	-	8.18 (1)	-	0.72 (1)	0.49 (2)
Srisaket	-	1.58 (1)	3.24 (1)	0.85 (4)	0.53 (2)	-
Kampangphet	-	-	-	-	-	-
Lampang	4.11 (5)	1.76 (2)	-	-	-	-
Songkhla	4.18 (3)	-	1.94 (7)	0.94 (6)	0.77 (4)	0.43 (3)
Chantaburi	7.43 (8)	3.57 (4)	1.83 (8)	3.17 (5)	0.85 (3)	0.66 (2)
Roi-et	5.92 (10)	2.69 (10)	4.02 (8)	1.43 (8)	-	-
Udornthani	7.97 (10)	2.88 (6)	2.36 (4)	1.47 (2)	0.62 (1)	-
Chiang Mai	4.43 (9)	1.91 (7)	2.39 (5)	-	3.12 (1)	0.55 (3)

Note - numbers in parentheses are sample sizes

FIGURE 1

DISTRIBUTION OF BUFFALO DUNG WEIGHT AND ANIMAL HEIGHT

(Kg. Dry Matter Per Day)

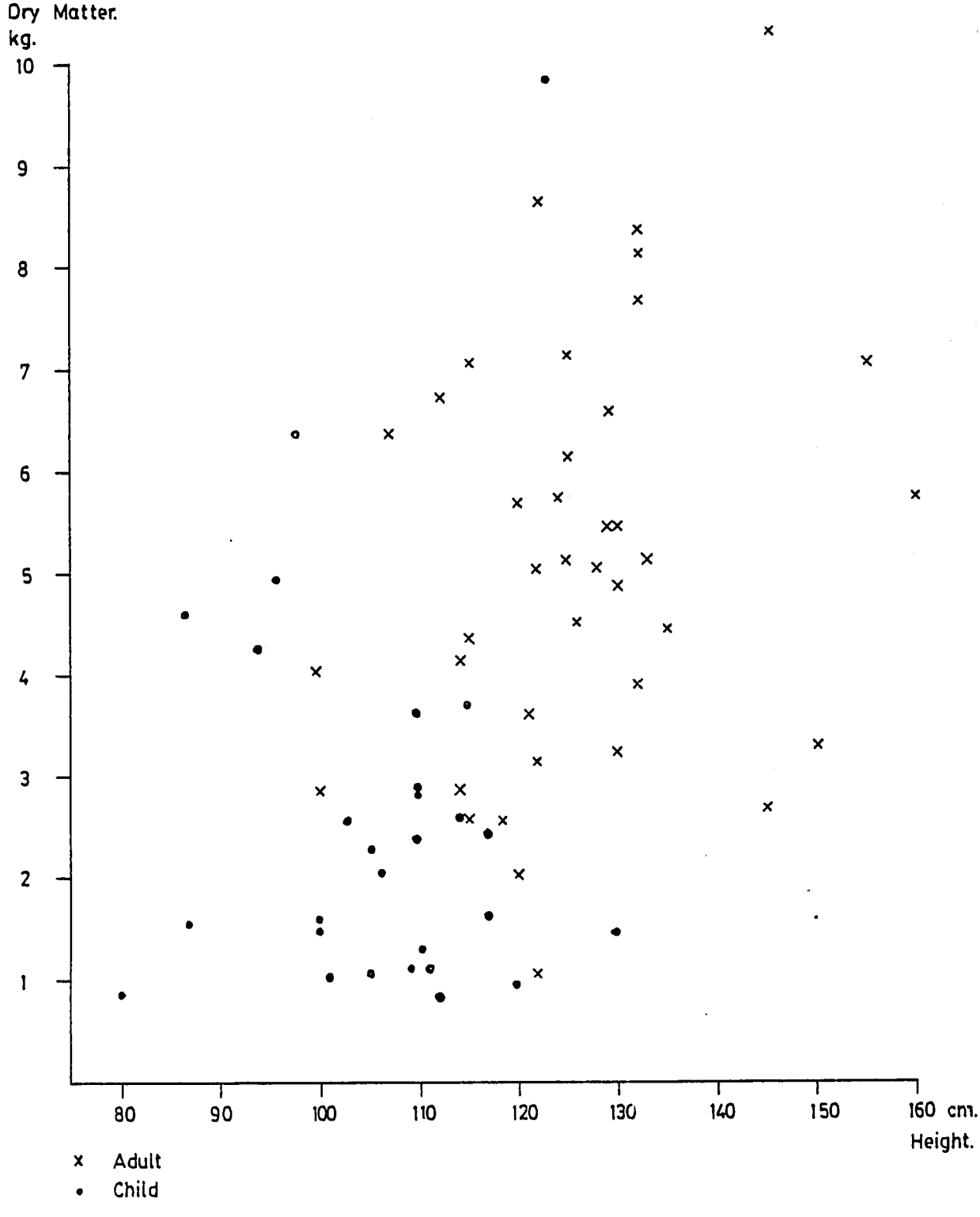


FIGURE 2

DISTRIBUTION OF COW DUNG WEIGHT AND ANIMAL HEIGHT

(Kg. Dry Matter Per Day)

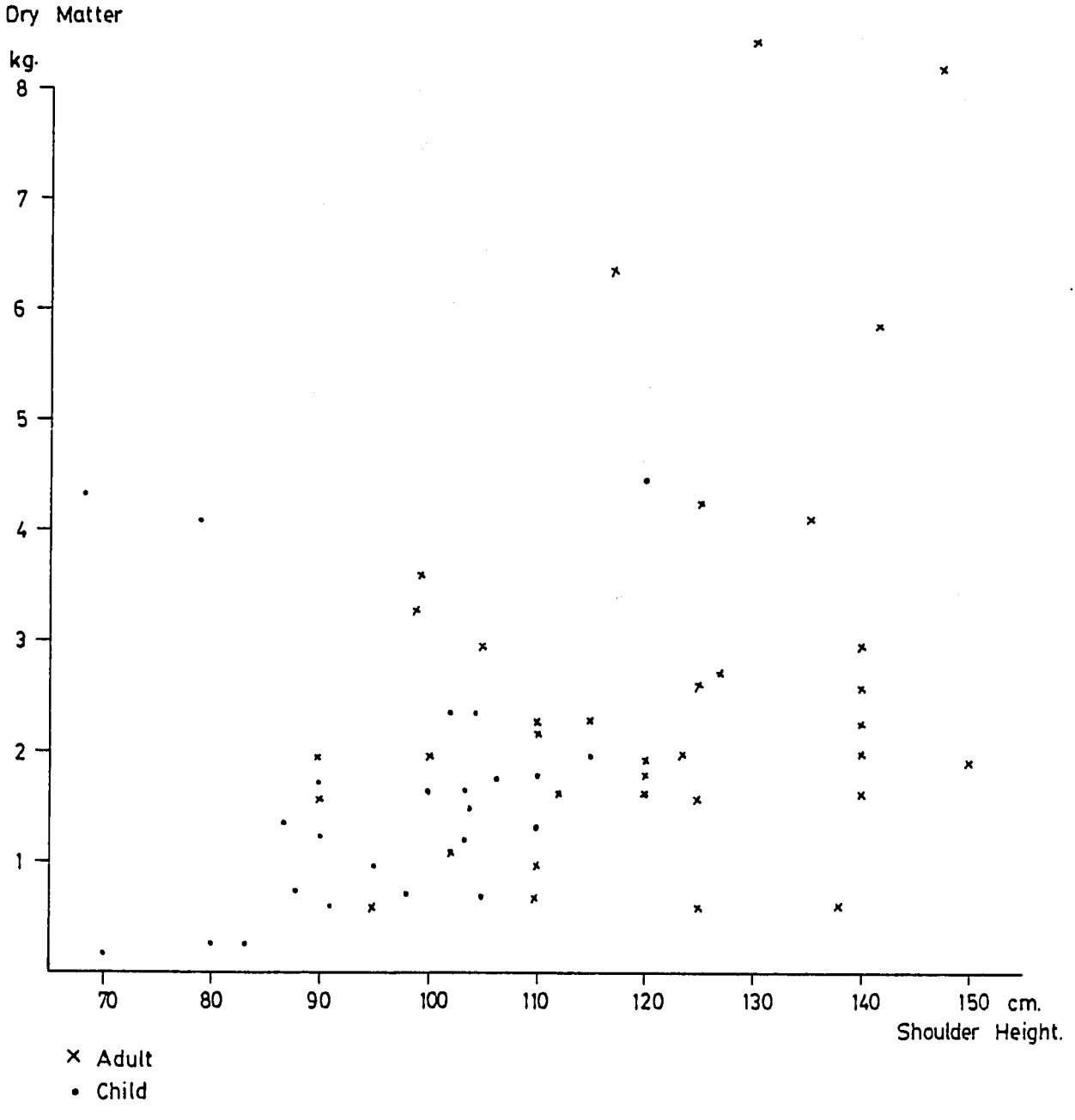
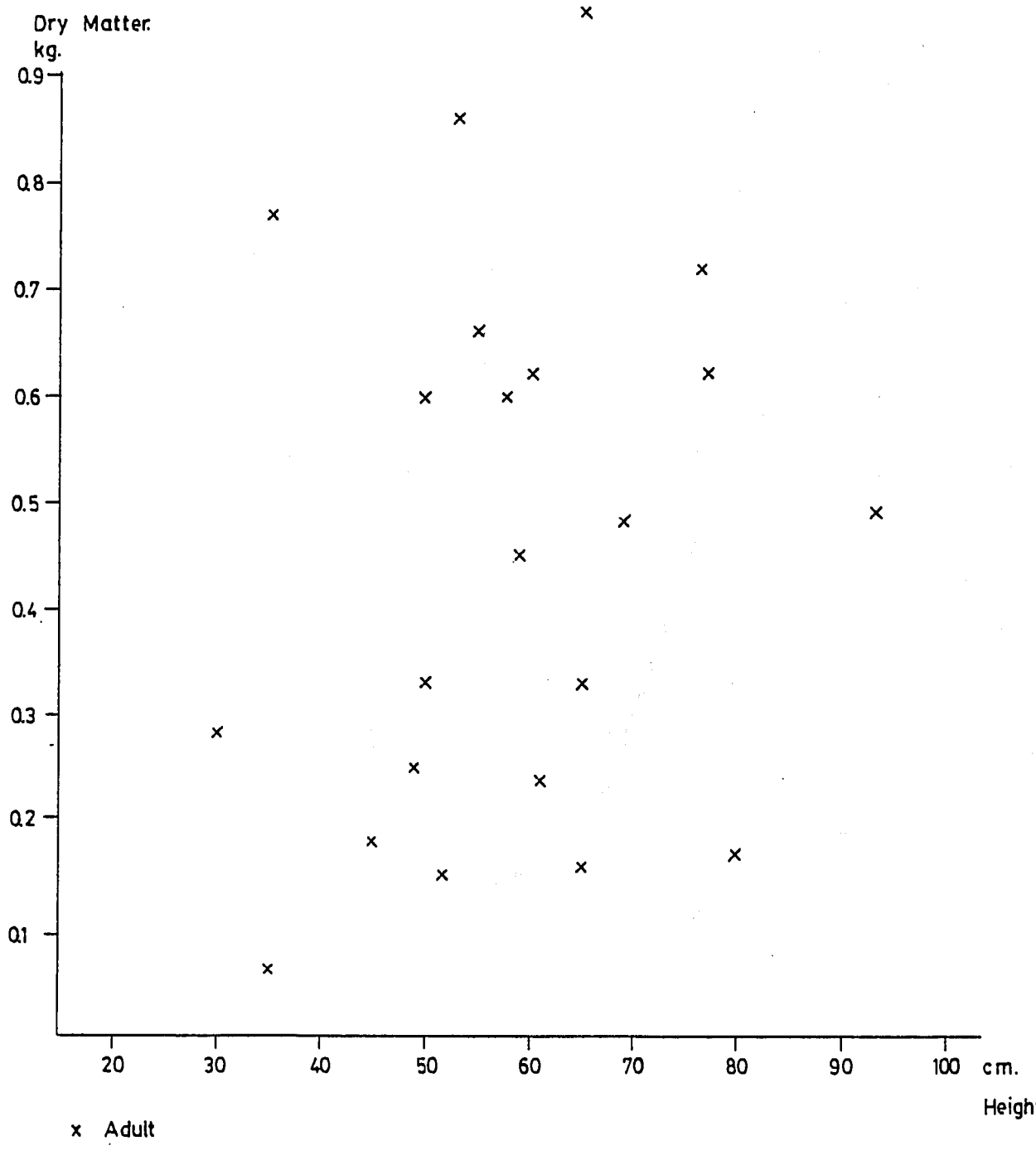


FIGURE 3

DISTRIBUTION OF PIG DUNG WEIGHT AND ANIMAL HEIGHT

(Kg. Dry Matter Per Day)



1. weighing of a single fece is not an accurate measure for estimating a day's production
2. the reliability of field measurements was less than the degree of explanation provided by any one variable,
3. sample collection, preservation, and handling were more problematic than for other forms of biomass,
4. the variables examined for their explanatory value were those accessible to surveyors rather than those which would be most directly related to dung production.

The variation in dry matter production is most likely a function of a number of variables relating to animal husbandry practices and local sources of animal fodder. Because of the complexity of this inter-relation it may be best to model the dry matter production in probabilistic terms using the basic parameters in table 1.

A subset of the samples were tested for energy content and the results are summarized in table 3. The coefficient of variation for these results is considerably lower than for the measurements of dry matter production. Pig dung was found to have an average energy content per kilogram of dry matter of 3569 kilocalories.+ For buffaloes and cows the respective numbers were 2818 and 3067 kilocalories.+ Adult animals had a 6-12% lower average energy content than non-adults for buffaloes and pigs, but for cows the numbers were about the same. The average energy content differed by sex but again only by a small percentage. For buffaloes and pigs the females had a higher energy content, but for cows the opposite was true. Clearly the sample size is too small to make precise statements, but the lack of significant differences in such a small sample would indicate that with a larger set of observations the numbers might converge, leaving even less distinction between the sexes and between adults and non-adults. The limitation on sample size was even more severe when examining regional differences in energy content as shown in table 4. Most cells have one or no observations.

Energy production figures were derived from all samples which have both a production and energy content measurement.
The results are shown in table 5. For adult animals 4 buffaloes produce the same energy content in dried dung as 13 cows or 23 pigs. For non-adult animals the ratio is 8:13:23.

3.2 Field Residues Energy Production

The moisture content of the biomass samples was widely distributed over a range of 5% to 95% as shown in the histogram in figure 4. The double peaked distribution is thought to be caused by two classes of biomass samples. The first, those with the lower moisture content, are the field residues which have been cut and left to dry in the field or elsewhere. The second, those with higher moisture content, are fresh cut samples of biomass gathered by the surveyors either prior to or during harvesting.* The relationship between this distribution and

+ including males, females, young and adults

* the survey staff had been requested to collect samples of fresh-cut biomass samples from commonly available species which were not being harvested. The size of this group was much larger than expected and no record had been kept of the method of collection.

a concatentated normal distribution was examined graphically.++ The results are presented in figuares A1 and A2. The fit was close enough so that an idealized model of the distribution could be prepared as shown in figure 5. The dried field residues had an average moisture content of 17% (20% on a dry basis) with a coefficient of variance of

++ The split of the observations between fresh and residue samples was made by visually spearating the histogram into two peaked groups and computing the statistics for each.

Table 3

ANIMAL DUNG ENERGY CONTENT STATISTICS

(kilocalories per kilogram oven-dried matter)

ANIMAL	AGE	SEX	AVERAGE	STANDARD DEVIATION(%)	SAMPLE SIZE
Buffalo	Adult	Male	2590	468	3
		Female	2721	506	5
		All	2672	496 (18.5)	8
	Young	Male	3002	-	2
		Female	3084	539	3
		All	3051	493	5
	All	All	2818	528 (18.7)	13
Cow	Adult	Male	3147	481	5
		Female	3106	587	4
		All	3129	531 (16.9)	9
	Young	Male	2920	-	1
		Female	2655	-	1
		All	2788	133 (4.8)	2
	All	All	3067	501 (16.3)	11
Pig	Adult	Male	3384	32	2
		Female	3573	369	3
		All	3498	301 (8.6)	5
	Young	Male	3495	-	1
		Female	3999	-	1
		All	3747	252 (6.7)	2
	All	All	3569	309 (8.7)	7

Table 4

REGIONAL VARIATION IN DUNG ENERGY

(Kcal/kg dry matter)

AREA	BUFFALO		COW		PIG	
	Adult	Young	Adult	Young	Adult	Young
Petchburi	-	-	3180 (3)	-	-	-
Chantaburi	-	-	3138 (1)	-	3084 (2)	-
Srisaket	2173 (1)	2638 (1)	2429 (1)	2787 (2)	3605 (2)	-
Kampangphet	-	-	-	-	-	-
Lampang	3131 (3)	3154 (4)	-	-	-	-
Songkla	2353 (1)	-	3943 (1)	-	-	3999 (1)
Chantaburi	2921 (1)	-	2250 (1)	-	-	3495 (1)
Roi-et	2114 (1)	-	-	-	3809 (1)	-
Udorn Thani	-	-	3347 (1)	-	-	-
Chiang Mai	2418 (1)	-	3512 (1)	-	-	-

Table 5
ENERGY CONTENT OF DUNG PRODUCED IN ONE DAY BY TYPE OF ANIMAL

ENERGY AND MOISTURE CONTENT MEASURED

	AVERAGE (Kcal)	STD. DEV. (Kcal)	COEFF. OF VAR.	SAMPLE SIZE
BUFFALO :				
Adult	16732	6102	.36	7
Young	4889	1273	.26	3
COW :				
Adult	5108	2740	.54	8
Young	2972	665	.22	2
PIG :				
Adult	2874	1570	.55	5
Young	1688	568	.34	2

FIGURE 4

BIOMASS MOISTURE CONTENT

(% wet basis)

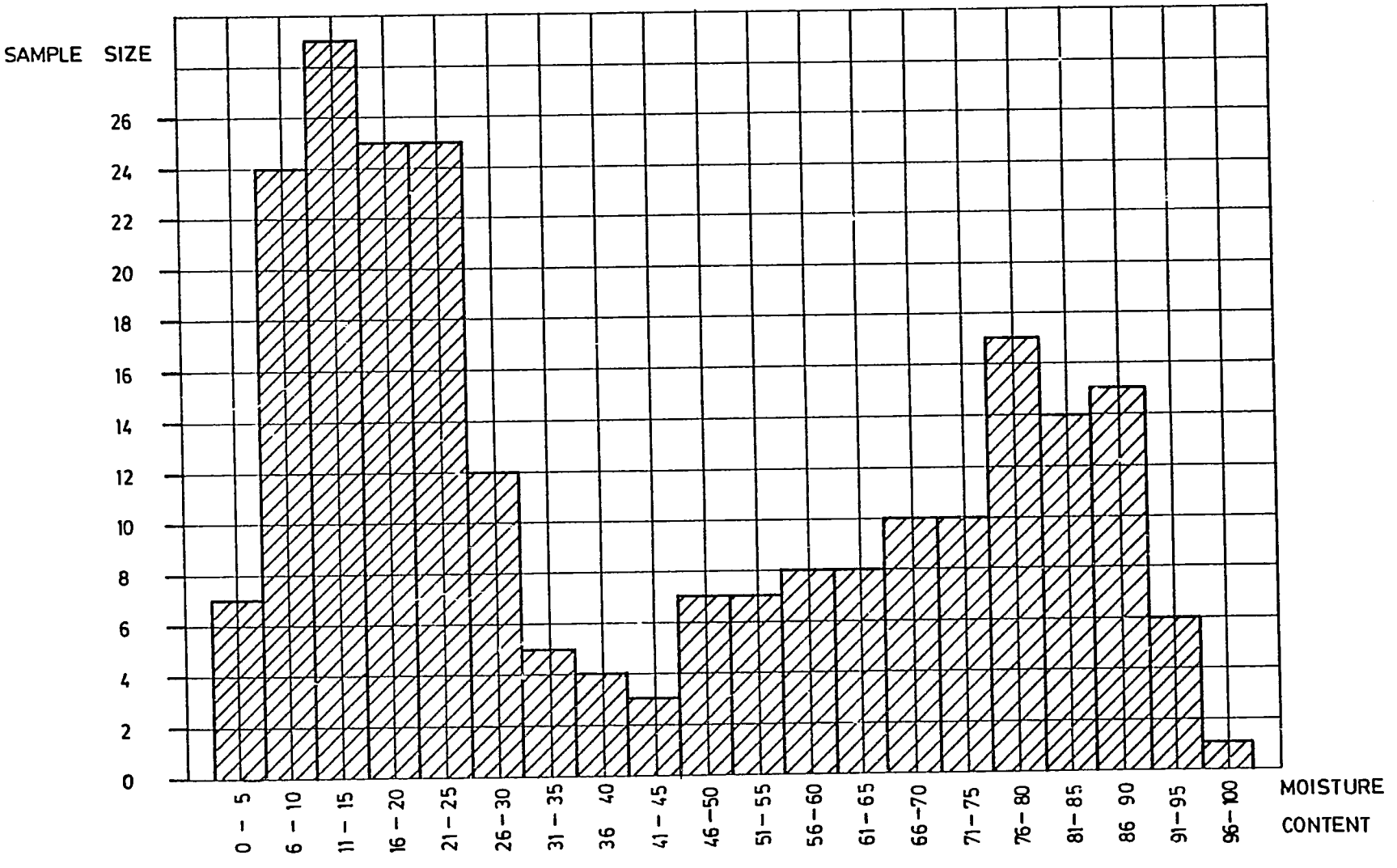
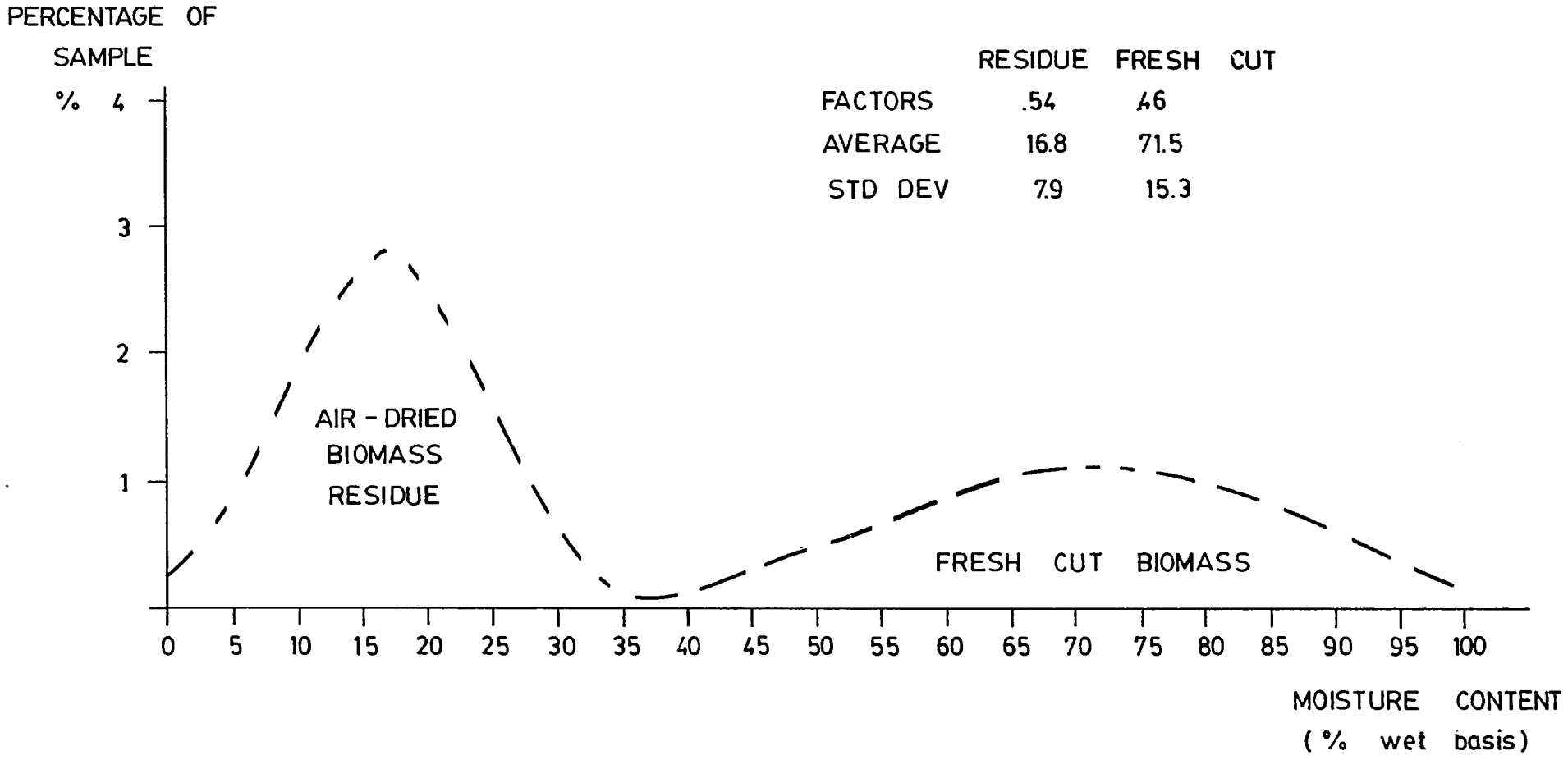


FIGURE 5

MODEL OF BIOMASS MOISTURE CONTENT

(CONCATENATED NORMAL DISTRIBUTIONS)



.47, whereas the fresh field residues had an average moisture content of 72% (257% on a dry basis) with a coefficient of variation of .21.

In order to narrow the range of moisture content, the samples were analyzed by species. This division presented two problems. First, the division between fresh cut and dried samples could not be easily observed from the data (the field sample sheets did not include information on the collection procedure). Second, with the smaller sample size the coefficient of variation increased for most samples. The results are presented in table 6. The highest moisture contents were recorded for recently harvested samples of field residues from sugar cane, tobacco, corn, beans and cassava as well as water hyacinth. Relatively low moisture contents were recorded for rice husk and straw, kapok, fan palm and chili plants. Grasses, bamboo and mimosa trees had intermediate moisture contents.

While the data on moisture content accurately reflects the situation in the villages during the survey, the moisture content for any given species is variable. It is dependent on the condition of the plant and the weather during the period prior to collection, among other things. If these species were to be used as fuels, the more interesting value would be the equilibrium moisture content achieved after the fuel was stored in a sheltered area for two or more weeks.

The data on the energy content of the dried matter for different species had less variance than the data on moisture content. Despite the relatively small sample sizes for these measurements, the coefficient of variation was less than 14% for all species. The highest energy content of those presented in table 7 is for dried latex. This resin is used as a starter for charcoal fires and has a heat content comparable to crude oil. Other high heat content species like cassava, mimosa, tomato, chili, sugar, bamboo and coconut husk had calorific values similar to wood. Rice husk and straw, hyacinth, tobacco, corn and beans all had lower calorific values centering around 3500 kilocalories per kilogram of dried matter.

The information on energy and moisture content was combined with the data on the quantity of residue produced per unit area for various field residues to produce estimates of the megacalories of energy available in the plant residues per square meter of crop planted. The values for energy content were derived from the average values in table 7, but the moisture content data was measured directly. Because this data sample was limited, an extended sample was computed by using standard moisture content figures for those samples in which no moisture data was recorded. The largest energy value was for the mimosa tree. The second highest value was for water hyacinth.* Both of these plants were recorded as producing large quantities of dry matter per unit area as shown in table 8. The intermediate value energy sources included sugar cane, rice straw, chili, cassava and whole beans. The variances for all the species in table 8 are large reflecting; 1) the variation in moisture content among samples 2) the variation in size of plants in different locations, and 3) the differences in harvesting techniques which alter the amount of the plant left in the field. The potential of the various species of biomass as sources of

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* The water hyacinth was collected from the area of densest growth which overestimates the productive capability of a body of water.

Table 6
BIOMASS MOISTURE CONTENT

SPECIES		MOISTURE CONTENT			
THAI	ENGLISH	AVERAGE	ST. DEV.	COV	SAMPLE SIZE
ตอซังข้าว	rice straw	27	19.2	.70	13
แกลบ	rice husk	14	7.3	.50	21
อ้อย	sugar cane	79	9.3	.11	15
ต้นมันสำปะหลัง	cassava plant	65	22.9	.35	19
ทางมะพร้าว	coconut palm fond	30	19.2	.63	29
กาบมะพร้าว	coconut husk	31	23.5	.77	14
กะลามะพร้าว	coconut nut	25	13.5	.52	8
ถั่ว	whole bean	59	28.9	.49	16
ไมยราพยักษ์	mimosa	48	11.5	.25	4
เปลือกนุ่น	kapok	17	4.5	.24	5
ผักตบชวา	hyacinth	92	1.7	.02	3
ยาสูบ	tobacco	74	23.5	.32	7
ละหุ่ง	castor-oil bean	78	10.2	.13	3
ฟางข้าว	rice straw *	22	16.5	.77	12
มะเขือ	eggplant	48	14.7	.31	3
พริก	chili	22	16.5	.77	6
ไผ่	bamboo	41	15.6	.39	5
กาบตาล	fan palm	22	7.9	.36	5
หญ้า	grass	39	27.2	.69	6
กล้วย	banana	69	27.1	.39	6
ชี ยางพารา	resin	15	16.0	.06	11
ต้นข้าวโพด	corn stalk	78	14.4	.18	9
	* Same as rice root				

+Measured on a wet basis.

Table 7

BIOMASS ENERGY CONTENT FOR FIELD RESIDUES

SPECIES		SAMPLE SIZE	AVE. 10^6 cal/kg	ST. D	COV
THAI	ENGLISH				
ยาสูบ	tobacco	3	3.75	.474	.13
มันสำปะหลัง	cassava	2	4.40	.277	.06
อ้อย	sugar cane	2	4.16	.260	.06
ต้นข้าวโพด	corn stalk	3	3.60	.120	.03
ต้นถั่วเหลือง	bean	3	4.65	.284	.06
ข้าว	rice straw	6	3.61	.062	.02
กาบมะพร้าว	coconut husk	2	3.82	.475	.12
ก้านมะพร้าว	coconut palm fond	3	3.47	.275	.08
กะลามะพร้าว	coconut nut	2	4.21	.127	.03
ยางดิบ	dried latex	2	9.68	.471	.05
แกลบ	rice husk	2	3.44	.084	.02
ต้นพริก	chili	1	4.22		
ต้นมะเขือ	eggplant	1	4.28		
ใบยาพญิกษ์	mimosa	1	4.22		
ถั่วลิสง	bean	1	3.03		
ถั่วเขียว	bean	1	3.56		
เปลือกถั่ว	bean skin	1	3.65		
ไม้ไผ่	bamboo	1	4.17		
ผักตบชวา	hyacinth	1	3.04		
หญ้า	grass	1	4.25		
หญ้าขันมัน	grass	1	3.63		
ก้านตาล	fan palm	1	3.71		
ใบตาล	palm leaves	1	3.06		
ใบพืช	grass	1	3.95		

Table 8

BIOMASS ENERGY PRODUCTION PER UNIT AREA

SPECIES		LIMITED SAMPLE				EXTENDED SAMPLE			
THAI	ENGLISH	SAMPLE SIZE	DRY MATTER (KG/M^2)		ENERGY ($MCAL/M^2$)	SAMPLE SIZE	DRY MATTER (KG/M^2)		ENERGY ($MCAL/M^2$)
			AVE	Std. DEV.			AVE	Std. DEV.	
อ้อย	sugar can	7	4.38	2.26	18.2	10	4.27	2.29	17.8
ต้นมันสำปะหลัง	cassava plant	13	3.70	1.83	16.3	16	3.49	1.76	15.4
ถั่ว	whole bean	6	3.53	3.13	13.2	11	3.40	2.53	12.7
ไมยราพนักษ์	mimosa	5	39.48	28.00	166.1				
ผักตบชวา	hyacinth	2	18.30	9.69	55.7				
ยาสูบ	tobacco	6	1.05	.52	9.5	9	1.13	.50	15.8
ฟางข้าว	rice straw	7	3.42	2.17	13.2				
มะเขือ	tomato	1	2.74	0	11.7				
พริก	chili	6	4.51	2.27	19.0				
ต้นข้าวโพด	corn stalk	8	1.35	1.15	4.9				

energy would require a more rigorous and perhaps,local analysis. Not only is it important to know the local planting and harvesting methods but also the size of the fully grown plants. Even more important, it is necessary to analyze the alternative uses of the biomass especially as a fertilizer or fodder. The existing pattern of use for many of these biomass species was examined during the survey. The results are summarized in a later section of this report.

3.3 Wood Energy Content

The wood samples included stored fuels used for cooking, green wood collected for charcoal making and fresh cut wood from selected species in the forest. The distribution of moisture content for the wood samples ranged from 5% to 80% on a wet basis (5% to 400% on a dry basis). It is likely that some of the higher and lower values result from measurement errors and that the range is closer to 10-65% The distribution as shown in figure 6 has the same double peak characteristic as the biomass samples. A comparison of this distribution with two concatenated normal distributions is shown in the appendix, figures A3 and A4.* The fit is reasonable; therefore, the moisture content has been modelled as two normal distributions, one with an average of 13.6% (15.7% on a dry basis) and a standard deviation of 6.4% for fuel wood and the other with an average of 45.6% (83.8% on a dry basis) with a standard deviation of 12% for fresh cut wood (figure 7).

The energy content of wood was recorded for 31 samples. The average calorific value of dried wood was recorded as 4258 kilocalories per kilogram. The variance was fairly low with a coefficient of variation of .11. The distribution of calorific values is shown as a cumulative percentage in figure 8. The similarity to a normal distribution is not as close as for moisture content but this could be due to the small sample size. The variance in energy content is due in part to differences in the species being tested. A breakdown of energy content by species is shown in table 9 for the 21 species identified. Where two measurements have been made for one species, both measurements have been listed. While most of the double measurements are within 5% of each other, the two measurements for Teetona Grandis, Linn differ by 20%. This difference could be explained by differences in the age or parts of the trees, incorrect species identification, or differences in the bombe calorimetry equipment and techniques. Three other sources of calorific value have been consulted in an effort to reduce the variance. The first is a series of measurements made at the Thailand Department of Science** in 1972. A complete list of their findings is given in the appendix, but the energy content for the same species which were measured in the survey are included in table 9. The DoS data tends to be higher by 10-30% with the exception of Dipterocarpus alatus, Roxb. which was lower by 20%. A second point of comparison is data recently gathered by the Thailand Institute of Scientific and Technical Research. Two of their measurements were for species included in the survey and the DoS data. While their figures tended to be 15% lower than the DoS data they were higher than the survey data. A final point of comparison

*The method for deriving this curve was the same as for the biomass samples
**Department of Science News, No. 70, Thailand Ministry of Industry

FIGURE 6

WOOD - MOISTURE CONTENT

(% wet basis)

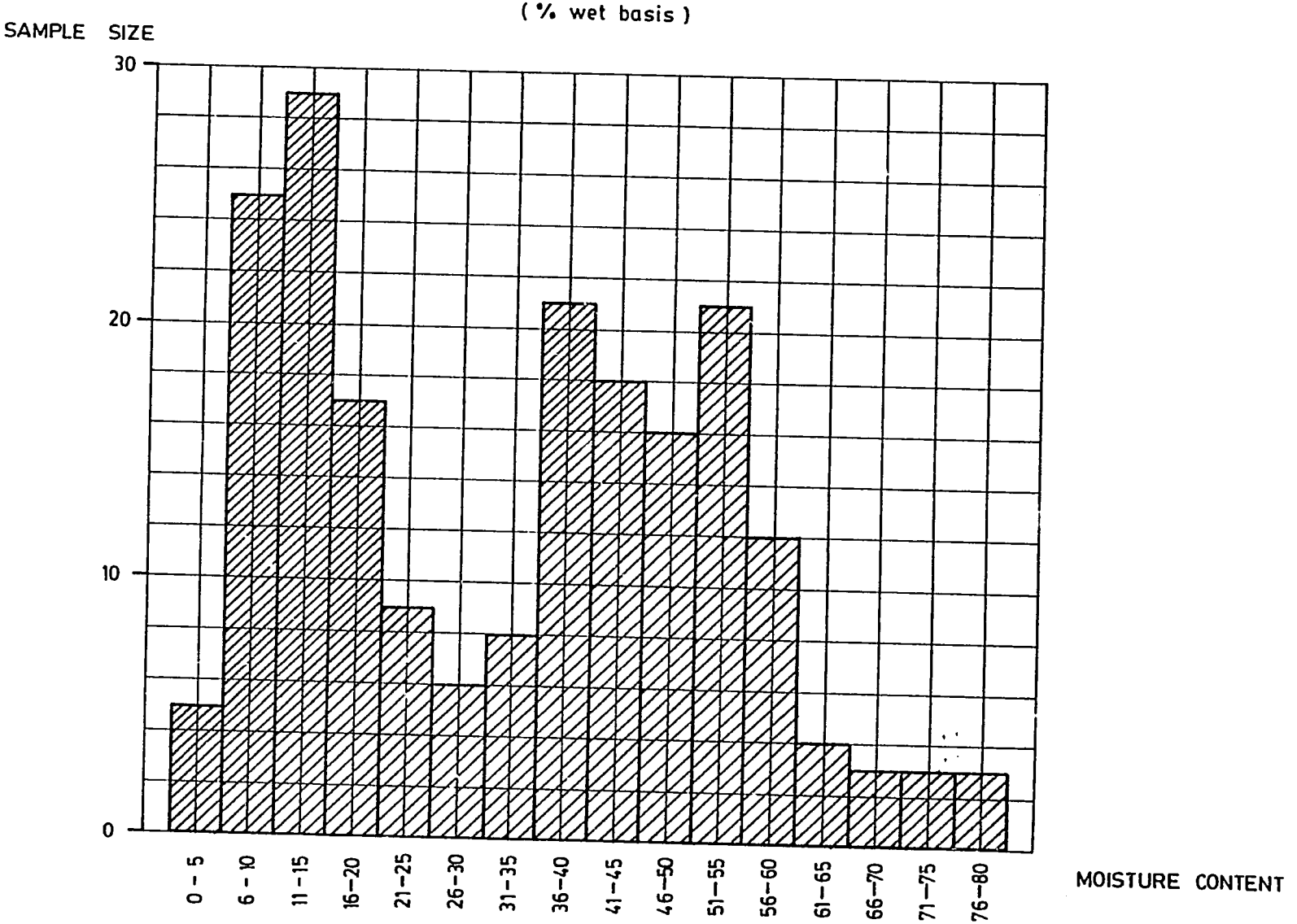
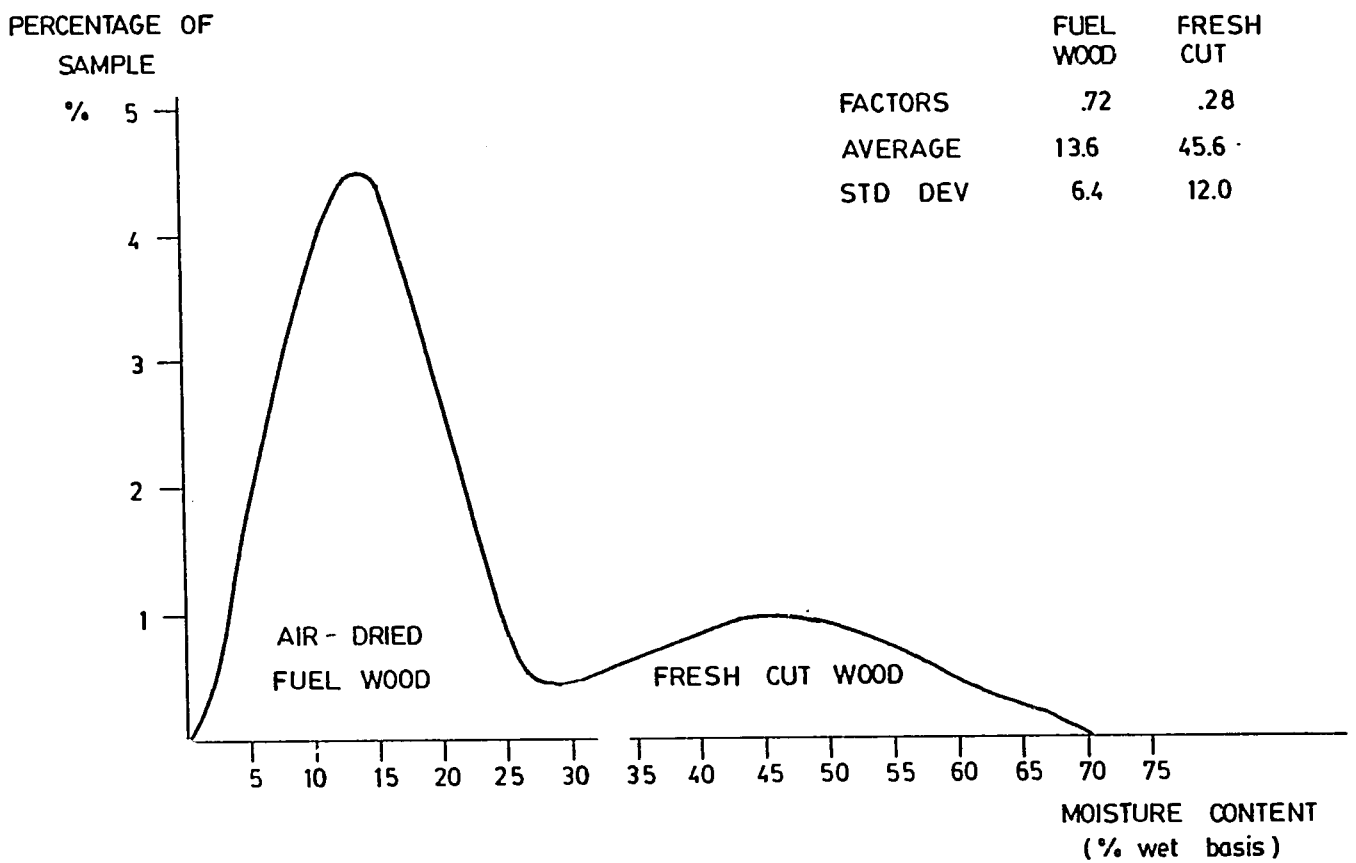


FIGURE 7

MODEL OF WOOD MOISTURE CONTENT

(CONCATENATED NORMAL DISTRIBUTION)



	FUEL WOOD	FRESH CUT
FACTORS	.72	.28
AVERAGE	13.6	45.6
STD DEV	6.4	12.0

FIGURE 8

CUMULATIVE DISTRIBUTION OF OBSERVATIONS OF ENERGY CONTENT OF WOOD

(0 % MOISTURE CONTENT)

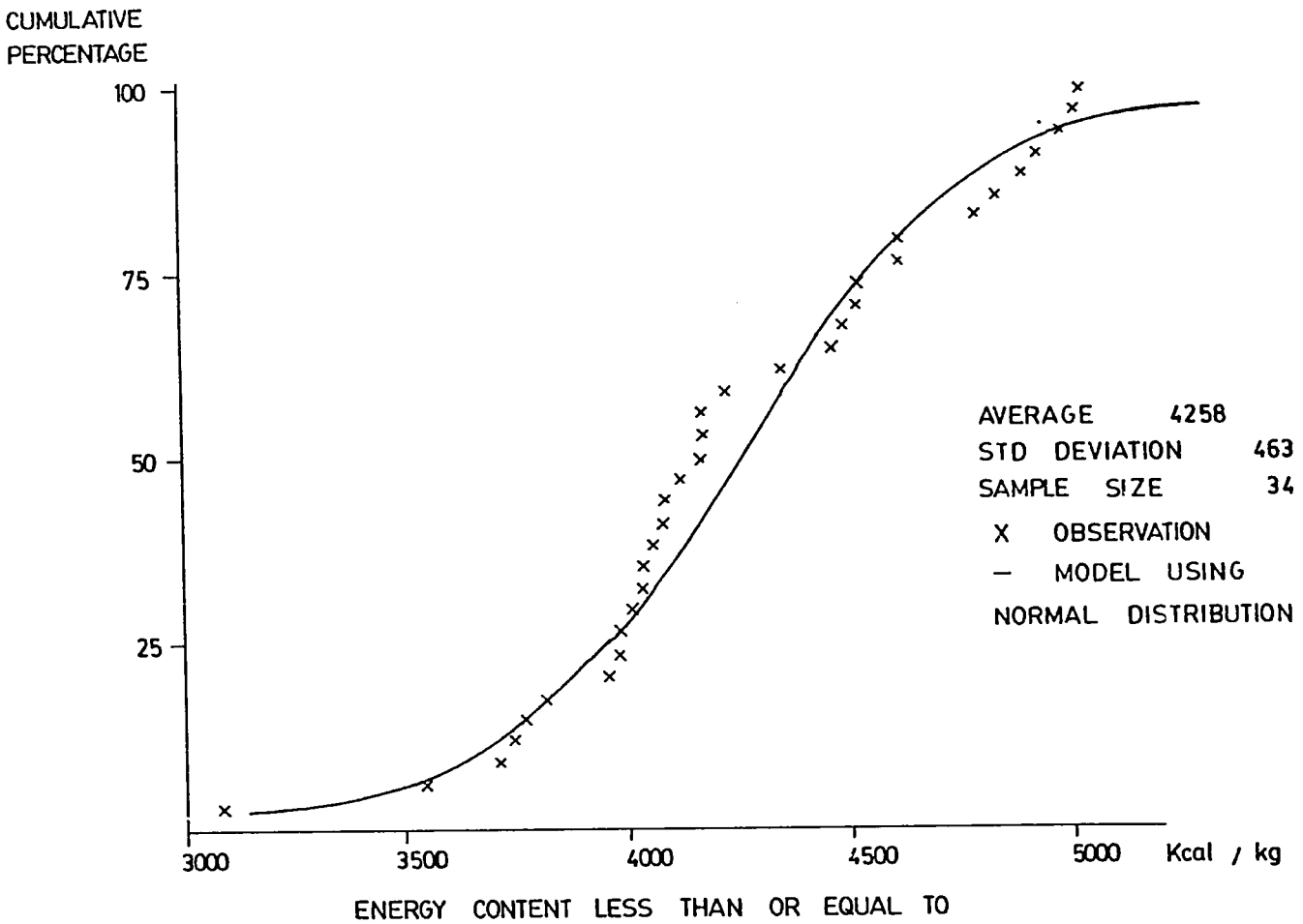


Table 9

ENERGY CONTENT OF FUELWOOD

(SPECIES TABLE)

	SPECIES		ENERGY CONTENT		
	THAI	LATIN	SURVEY	DoS	TISTR
1.	สะเดาบิก	Vatica cinerea King.	4977		
2.	กะปง		4519		
3.	ไผ่	Bambusa sp.	4168		
4.	มะขาม	Tamarindus indica	3766		
5.	ตะแบง	Dipterocarpus obtusifolius, Teysm.	4112	4861	
6.	กะบก	Irringia malayana, Oliver.	4080		
7.	อะราง		3981		
8.	หอก	Parinari anamense Hance.	4219		
9.	อ้อยช้าง	Mayodendron igneum, Kurz	3899	4497	
10.	โมยราพภัทย์		4031 4215		
11.	มะม่วงป่า	Mangifera spp.	3706	5855	
12.	กระท้อน	Sandoricum indicum, Carr.	3818	4911	
13.	มะหมก	Adenia penagiana Wilde	3980		
14.	ประดู่	Pterrocarpus, macrocarpus, Kurs	3951 4161	5022	
15.	ยาง	Dipterocarpus alatus, Roxb.	5981	4810	
16.	ไม้สัก	Teetona grandis, Linn.	4032 5026	5094	
17.	เต็ง	Shorca obtusa, Wall	4466	4960	
18.	เหียง	Dipterocarpus obtusifolium, Teysm.	4835 4782		
19.	สะเดา	Azairachta indica, A. Juss. Var.	4058	5046	4344
20.	เสม็ด	Melaleuca Leucadendron, Linn.	5187	5378	
21.	ยางพารา	Hevea brasiliensis, Wuell- Arg	4622		
22.	สะแก	Combretum quadrangulare, kurz		4937	4185

Units: Kcal/kg

is the measurement of J. Doat [1] as reported in Jan Bialy's monograph.[2] Doat examined the calorific value of tropical hardwoods from Africa, Asia and South America and found them to average 4770. This value is similar to that recorded by Dos. A summary of Bialy's findings based on secondary sources is shown in table 10. Clearly the survey figures are lower, as can be seen in the histograms for Dos and the survey in figure 9. Differences in measured heat content are not unusual. Despite the use of four significant figures in the results, the reliability of these measurements for biomass is ± 5% at best.*

3.4 Charcoal Energy Content

The distribution of moisture content for charcoal resembles a log normal distribution as can be seen in the histogram in figure 10 and confirmed by the graphical analysis in the appendix, figure A6. In order to analyze the data, samples with zero moisture content and with moisture content greater than 20% (25% dry basis) were eliminated.** This reduced the sample size from 230 to 219. The resulting statistics indicate an average moisture content of 7.9% (8.6% dry basis) with a standard deviation of 5.4%. The large variance (coefficient of variation .68) and relatively high moisture content may be due to the degree of pyrolysis of the charcoal which would affect its moisture content. However, attempts to compare the degree of carbonization as measured by energy content and moisture content did not indicate a strong relationship. The high moisture content could also result from the relatively high humidity. Earl reported similar findings for rubber wood charcoal in Malaysia [3].

The energy content was recorded for some 60 samples ranging from partially carbonized wood to completely carbonized charcoal. The distribution of energy content averaged 6350 kilocalories per kilogram with a variance of 645 and resembled a normal distribution as can be seen in figures 11 and A6 in the appendix.

*for further discussion of the differences see Appendix 3

**The 20% figure was chosen as a cutoff point as this was well above previously observed values and the tail of the distribution in figure 10 was thought to be due to errors in field measurements

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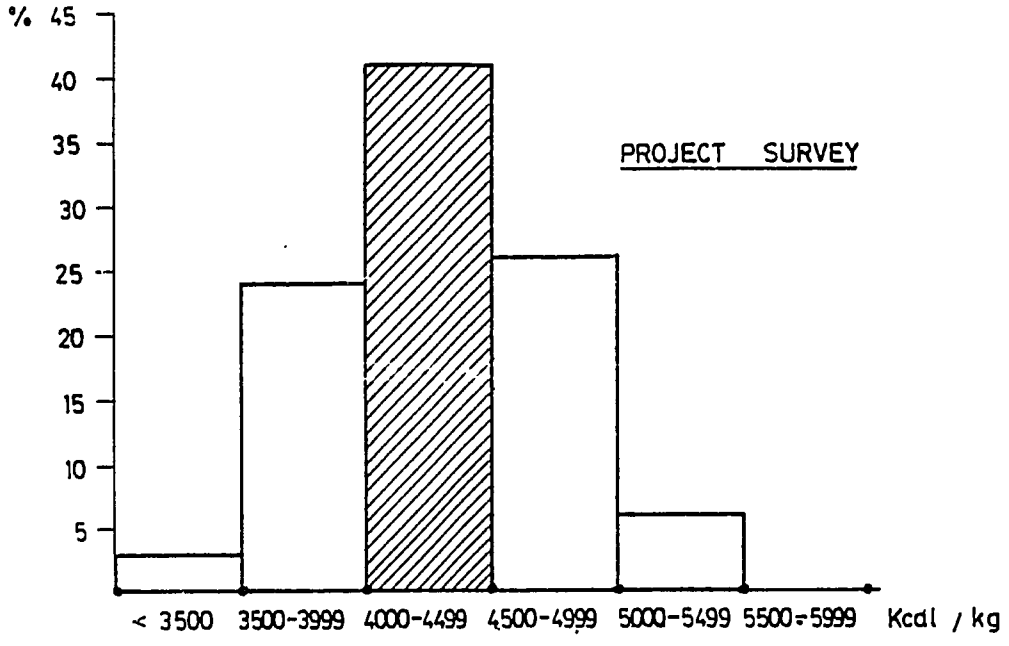
1. J. Doat, "Le Pouvoir Calorifigure des Bois Tropicaux, Revue Bois et Foret des Tropiques, 172, March - April, 1977 pp. 33-55
2. J. Bialy - "Measurement of the Energy Released in the Combustion of Fuels" Occasional Papers AT022, University of Edinburgh, December, 1979.
3. D.E. Earl, "Charcoal", FAO, Rome 1974. A reference to the work of S.B.M. Hannif, "Study of Industrial Use of Rubber Wood in Kedah and Penang, Malayan Forester, V.31 N.4 1968.

FIGURE 9

DISTRIBUTION OF ENERGY CONTENT OF WOOD



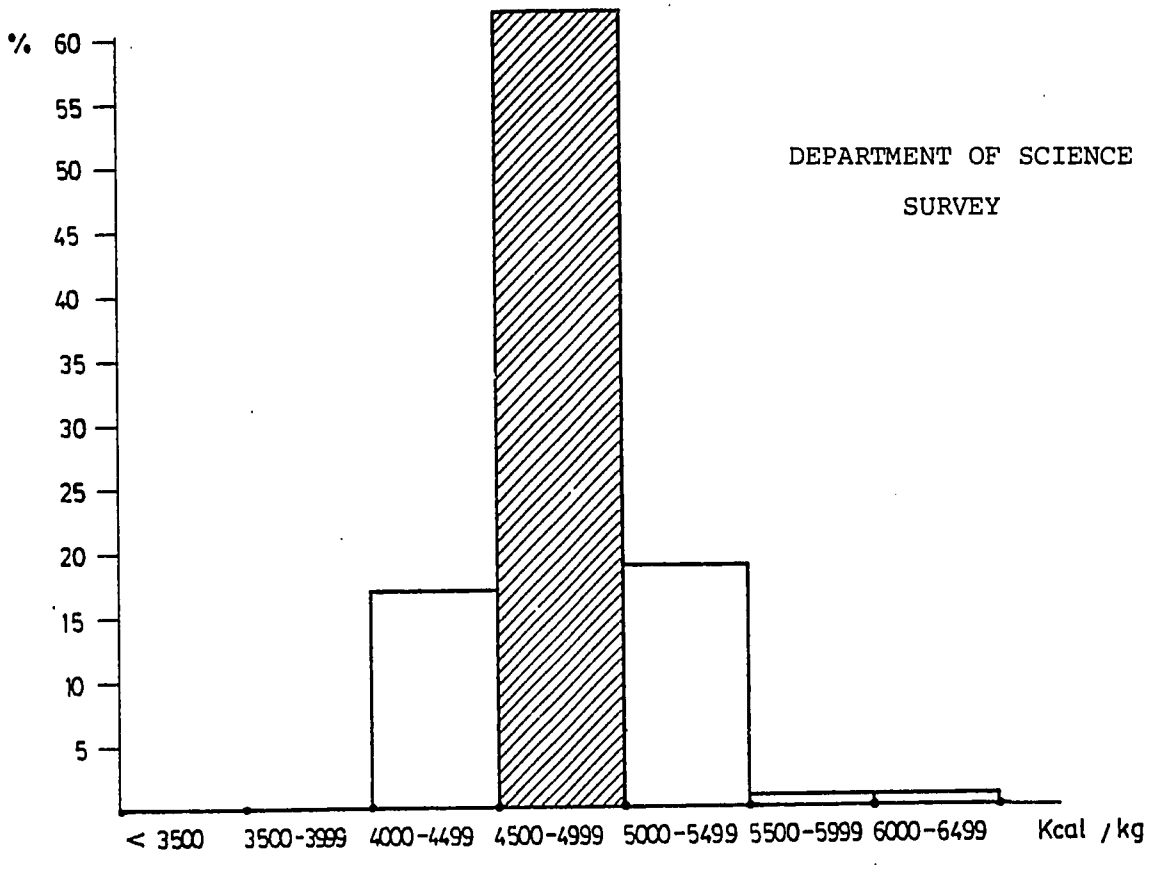


Table 10

PUBLISHED VALUES OF WOOD

AND CHARCOAL MOISTURE AND HEAT CONTENT DATA

Fuel	Moisture Content (% Wet basis)	Hydrogen Content (% dry basis)	Ash Content (%)	High heat Kcal/gm	low heat Kcal/gm
Wood					
oven dry	0	6	1	4.78	4.54
air dry	13	6	1	4.06	3.82
damp	21	6	1	3.59	3.35
Wood Charcoal+					
air dry	7	2.5	4	6.93	6.69
oven dry	0	2.5	4	7.34	7.17
ash-free, oven dry	0	2.5	0	7.65	7.48

+ Small Scale Kiln
adapted from Jan Bialy op.cit page 16

FIGURE 10

DISTRIBUTION OF CHARCOAL MOISTURE CONTENT (% wet basis)

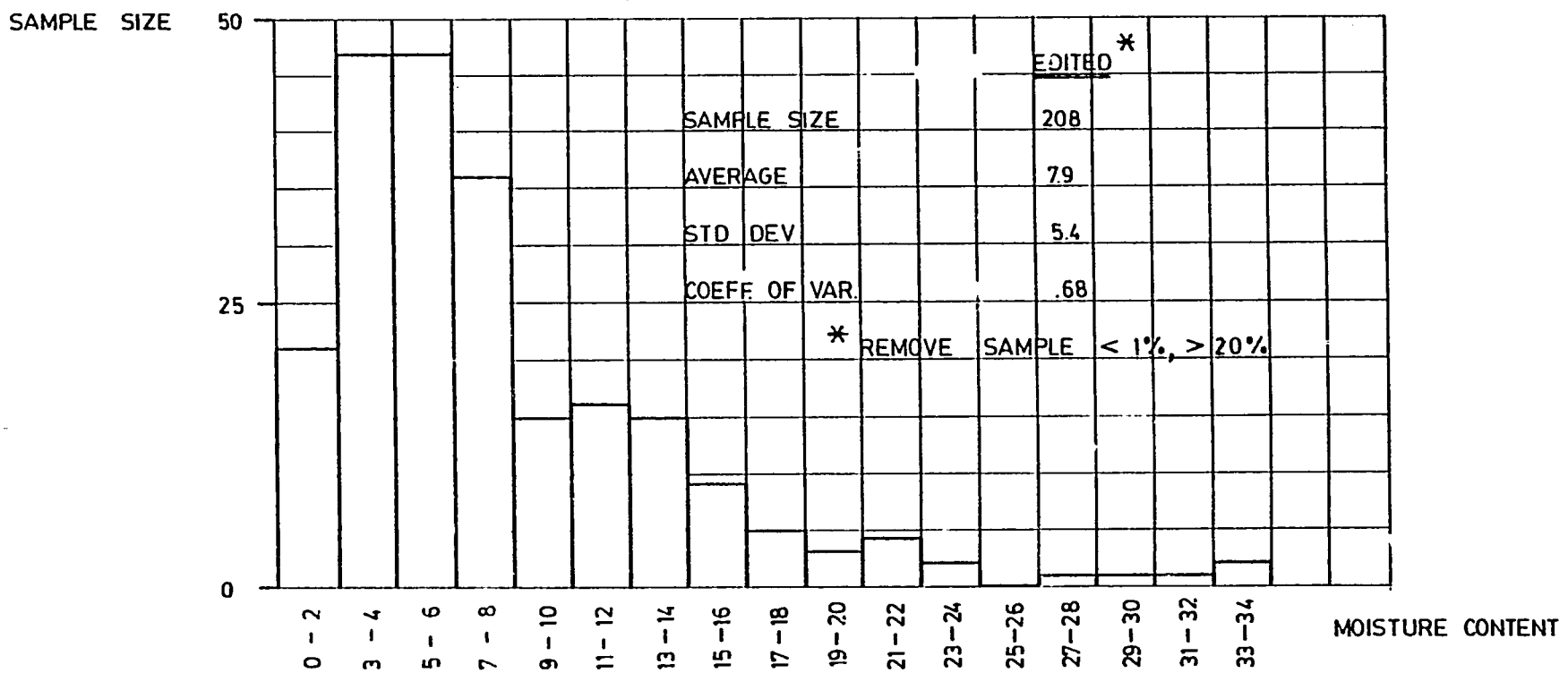
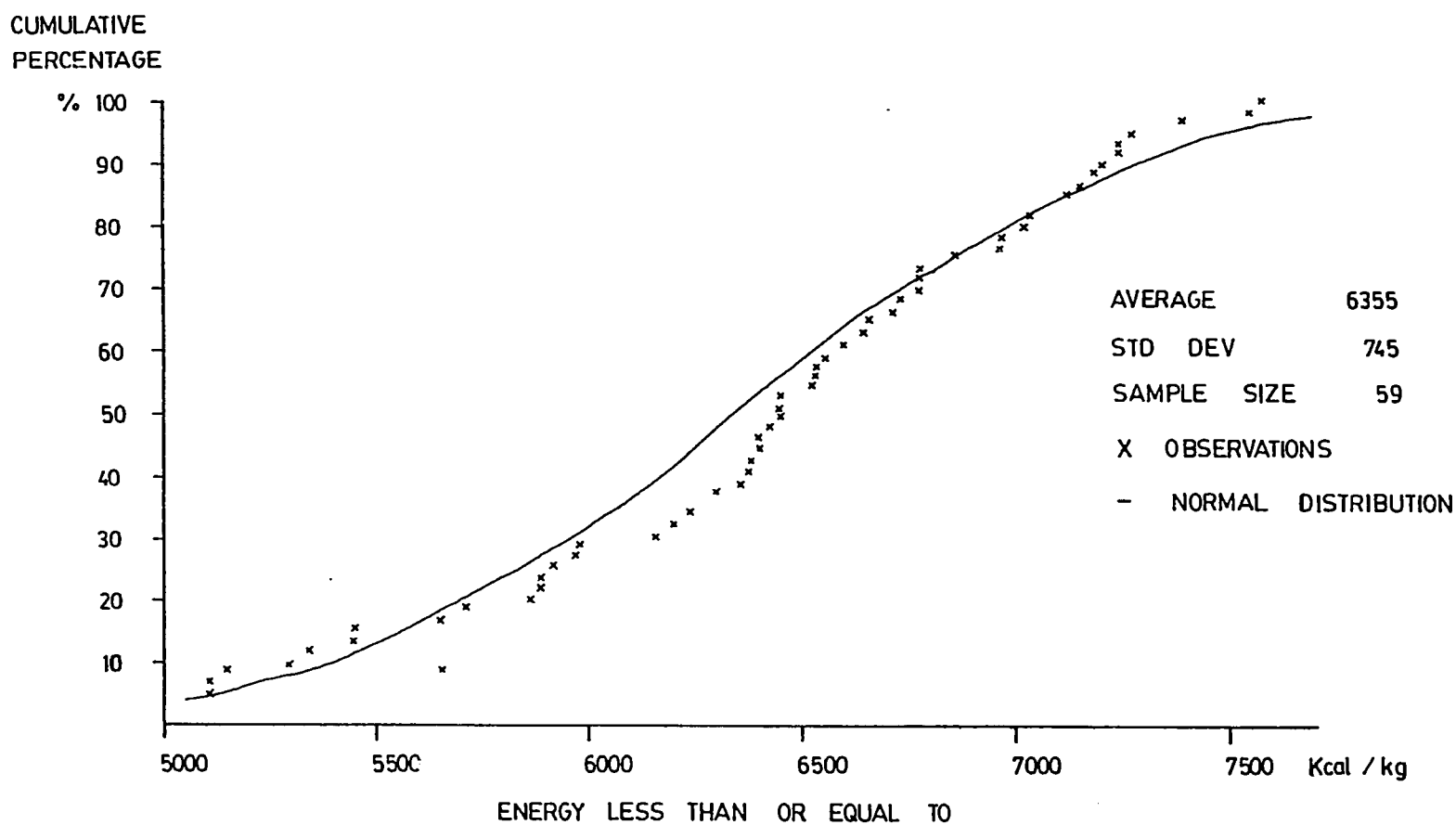


FIGURE 11

CUMULATIVE PERCENTAGE FOR OBSERVATIONS ON THE ENERGY CONTENT OF CHARCOAL

(0% MOISTURE CONTENT)



The major source of variation in energy content is thought to be the degree to which the samples were carbonized. The information from the charcoal-making survey reported in the "charcoal" report indicate a wide range in quality of charcoal. However, it was not possible to determine the extent of carbonization for the samples in this survey. Another possible source of variation was the species of wood used. The calorific value for different species is shown in table 11. For three of the species two samples each were measured. The range of the measurements for each of the species is nearly as great as for all the species. It seems reasonable to conclude that while some species may be easier to pyrolize, the type of species alone has very little effect on the energy content of the charcoal. Others sources of variation in energy content are the ash content and the percentage of fixed carbon for different species; however, no lab tests were conducted to determine ash content.

The comparative data from DoS and TISTR indicate a similar measurement problem as with fuelwood. The DoS data tends to be 20% higher than the survey data. A comparison between survey, DoS and TISTR data indicates additional variance. This variance can be explained not only by the species, age and part of the trees used but also by the degree of pyrolysis. The higher values for the DoS data as shown in the graphs in figure 12 may be due to different procedures. The survey samples were collected in the field, but the DoS samples may have been pyrolyzed in the laboratory.

4. Use of Biomass Residues in The Survey Changwat

As part of their survey activity, the enumerators observed the way the villagers used the residues from agricultural production. They also discussed these uses with the village leaders. The six biomass residues that are frequently used in the villages are rice husk, rice straw, rice stalk, bean shells, corncob and millet residues.* The rice husk had a number of uses. Principal among these was as fuel for the charcoal kiln and as a fertilizer turned under in the field. To a lesser extent it was used as a fodder,** a cooking fuel, and an insulation for ice. In only a few changwat was the rice husk burnt in the field. The rice straw was used in almost all changwat as a fodder and, to a lesser extent, as a fertilizer. Less important uses included fuel for charcoal kilns, fuel for cooking, mulch for mushroom growing, roofing material, and fuel to burn for insect protection. The principal use of rice stalks left in the field was as a source of fertilizer. These stalks were either turned under or burned in the fields to provide this fertilizer. The rice stalks were also an important source of fodder on which the cattle and other animals grazed. The uses of the bean shells and bean plant residues were similar to those for the rice stalks. They were either burned in the field or turned under for use as a fertilizer. In only one changwat were they observed to be used for a fodder or a fuel for cooking or insect protection. In only half the changwat was there any record of corncob and millet residues being used and there the uses were limited to being burned in the field, used as a cooking fuel or fed to animals.

* The products from rice cultivation include the uncut stems or stalks, the cut plant exclusive of the rice kernels or the straw, the hard surface on the kernel or the husk, the inside of the kernel or the rice and the bran, a byproduct from milling the rice. Millet refers to the Thai word.

** The fodder is probably bran rather than husk.

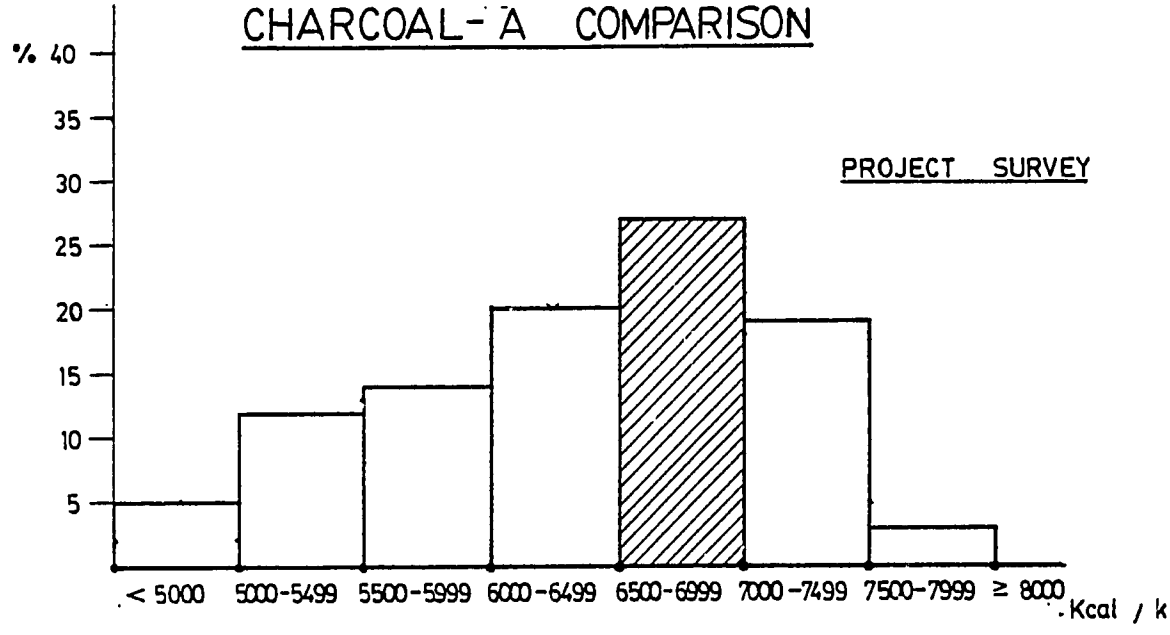
Table 11

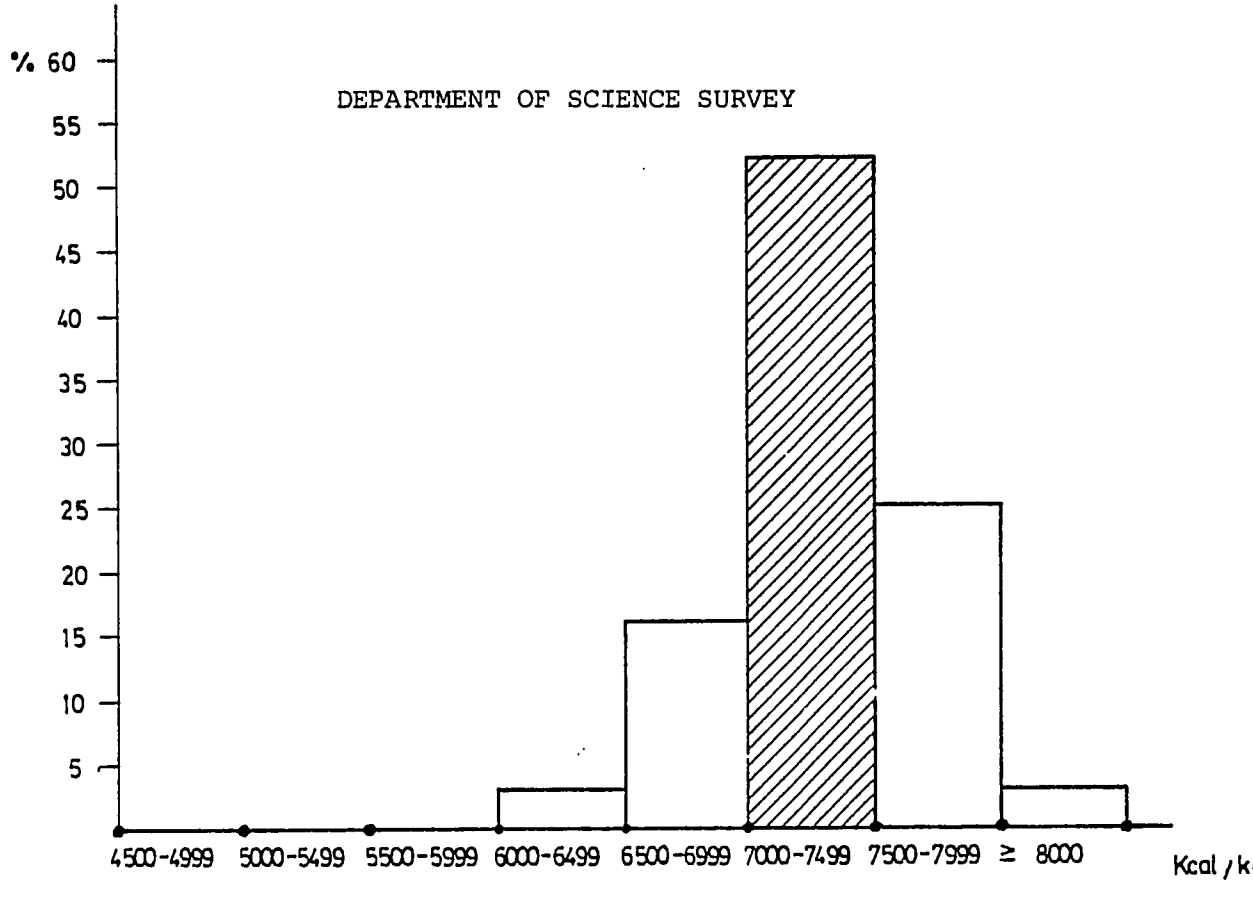
ENERGY CONTENT OF CHARCOAL
(SPECIES TABLE)

	SPECIES		ENERGY CONTENT		
	THAI	LATIN	SURVEY	DoS	TISTR
1.	มะหมก	Adenia Penagiana, Wilde	5844 6518		
2.	สะเดาบิก	Vatica Cinerea, King.	6209		
3.	ฝรั่ง	Psrdium guajava, Linn.	5319		
4.	มะขาม	Tamarindus Indica, Linn.	6649 7237		
5.	พยอม	Shorea talura, Roxb	7116		
6.	ประดู่	Pterocarpus macrocarpus, Kurz.	6403 6427	7539	
7.	เสม็ด	Melalcuca Leucadendron, Linn.	6454		
8.	ยาง	Dipterocarpus alatus, Roxb.	7554		
9.	ตะคร้อ	Schleichera trijuga, Willd.		7765	6704.4

FIGURE 12

DISTRIBUTION OF ENERGY CONTENT OF CHARCOAL- A COMPARISON





The use of other plant residues was limited to a few changwat in which those residues were readily available. Palm leaves were used as a cooking fuel in Petchburi and Chantaburi, as a fuel for charcoal kiln, a roofing material in Udorn Thani, and as a fertilizer in Roi-Et. Cassava plants were used as a cooking fuel in Petchburi and Korat. Cassava plant residues were burned in the field in Petchburi, Korat, Kampangphet, Chantaburi, and Udorn Thani. Scraps from rubber and rubber trees were used in Songkla and Chantaburi as fuel for charcoal kilns, cooking fuel, fodder and fertilizer. The wood from the rubber trees was used to make charcoal or was sold as a fuel to the brick makers. Rubber plant residues were used in Petchburi as a fodder burned in the field or turned under as a fertilizer. Sugar cane residues were burned in the field in Petchburi, Kampangphet, and Lampang but were used as a cooking fuel in Roi-Et and Udorn Thani and turned under as a fertilizer in Roi-Et. The residues from garden plants were either burned or turned under for fertilizer but the use of these residues was only observed in Petchburi, Srisaket, Songkla and Udorn Thani. A summary of the enumerators' responses by type of residue, use, and changwat is presented in table 12. A more detailed breakdown on a village basis is included in the survey volume "Questionnaires".

In addition to the question of what uses were made of specific types of agricultural residues, the enumerators were also asked about the general availability of these residues in the survey villages. This question was extended to include animal dung. For those villages which had various biomass residues, an analysis was made as to which villages did not use the residues. The results for each village are presented in another volume. A summary by changwat is shown in table 13. The lower number indicates the number of survey villages in which the enumerators reported that the residue was available. The upper number indicates which of these villages made no use of the residues but left them in the field to be burned or turned under. The observations by the enumerators concern general village practice. Their observations that a residue is not used does not imply that no use is made by the villagers but rather that any use is limited with most of the villagers not taking part.

Most villages used the rice straw except in Songkla and Kampangphet. Rice husk was also used in most villages where local milling activity made them available. The two reported exceptions were Kampangphet and Lampang, but even in these changwat the husk was used for charcoal-making. Perhaps there was not much charcoal-making during the phase I survey of Lampang and Kampangphet. The field residues from cassava were not used in any of the survey villages. Where the plants were not left in the field they were collected and discarded away from the field. The field residues for sugar cane, tobacco, cotton and beans were turned under or burned in the field by most of the villagers in the survey villages having these crops. Though there was some use of these residues for fodder and fuel, it was not widespread.

Coconut leaves and husks are useful as a fuel and building material but these uses were not prevalent enough to be included in the enumerators' observations. Banana trees are a popular tree in all the survey provinces, but they are grown mostly in family compounds and the enumerators made few

Table 12 USES OF BIOMASS RESIDUE IN CHANGWATS - PETCHABURI (1), KORAT (2), SRISAKET (3), KAMPANGPHET (4), LAMPANG (5)

	Rice husk	Rice stalk	Rice straw	Corncob, millet residues	Bean shells	Palm leaves	Cassava plant	Banana plant	Sugarcane stalk, fiber plants	Leaves, wood wastes	Garden, vegetable residues	Sawdust
1. BURN IN THE FIELD	5	1,2,3,4,5	4	1,3,4	1,2,3,4,5		1,2,4	1	1,4,5	2	1,3	
2. FUEL FOR CHARCOAL KILN	1,2,3,4		1,4									
3. COOKING FOOD, DRYING FRUIT			1,2	1,2,4	1	1	1,2			1		3
4. FODDER	3,5	1,5	1,2,3,4,5	1	5			1				
5. HEATING FUEL INSECT PROTECT	3		3	4						2		
6. FERTILIZER	1,3,5	1,2,3,4,5	1,2		1,2,4	3		1			3	
7. ROOFING MATERIAL			3									
8. MUSHROOM GROWING			1,2,4,5									
9. INSULATION FOR ICE	2,4											
10. SELL	5											

Table 12 (Cont.) USES OF BIOMASS RESIDUE IN CHANGWATS - SONGKLA (6), CHANTABURI (7), ROI-ET (8) UDORN THANI (9), CHIANG MAI (10)

	Rice husk	Rice stalk	Rice straw	Corncub, millet residues	Bean Shells	palm leaves	Cassava plant	Sugarcane stalk, fiber plants	Part of rubber plant	Garden, vegetable residues
1. BURN IN THE FIELD	9,10	7,8,9,10	6,10	6,9	7,8,10		7,9			6,9
2. FUEL FOR CHARCOAL KILN	6,7,8,9	7	6,8			9			6	
3. COOKING FOOD, DRYING FRUIT	7,8		6,8			7		8,9	7	
4. FODDER	10	7,8,9,10	7,8,9,10	10					6	
5. HEATING FUEL INSECT PROTECT	10		9							
6. FERTILIZER	7,8	6,7,8,9,10	7,8,9,10		7,8,9,10			8	6	9
7. ROOFING MATERIAL			10			9				
8. MUSH ROOM GROWING		10	10	10	10					
9. INSULATION FOR ICE	8									
10. SELL									6	

Table 13

Agricultural Residues Not Used in The Survey Changwat

	Petchaburi	Korat	Sisaket	Kamphangphet	Lampang	Songkla	Chantaburi	Roi-et	Udorn Thani	Chaing Mai
Rice husk	0/5	0/5	1/5	4/4	3/3	0/5	0/5	0/4	1/4	2/4
Rice Straw	1/5	0/5	0/5	4/5	1/5	3/5	1/5	2/5	0/5	1/5
Rice Stem	4/5	5/5	5/5	5/5	4/5	5/5	5/5	5/5	4/5	2/5
Cassava plant	1/2	4/4	0/0	3/3	0/0	0/0	3/3	0/0	3/3	0/0
Sugarcane stalk	3/3	0/0	1/1	1/1	1/1	0/0	0/0	0/0	2/2	0/0
Coconut residues	1/2	0/1	2/2	1/1	1/1	1/1	2/2	0/0	0/1	0/0
Banana residues	3/4	0/0	0/0	0/0	0/0	0/0	0/0	0/0	0/0	1/1
Bean plant	2/2	1/1	1/1	5/5	2/2	2/2	3/4	1/1	1/1	3/5
Cotton or tobacco residues	0/0	0/0	3/3	0/0	0/0	0/0	0/0	4/4	1/2	0/0
Kitchen garden residues	1/3	0/0	5/5	0/0	0/0	1/0	0/0	0/0	2/2	0/0

lower number - survey villages having this residue
upper number - survey villages having but not using this residue

observations on their use. The same is true of small gardens, so that no significant use of garden residues was observed.

5. Conclusions

5.1 Methodological Problems

The biomass survey provided valuable experience for both the survey personnel and the project consultants on the difficulties of collecting and preserving biomass samples during long periods in the field. It also provided an insight into the level of detail required to obtain accurate information. The two major limitations on the reliability of the biomass data were the lack of formal scientific training among the survey personnel and the accuracy of the measuring equipment used under field conditions.

Preservation of field samples, especially animal dung and recently cut biomass, was the major difficulty encountered during this survey effort. Another serious problem was the limitations on accuracy of field measurements. While errors on any one type of measurements were not severe and could be accounted for, many of the variables being measured were interdependent so that the errors were compounded. For example, the calculation of the potential production of energy from a specific species of animal or biomass required a multiplication of the three factors; the quantity of biomass produced per unit resource, the ration of the dry weight to the wet weight of the biomass and the calorific value of the dried biomass. If the accuracy of the individual measurements was held to $\pm 10\%$, the reliability of the product of these three would be -27% to +33%.

The other methodological problem with measuring biomass is associated with the many factors affecting the energy yield from biomass production. These factors are summarized for agricultural residues in the following species-specific formula :

$$E_A = W_A F_1 F_2 F_3 F_4 (1-M_C) E$$

where E_A = Energy produced per unit area

W_A = crop yield per unit area

F_1 = ratio of total plant weight to weight of preprocessed food portion*

F_2 = fraction of plant weight left in field

F_3 = deterioration of field residue

F_4 = loss factor for collection or processing

M_C = moisture content (wet basis) of residue (decimal)

E = dry weight energy content

*e.g. unmilled rice

The result would be the gross energy content produced. The actual availability would vary depending on alternative uses of the residues. As an example of the use of this formula, the energy content of the stalk left in the padi field could be computed by first multiplying a regional estimate of padi production by the ratio of average plant weight to average weight of padi per plant, F_1 as determined through sampling for different varieties in different agro-climatic zones. This value would then be multiplied by the fraction of the average weight which is left in the field after harvesting, F_2, and the loss factors due to deterioration in the field, F_3, and to collection from the field, F_4. F_2 would be determined from sampling of different padi fields. The loss factors would be determined through direct observations over time in the fields and during the collection of stalks in the field. Finally the moisture content of the stalks at the time of collection, M_C, and the energy content of the oven dried stalk, E, would be measured in the laboratory and factored into the calculation.

In the baseline survey the residue per unit area was measured directly rather than computing W_A and F_1 separately. However both W_A and F_1 vary with specific plant varieties, soil conditions, and seasonal weather. The factor F_2 is affected by the method of harvesting and the equipment used. This factor will vary regionally but will be relatively constant among adjoining villages. The variation in F_2 can be seen in the harvesting of rice where the type of knife used and the method of storage will determine how much stalk is left in the field. The deterioration factor, F_3, is determined by factors ranging from the presence of grazing animals to the amount of rain following the harvest. The factor is time-dependent since the deterioration of the residue increases with time. The moisture content, M_C, will vary with the weather during the period preceding its measurement. This factor will in turn affect the weight of the residue, $W_A F_1$. One way to reduce this complexity is to combine the three factors into a measure of dry weight per unit area, $W_A F_1 (1-M_C)$. The loss factor, F_4, refers to losses involved in collecting or processing the residue. This can vary with the type of equipment as in the case of rice husks produced by different milling techniques. The energy content of the residues will also vary with varieties but the variance is thought to be less than for the other factors.

In summary agricultural residue production varies not only with species and planting density W_A, but also with time-dependent factors, M_C and F_3, and with regional-dependent factors F_1, F_2 and F_4. An interregional survey which is scheduled for reasons other than the agricultural cycle is not appropriate for measuring residue production but is appropriate for identifying the potential range of these factors and their possible importance. It can also be used for determining the uses which are made of the residues but not for quantifying these uses.

5.2 Results

The daily production of animal dung measured in terms of dry matter averaged 5.6 kilograms for adult buffaloes, 2.2 kilograms for adult cows and .6 kilograms for adult pigs. The corresponding numbers for young animals were 2.5 kilograms for buffalo, 1.7 kilograms for cows and .5 kilograms for pigs. The variation in the results for different species is more affected by the variation in size of feces produced by an animal during a normal day and errors in measurement of these feces than by the sex, size or location of the animals. The average calorific value of the dry matter from animal feces was 2,820 kilocalories per kilogram for buffaloes, 3,070 kilocalories for cows and 3,570 kilocalories for pigs.

The variation in calorific value of the dry matter feces from the different species did not vary significantly with the sex or age of the animal. The standard deviation in the results was about 17% of the average value for buffaloes and cows, and only 9% for pigs. Based on the average values the production of energy from animal feces (in terms of the calorific value) amounted to 16.4 megacalories per day for adult buffaloes, 6.8 megacalories for adult cows, and 2.1 megacalories for adult pigs. For young animals the daily production of potential energy was 7.1 megacalories for buffalo, 5.2 megacalories for cows, and 1.8 megacalories for pigs.

For agricultural residues, the average moisture content measured on a wet basis was 17% for residues which had been left in the field, and 72% for residues which were recently cut. The moisture content of the residues depends on three factors. The first is the length of time during which the residue has been lying in the field. The second is the weather during the weeks prior to the measurement of the moisture content. The third is the species of biomass being measured. Relatively high moisture content was found in field residues of sugar cane, cassava, bean, water hyacinth, tobacco, banana and corn, whereas low moisture content was found in rice husk, coconut palm leaves, coconut husk, kapok shells, chili plants, and fan palm leaves.

The energy content of the dry matter from the biomass samples depended on species. Relatively high caloric values were found in field residues of cassava, mimosa, eggplants, chili plants, and sugar cane, and also in bamboo and coconut husks. These had heat contents similar to wood. Another group of biomass residues had heat contents about 80% of that of wood. These included rice husk, rice straw, water hyacinths, tobacco stalks, corn stalks and bean plants. The quantity of residue left in the field depended very much on the harvesting technique and the planting density. Estimates were made of the quantity of heat energy in the residues left per square meter of growing area for different species. These estimates indicate that mimosa and water hyacinths produce relatively large quantities of heat energy, about 160 megacalories per square meter for mimosa and 56 megacalories per square meter for water hyacinth. These high values are due primarily to the large weight of biomass produced per unit area by these two species. For other types of residues such as sugar cane, cassava, bean, tobacco, rice straw, tomato, chili, and corn, the heat energy produced ranged between 5 and 18 megacalories per meter square. These lower values were due to the fact that the average production of residue ranged from 1 to 4½ kilograms per square meter.

For wood samples the average moisture content for fuelwood which has been collected and stored is 14% whereas the average moisture content for recently cut wood is 46%. The distribution of results was normally distributed about these two means for the samples collected. The average calorific value for dried wood* was 4250 kilocalories per kilogram. The variance of the measurements for different samples was relatively small with a coefficient of variation of .11 for all samples of wood analyzed. However measurements ranged from as low as 3500 to as high as 5900 kilocalories per kilogram. It is likely that these extremes are due to measurement error. Despite the relative accuracy of the equipment used in measuring energy content, human error was thought to produce a reliability of only plus or minus 5%. The heat content varied with species. Particularly high values were recorded for dipterocarpus alatus, roxb. and melaleuca leucadendron, linn. Species alone does not explain the variation as was revealed for the three species in which two samples were analyzed. The differences between the low and high measurements of calorific value for these species ranged from a minimum of 5% to a maximum of 25%.

For charcoal the average moisture content was 8% on a wet basis. The standard deviation was 5½% and the results were distributed in log normal form. The average calorific value per kilogram of dried charcoal was 6350 kilocalories with a coefficient of variation of only 10% and a normal distribution around the mean. It was not possible from the data collected to explain the causes of this variation although it was thought to be due to varying degrees of pyrolysis.

5.3 Future Research

The implications for future research are clear. If more reliable data is required then better equipped and trained personnel must be used to collect data on a smaller scale. Whereas the baseline survey sought to identify regional and village differences in the quantity of biomass produced and energy content of this biomass, the biomass assessment component should concentrate on looking at a few locations carefully and in-depth. A smaller sample size should be compensated for by more careful measurement and by closer investigation into factors which determine the production level of the biomass. Specifically research into the ratio of plant weight to crop weight, F_1, the fraction of plant weight left in the field, F_2, the deterioration of residue left in the field, F_3, and the percentage losses for collection and processing, F_4, should be undertaken.

Careful planning is needed to determine the necessary sample size for measuring each of these variables. In the baseline survey the intended sample size for animal dung would have permitted analysis of regional variation but the realized sample was too small to perform this analysis. The factor F_1 will vary with different varieties of the same crop and the sample size should take into account major varieties. Also soils and weather may be important. The larger the sample size, the more geographical factors that can be analyzed. In terms of cost effectiveness, it is probably reasonable to look at two or three of the major agro-climatic zones and within these to select villages with different varieties and soil conditions. The factor F_2 may be easier to observe since survey activities during the harvest season will suffice and areas with different harvesting methods can be

*oven-dried, 0% moisture

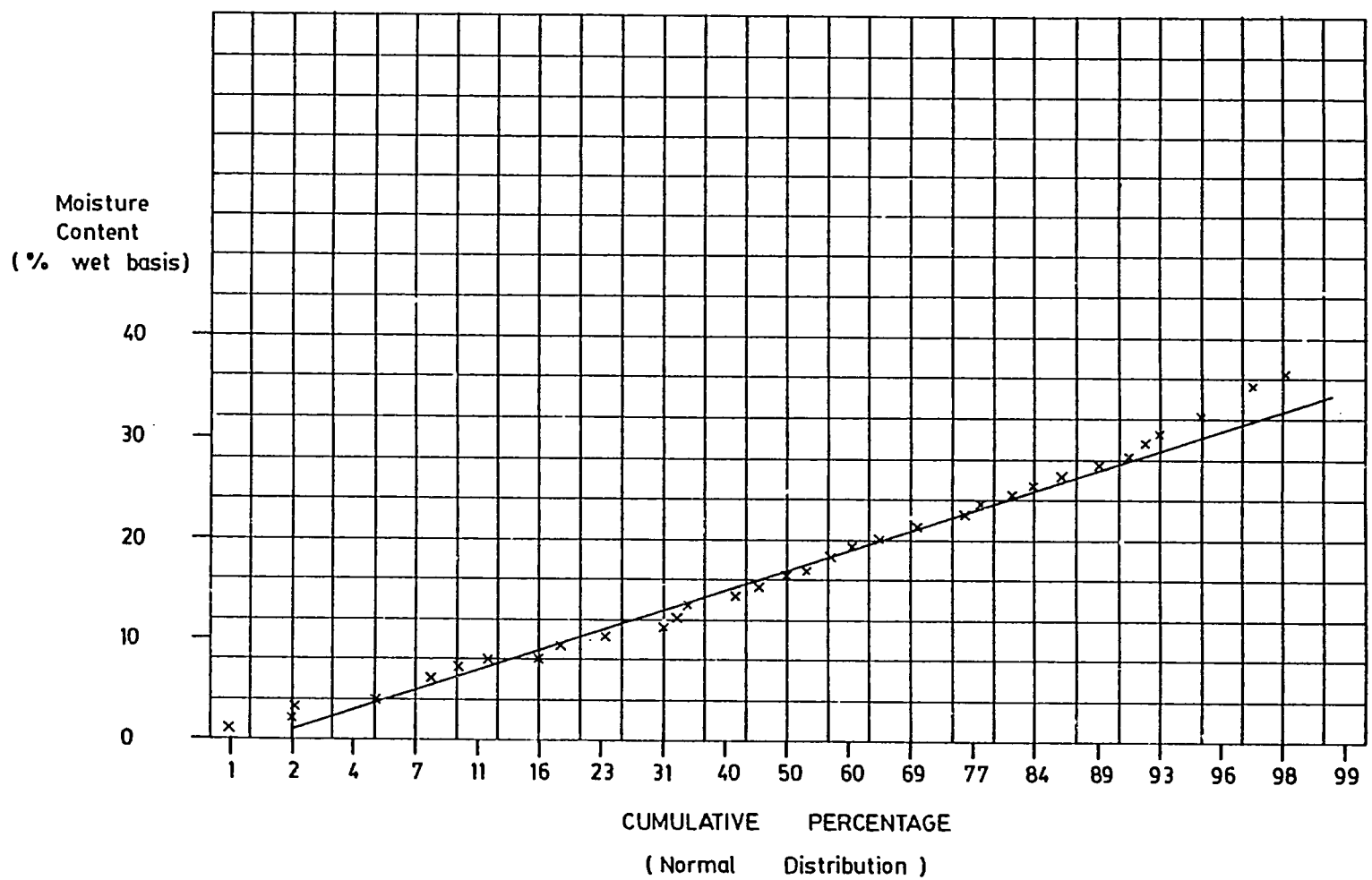
identified through discussions with agricultural agents. The sample should include areas which differ in the type of harvesting equipment and the use of the field residue. The variables F_3 and F_4 would have to be observed under more controlled conditions where researchers would take careful measurements of losses in material over time in the field and the weight ratio of input to output for collection/transport and milling activities. For the former, different sites should be sampled to allow for differences in the weather and grazing of animals following the harvest. For the latter, different collection and milling methods should be examined.

Specific recommendations for future research on the scale mentioned above should include:

1. for analysis of biomass samples
   a. sun dry the biomass samples after initial weighing
   b. minimize the time between collection and lab testing of the samples
   c. weighings equipment in the field should have an accuracy of $\pm$.5% within the sample weight range
   d. the labeling of samples must be done so as not to contaminate the sample. The label must stay with the sample through different weighing, drying, grinding and burning activities
   e. composite samples should be used for calorific tests unless specific variables are being tested which require distinct measurements of each sample
2. for analysis of animal dung
   a. one full day's production of feces from an animal should be collected and weighed
   b. information on where the animal is kept and the type of animal feed should be recorded
   c. comparisons between production of feces while penned and while grazing should be made to determine if temporary penning can be used to simplify the dung collection procedure
   d. the animal should be weighed; the age and size should be recorded as well as any health problems
   e. the spatial distribution of feces should be analyzed to determine the labor requirements for collecting the feces for use as a fuel
3. for analysis of biomass fuels including wood
   a. the average air-dried moisture content should be measured by storing the sample outside for a period of time until the sample weight does not change significantly due to drying
   b. field collection should be carefully controlled. Specific instructions should be given regarding the collection of freshly-cut, damp, dry, scavenged, or decayed samples.
   c. data on the source of each sample; the condition in which it was found and the period of drying should be recorded
   d. factors affecting the production of residues such as the size of plant at time of harvest, the method of cutting, and the alternative uses of the residues should be recorded on the sample data sheet
   e. the period of availability of these samples should be recorded indluding the time during which harvest activities are likely to occur and the rate of deterioration of the residue left behind
   f. the nutrient value of the sample should be analyzed for residues which are normally left in the field, burnt or turned under

FIGURE A1

BIOMASS RESIDUE - MOISTURE CONTENT



Note: Graph structured so that a normal distribution will produce a straight-line plot.

FIGURE A2

FRESH BIOMASS - MOISTURE CONTENT

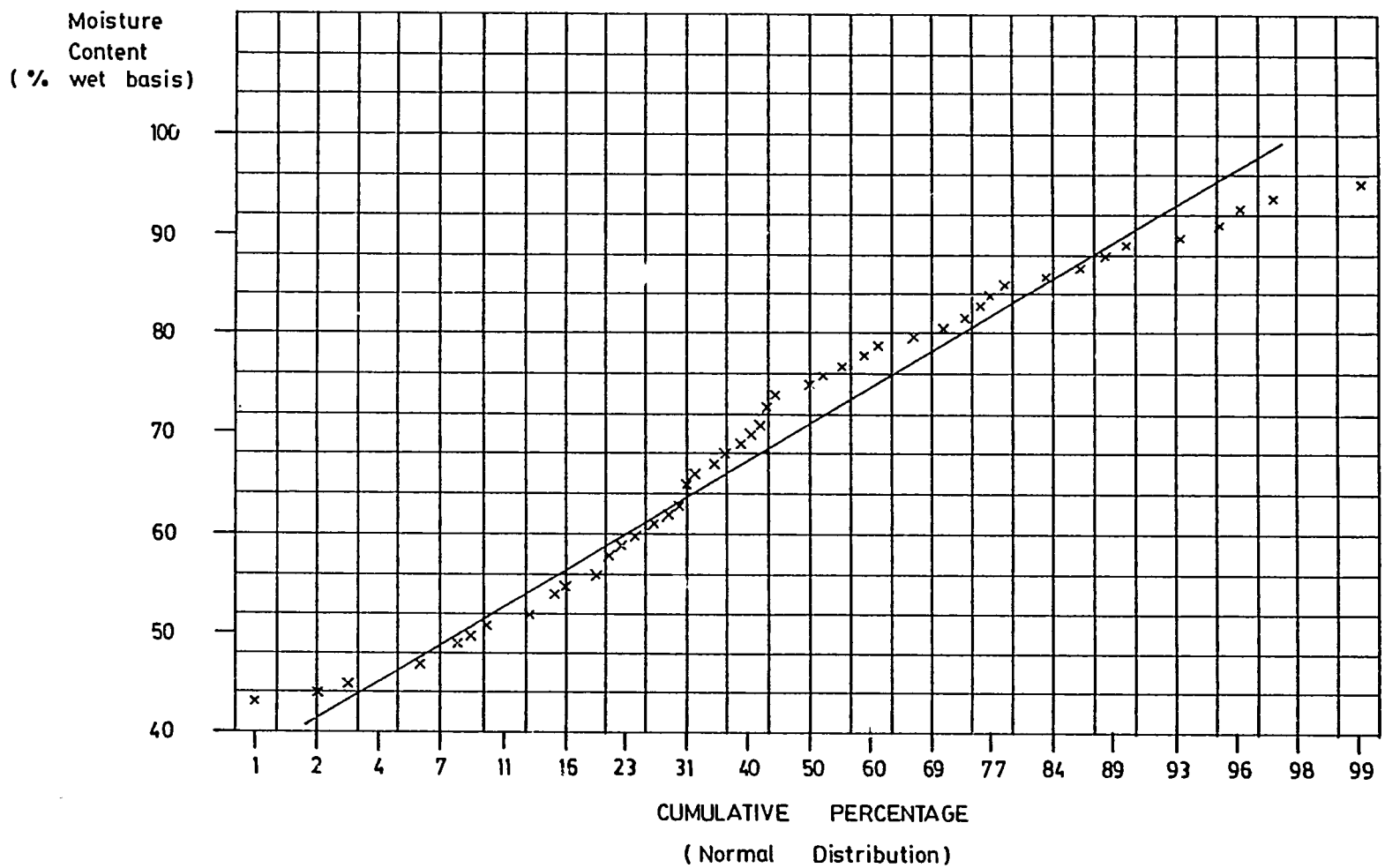


FIGURE A3

FUEL WOOD - MOISTURE CONTENT

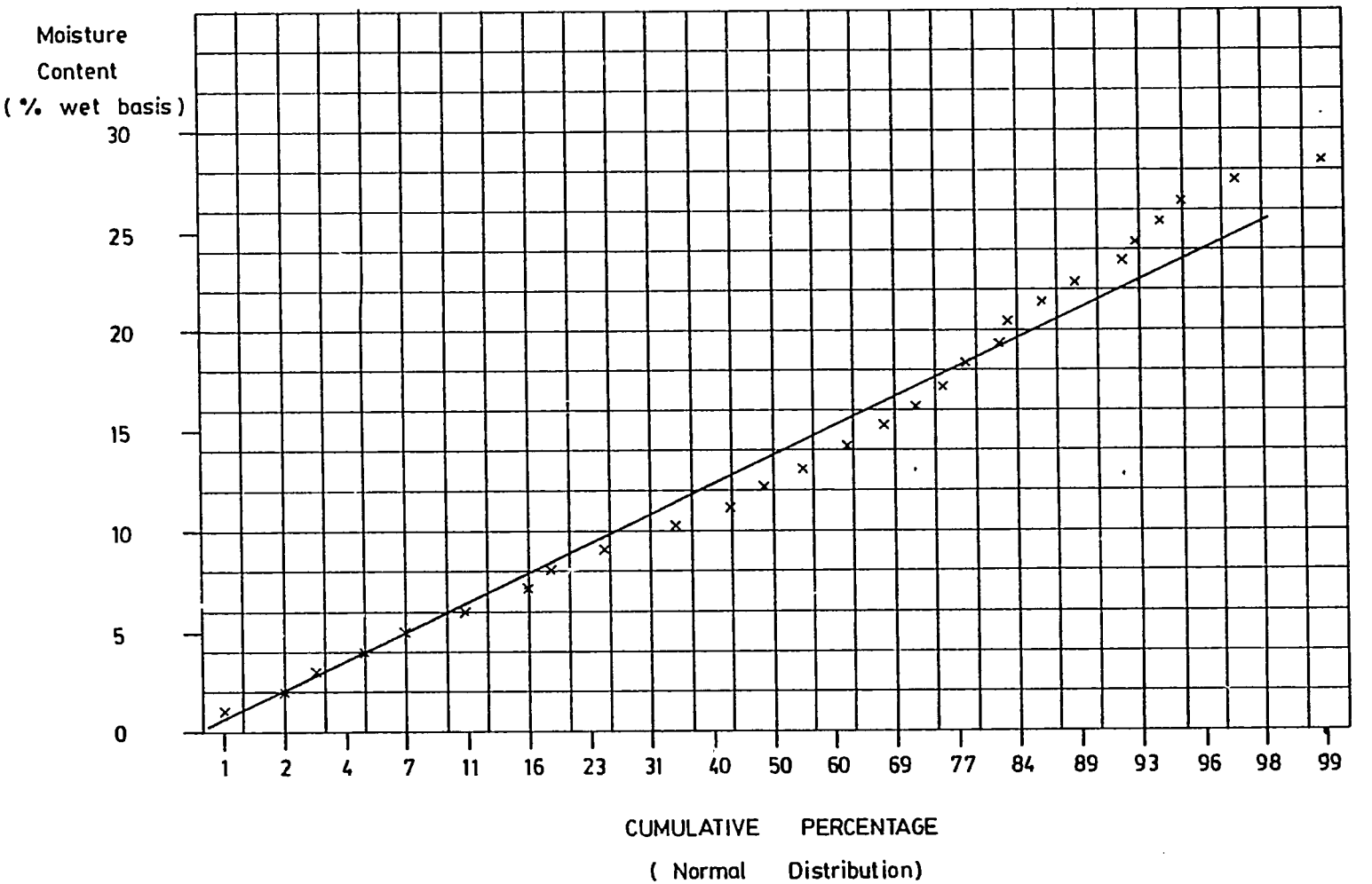


FIGURE A4

OTHER WOOD - MOISTURE CONTENT

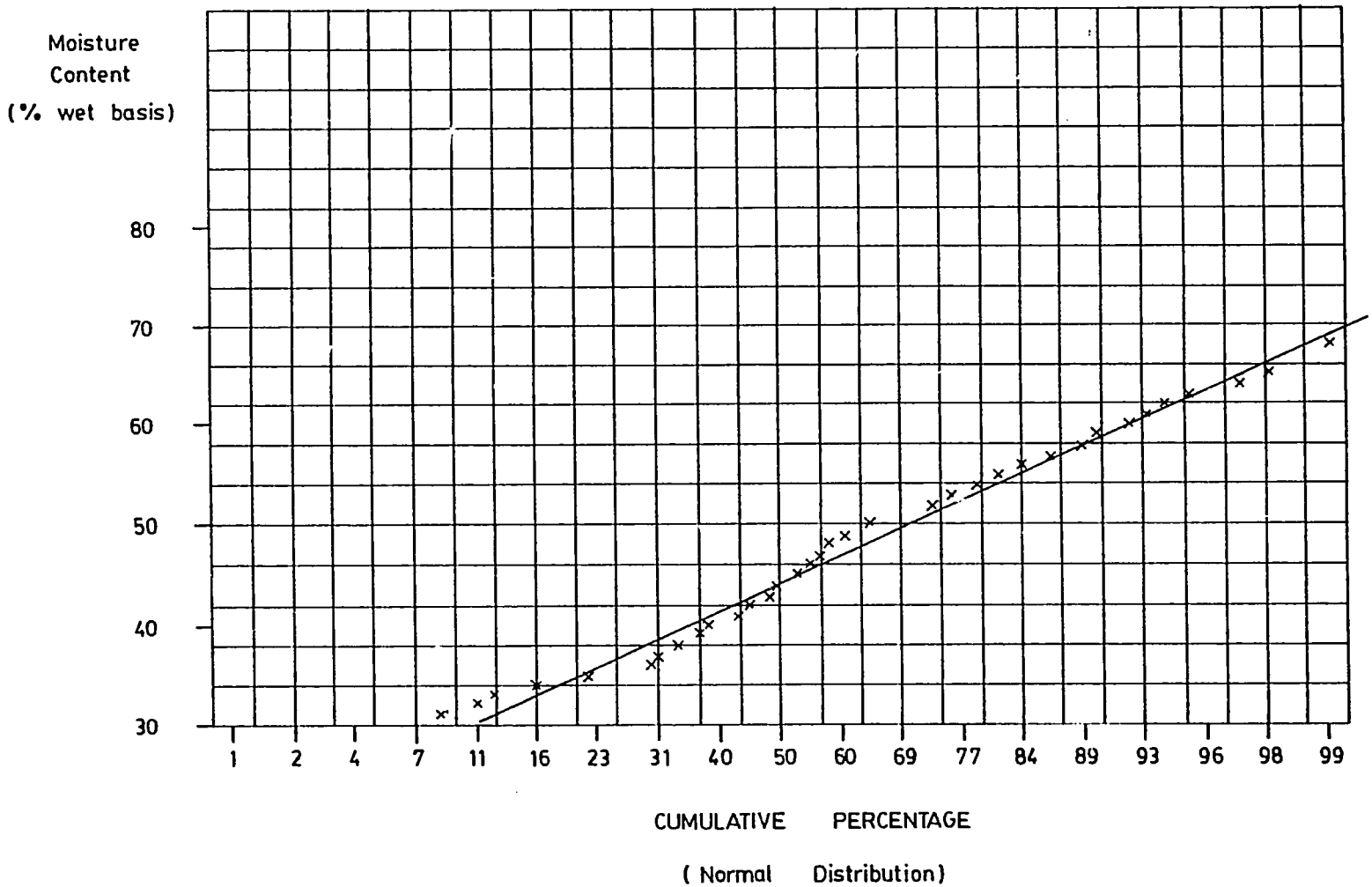


FIGURE A5

FUELWOOD – ENERGY CONTENT

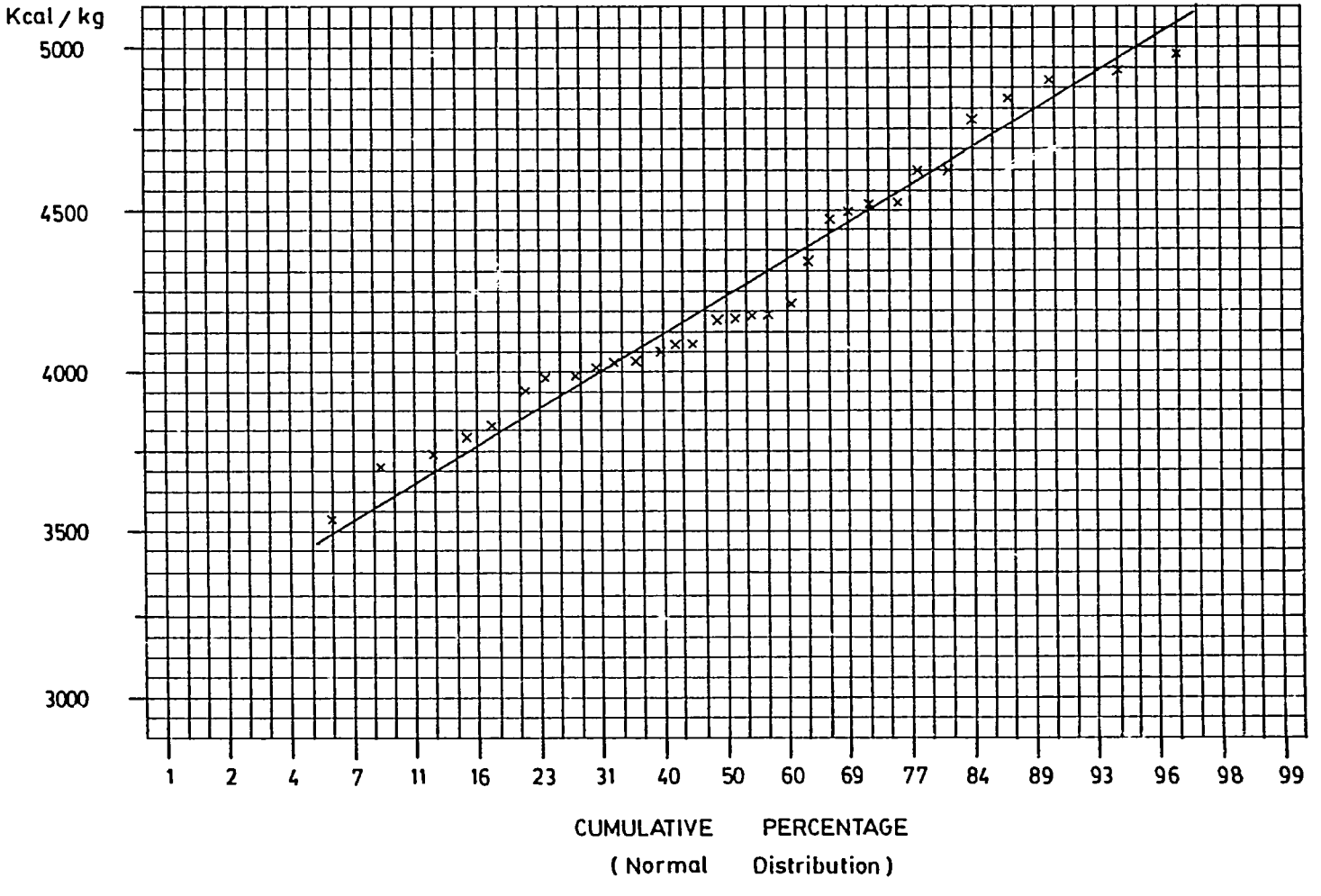


FIGURE A6

CHARCOAL - MOISTURE CONTENT

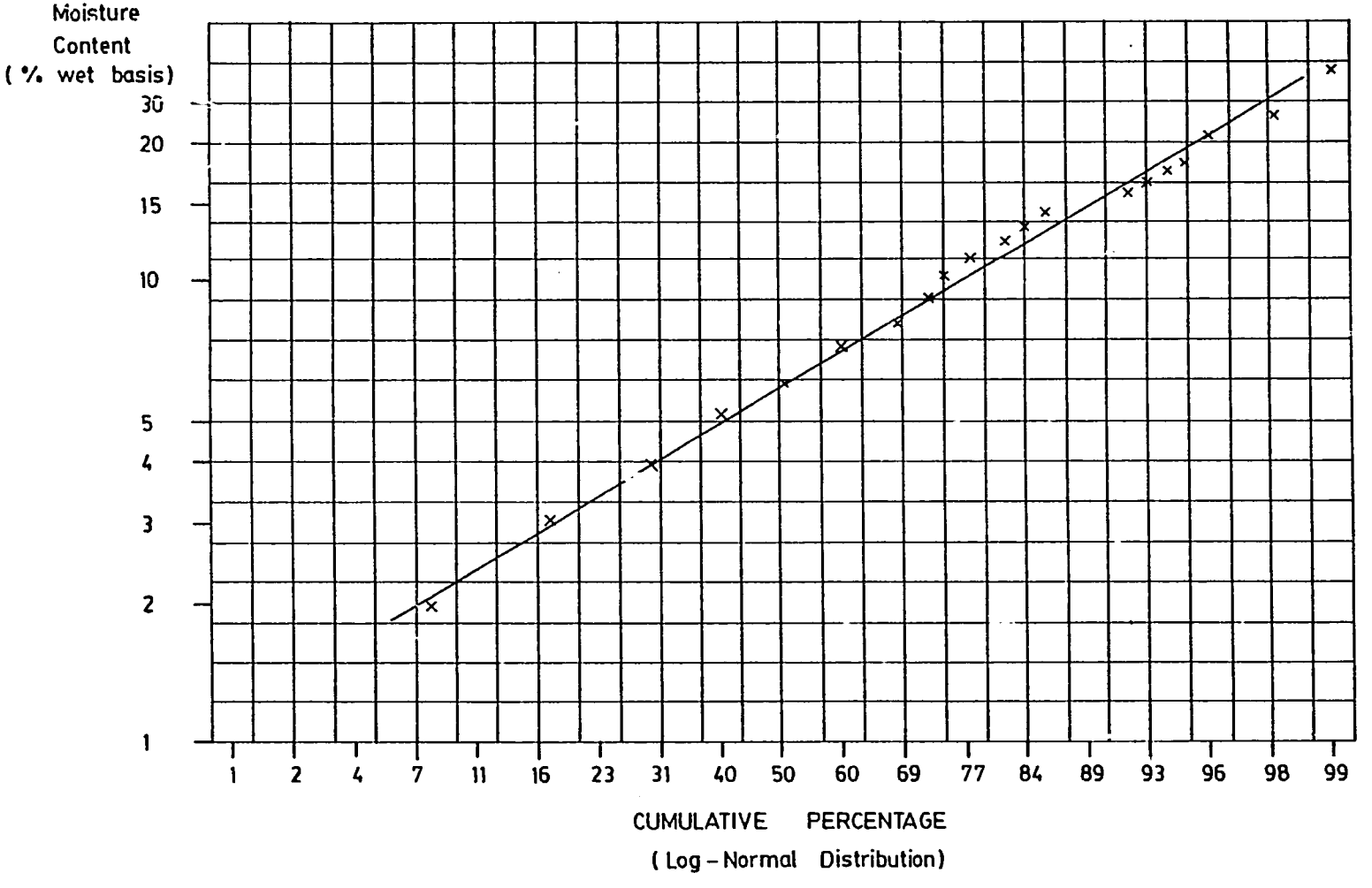
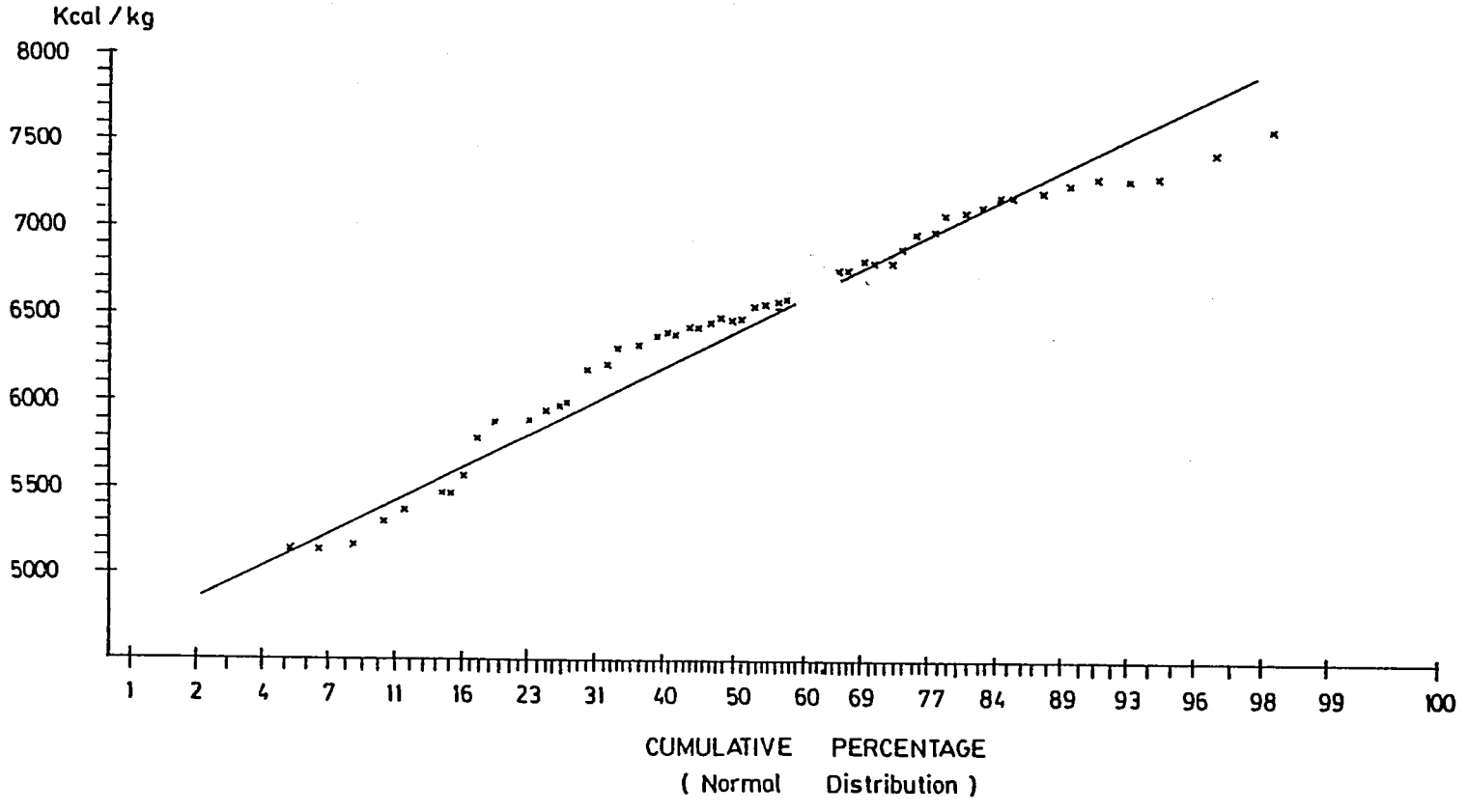


FIGURE A7

CHARCOAL - ENERGY CONTENT



A.2 Heat Value for Thailand Species of Wood

Thailand Department of Science +

Species	Kcal/kg.
Acacia siamensis	4792
Anisoptera curtisii, Dyer	5101
Sandoricum indicum, Carr	4911
Holbptelea integrifolia, Planch	4616
Dalbergia lakhonensis	4484
Anthocephalus cadamba, Miq	4673
Hydnocarpus ilicifolius, King	4641
Nauclea orientalis, Linn	4794
Dipterocarpus obtusifolius, Teysm	5132
Atalantia monophylla, Dc.	4661
Polyalthia & Mitrephora spp.	5594
Adina cordifolia Hk.F.	5030
Walsura trichostemon, Miq.	4558
Eragrostis pilosus, Beauv	4346
Homalium tomentosum	4938
padbruggea pubescens, Craib	4502
Vitex glabrata R.Br.	4530
Parashorea stellata, Kurz	4853
Cassia sianea, Lamk.	4441
Zollingeria dongnaiensis, Pierre	4543
Dialium cochinohinense, Pierre	4374
Cynometra bijuga, Span.	4560
Jacaranda mimosifolia, D.Don exot	4594
Stereospermum chelonoides A.DC.	4504
Shorea sericeiflora, Fisch & Hutch	5269
Shorea sp.	4685
Shorea sericeiflora, Fisch & Hutch	4407
Carallia brachiata, Merr.	4737
-	4586
Barringtonia macrostachya, Kurz	4511

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Species	Kcal/kg.
Grewia microcos, Linn	4590
Zizyphus jujuba, Lamk	4718
Dalbergia cochinchinensis, Pierre	5112
Ficus religiosa, Linn	5051
Adenaanthera pavonina, Linn	5191
Dipterocarpus tuberculatus, Roxb	4859
Schima wallichii, Korth	4646
Dyospyros mollis, Griff.	5205
-	5855
Artcarpus lakoocha, Roxb	5206
Afzelia xylocarpa	4716
Canarium Kcrrii, Craib	4434
Bonon burmanica, Griff.	4906
Baccaurea sapida, Hucll, Aro.	4674
Cmelina arborea, Roxb	5413
Camellia connata, Craib	4639
Dipterocarpus alatus, Roxb	4810
Dipterocarpus gracillis, BL.	4746
Morinda coreia, Ham.	4509
T.Terminalia tomentosa, W. & A.	4063
Pentaeme suavis A.DC.var Smith	4677
Intsia bakari, Prain.	4590
-	4530
Nephlium litchi, Comb.	4842
-	4999
Buchanania siamensis, Miq.	4760
Combretum quadrangulare, Kurz	4937
Azairachta indica, A.Juss.var	5046
Phoebe paniculata	5346
Terminalia citrina	4170
Tectona grandis, Linn.	5094
Vatica wallichii, Dyer.	4406
Melaleuca Leucadendron, Linn.	5378

Species	Kcal/kg.
-	4611
-	4170
Padbruggea atropurpurea, Craib	4749
ST. Syzygium spp. (red-barked)	4849
Hopea odorata, Roxb.	4913
Hopea ferrea, Pierre	5001
Anogeissus acuminata, Wall.,	5027
Lagerstroemia spp.	4556
Lagerstroemia floribunda, Jack	4664
Dipterocarpus obtusifolius, Teysm.	4861
ST. Aporosa villosa, Baill	4602
Protium serratum, Engl.	4574
Calophyllum floribundum, Hook.f.	4684
Shorea obtusa, Wall	4960
-	4782
Shorea conchinchincnsis	5472
Pseudodracontium anomalum, H.E.Br.	4545
Cratoxylon formosus, Dyer	4178
Fagraca fra runo, Roxb	4791
-	4430
Mallotus plilippinensis, Nucll, Ar.	4798
Litsea grandis, Hk.f.	4779
Vitex pinnata, Linn	5117
-	4585
Mesua forrea, Linn	4981
Calycopteris floribunda, Lank	4683
Pterrocarpus, macrocarpus, Kurs	5022
-	4549
-	4348
Lumnitzora littorea, Voigt	5532
Psidium guajava, Linn	4813
Shorea talura, Roxb	5339
Syzygium cumini, Merr & Perry	4794

Species	Kcal/kg.
-	5047
Melaleuca leucadendron, Linn.	4474
Syzygium gratum, Merr 7 Perry Var	4784
Cassia garrettiana, Craib	4418
Casuarina eguisetifolia, Blume.	4987
Chaetocarpus castanopsis	4886
Poincina regia, Rafin.	4492
Knema sphaerula, Airy Shaw	4880
-	4810
Dialium cochinchinense, Pierre.	4622
Syzygium thumra, Merr. & Perry.	4717
Dipterocarpus abtusifolius, Teysm.	4768
Syzygium ripicolum, Merr & Perry.	4647
-	4787
Hymenodictyon excelsum, Wall.	4727
Mayodendron igneum, Kurz.	4497
Neolitsea zeylanica, Merr.	6317

A.3 Note on Heat Value Measurements

The variation in heat value measurements within this report and between this report and others has several possible explanations. The bomb calorimeter tests were conducted at two facilities, only one of which has a desiccator (storage unit with a partial vacuum). The samples were stored in cans following drying and grinding for between one and ten days before being placed in the bomb calorimeter. The possibility that the moisture content of the dried sample increased prior to being placed in the bomb calorimeter was explored by weighing some dried composite samples which were not stored in a desiccator. Despite the high humidity and the high surface-to-volume ratio of the samples, the increase in moisture content was only 3-1/2% for wood and 2-1/4% for charcoal as shown below.

Experiment	Material*	Period (days)	Weight increase (percent)
1	Wood	1	1.4
2		2	3.1
3		3	3.8
4		4	3.2
5		5	3.3
6	Charcoal	1	2.2
7		2	1.5
8		3	2.0
9		4	2.3
10		5	2.8

* biomass was always placed in desiccator

More significant sources of error arise from the procedure for selecting the sample. For the survey a large percentage of the wood samples were collected from stacked firewood. This was primarily deadwood which has less resin and combustible carbon per unit weight than greenwood due to chemical degradation. These samples were frequently branches which included bark and sapwood as well as hardwood. The type of samples used in other reports is not indicated, but it is likely that they were recently cut pieces of hardwood. This selection procedure could easily explain a 5 to 10% difference.

A final source of error is the testing procedure itself. Multiple handlings and weighings reduce accuracy. Two tests were run for each sample. The average value was used since the two tests would generally produce results differing by 1 or more percent.