Development of Mathematical Models for Estimation of the Quantity of Biomass Residues

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Abstract

Biomass residues derived from agricultural and forest-based operations and processes in Kenya have been increasing rapidly over the years without effective interventions for their efficient and economic utilization, leading to environmental and human health and safety problems. This is due to limited and unreliable documented data on the quantity of various biomass residues as well as lack of a common methodology for estimating the recoverable quantities. In this paper linear regression models of the form $Y = b_0 + b_1X$ *were developed for estimation of bagasse and sawdust residues using computer-based conceptual models. The models were statistically tested for their suitability in application using 95% confidence limits. The residue indices of bagasse and sawdust were found to be 0.364 and 0.528 respectively at 0.996 and 0.857 coefficient of determination,*(R^2) *respectively. Currently there are enormous quantities of bagasse in Kenya of about 1.6 million tones annually with a potential of 2.6 million tonnes compared to between 800,000* m^3 *and 1.3 million* m^3 *of sawdust. Although bagasse contribute almost 95 % of the total amount of residue generated, only 25% is economically utilised, leaving the bulk of it unexploited. Bagasse had enormous potential for utilization in modern commercial applications. In conclusion, regression models were found to be useful in estimation of biomass residues and since these residues are available in enormous quantities, they are recommended for use in various industrial applications.*

Introduction

Kenya is basically an agro-based economy with agricultural operations and processes contributing over 80 % of Gross Domestic Product (GDP). The country generates enormous quantities of agricultural, agri-industrial and forest wastes and residues with huge potential for exploitation due to (a) rising fossil fuel prices (b) availability in relatively high abundance at almost zero cost (c) national and global environmental concerns (GoK, 2002).

On-farm and factory crop residues constitute the highest proportion of biomass wastes. They consist of woody residues such as corn cobs, millet stalks, jute sticks and cotton straws; crop straws such as rice, wheat and barley; green crop residues such as tops of root crops; and crop processing or factory processing residues such as coconut, rice and coffee husks, sugarcane bagasse, groundnut, coconut and macadamia shells and maize residues like cobs, stovers and parchment (Massaquoi, 1990).

Forestry operations also contribute to residues and wastes which include whole trees and remaining tree portions after logging activities; mill residues including bark, sawdust, edging and trimmings as well as pulp chips and planer mill shavings; other sources are dead wood and urban wood wastes. In Kenya major crop residues are bagasse, coffee husks, macadamia shells and sawdust. Some of the residues are used to a limited extent in boilers to generate process heat. The bulk of these residues are considered an environmental hazard and are generally disposed at the roadsides and dumpsites within the factories.

The amount of agricultural residue produced is directly related to the total crop yield by a factor called residue index, which is the quantity of residue generated per unit weight of crop yield (Bisanda, 1999). The residues associated with sugarcane and coffee (dry process) are bagasse and husks respectively.

Accurate estimation of forestry residues rely on data on total standing biomass, mean annual increment, plantation density, thinning and pruning practices, and current utilisation options. Woods and Hall (1994) have estimated the recoverable residues from forests to have an energy potential of about 35 Exajoules (EJ) per year worldwide.

Optimum and efficient commercial utilization of these residues is constraint by inadequate information on the raw material base. There is also lack of common methodology for estimating the recoverable quantities. This situation requires research to build database on the raw material supply, and their viability for utilization in various modern applications. Mathematical models developed based on the quantity of crop and its corresponding quantity of residues could assist in estimation of quantities of biomass residues.

The objectives of this study were:

1. To carry out data collection and analysis on sugarcane bagasse and sawdust by determining the total area under cane and forest resource production
2. To determine crop yields based on total area under these crops as sources of these residues
3. To develop mathematical models to be used for estimating residues using actual biomass yields and quantities of residues

Methodology

Data for this study was collected from seven sugarcane milling factories in Western Kenya and fifteen sawmilling industries comprising five each from small, medium and large scale categories. Data on current and potential area under sugarcane production and its corresponding quantity of cane produced annually was collected from annual reports prepared by field agricultural offices. Data on the total area under cane and the quantity of cane produced was used to compute the average cane yield in tonnes per hectare. The average cane yield is useful in projecting the quantity of bagasse as a residue since the quantity of the cane within an area is an important parameter in estimating the quantity of bagasse. The formula used was:

$$\text{Average cane yield (t/ha)} = \frac{\text{Quantity of cane produced (t)}}{\text{Total area under cane production (ha)}}$$

Data was also collected on the quantity of the cane milled in the factories annually and their corresponding mill residue indices over a period of 10 years between 1994 and 2004. This data was used in computing the average quantity of the factory bagasse produced annually. The quantity of cane processed and the quantity of bagasse were then used to develop a mathematical model for the estimation of bagasse. The formula used to estimate the quantity of bagasse was:

$$\text{Quantity of bagasse (t)} = \text{Quantity of cane milled (t)} \times \text{Mill residue index (\%)}$$

The classification and selection of the sawmills was based on their annual conversion capacity and their national distribution. Large scale sawmills converted over 5,000 m^3 of roundwood into sawnwood annually while medium and small scale sawmills converted upto 5000 m^3 and 2000 m^3 annually respectively.

Secondary data on logs processed and sawnwood volumes obtained were collected from the selected sawmills. This information was useful in determining the sawntimber yield and the sawmilling residue index. Data was recorded in data sheets indicating name of sawmill, its category, district and number of logs considered.

Data on log and sawnwood dimensions were used to compute log and sawnwood volumes and sawnwood yield. The following formula was used to compute sawn timber yield:

$$\text{Sawn timber yield (\%)} = \frac{\text{Volume of sawn timber, } m^3 \times 100}{\text{Volume of logs, } m^3}$$

where

- Volume of sawn timber (m^3) was calculated as a product of width, breadth and length and number of pieces for each size
- Log volume was calculated using the formula:

Log volume (m^3) = $\pi(D/2)^2L$, where

- D is the average log diameter
- L is the average log length
- π is a constant, 3.14

Sawmill residues were calculated as the difference between 100 % and the sawn timber yield such that *(100 – Recovery Rate) = Sawmill residue, % (residue index, %)*. The sawmill residue indices were used to compute mill residues as a product of log volume and residue index, such that:

$$\text{Log residues } (m^3) = \text{Log volume } (m^3) \times \text{residue index } (\%)$$

The independent variables were quantity of cane and log volumes and the dependent variables were bagasse and log residues. These quantitative variables were used to develop mathematical models based on regression analysis to estimate the factory residues and also to determine their confidence intervals and statistically test the models for their effectiveness in application (Clarke and Cooke, 1992; Ott, 1984).

Data analysis and interpretation

Data collected from sugar factories and sawmills was analysed using MS Excel 2000 statistical package to give summarised properties (arithmetic mean, standard deviation, minimum and maximum values). Linear regression models were derived to estimate quantitative variables. The main variables were the average quantity of crop processed in the factories and mills over a period of 10 years and their corresponding quantity of factory crop residue produced as independent and dependent variables respectively.

The linear regression model used was based on regression analysis of the form:

$$\mathbf{y = \beta_o + \beta_1 X + \xi}$$

where

β_o and β_1 are coefficients of the equation. If the model was of the best-fit regression line it becomes:

$$\mathbf{Y = b_o + b_1 X}$$

where

b_o and b_1 are sample-based estimators of β_o and β_1 respectively. The assumptions associated with this regression model are:

- Y and X are random variables, such that neither of them contain common element in additive, multiplicative or divisional form
- The error component, ξ, must have mean zero and homogenous variance. The variance of the error term must be independent of the variable (Haan, 1977; Jakeman, *et al*, 1993).

Confidence intervals for β_o and β_1 were specified using the formula, *estimate $\pm$ t standard error* which are expressed as follows:

$$\beta_o \pm t_{\alpha/2}\, s_\xi \sqrt{((\sum x^2)/ns_{xx})}$$

and

$$\beta_1 \pm t_{\alpha/2}\, (s_\xi / \sqrt{s_{xx}}); \quad \text{where } s_{xx} = \sum x^2 - (\sum x^2) / n,$$

$t_{\alpha/2} = t_{.025}$, s_ξ is standard error and degree of freedom (df) = n-2

The statistical tests for intercept β_o and slope β_1 used a t statistic (T.S.) of the form *t = estimate / standard error* alongside three hypotheses with their corresponding rejection regions (R.R.) shown below (Ott, 1984):

Intercept β_o	Slope β_1
Ho: $\beta_o = 0$	Same as those
Ha: 1. $\beta_o > 0$	for β_o
Ha: 2. $\beta_o < 0$	
Ha: 3. $\beta_o \neq 0$	
T.S.: $t = \beta_o / (s_\xi \sqrt{((\sum x^2)/ns_{xx})}$	T.S.: $t = \beta_1 / (s_\xi / \sqrt{s_{xx}})$

R.R.: For a given value of α and df = n – 2 R.R: Same as those shown for β_o

1. Reject Ho if $t \geq t_{\alpha}$
2. Reject Ho if $t \leq -t_{\alpha}$
3. Reject Ho if absolute $t \geq t_{\alpha/2}$

These statistical procedures were used in determining confidence intervals and statistically testing the models developed for estimating the quantity of bagasse and sawmilling residues.

Results and Discussion

Cane and timber production as measures of their residues

Cane production

The current crushing capacity of the sugar industry in Kenya was 22,000 tonnes of cane per day, which was about 6.5 million metric tonnes of cane annually. But based on data analysed over a period of 10 years between 1994 and 2004, the quantity of sugarcane crushed annually was about 4.2 million metric tonnes, which is about 35 % less than the capacity of the sugar factories.

Table 1 gives a summary of maximum area under cane per factory zone and their corresponding average cane yield derived from data over a time-span of 10 years between 1994 and 2003. The total area under cane production was 102,952 ha which produced 7,743,313 tonnes of cane per year. Mumias factory zone had the highest area under cane production (41,513 ha) with the highest cane production (about 4 million metric tonnes) and the highest cane yield of 87 t/ha. Muhoroni, Chemelil and Sony had almost the same acreage under cane production; they crushed about one third of the quantity of the cane crushed by Mumias factory.

Table 1. Area under cane production and average cane yield per zone

Factory Zone	Area under cane (ha)	Cane production (t)	Average cane yield (t/ha)	Crushing capacity (TCD)
Chemelil	15,397	962,620	62.52	3,000
Muhoroni	10,210	620,155	60.74	2,500
Mumias	41,513	3,612,046	87.01	8,000
Nzoia	13,884	926,340	66.72	3,000
Sony	12,654	1,075,337	84.98	3,000
Miwani	6,500	362,830	55.82	1,500
W.Kenya	2,794	183,985	65.85	1,000
Total	**102,952**	**7,743,313**	**69.09**	**22,000**

The wide variation in cane yield between factories was attributed to cane variety, soil type, land preparation and maintenance and the extent of utilisation of farm inputs particularly fertilizers. The utilisation of suitable cane varieties according to sugarcane zones, proper land preparation and maintenance and efficient and optimum use of farm inputs increased cane supply to factories for crushing. The quantity of cane crushed was directly proportional to the quantity of by-products generated. It was expected that large quantities of bagasse was produced with increased quantities of cane crushed.

Timber production

Table 2 gives a projection of timber supply for the sawmilling industry in Kenya from various types of land uses such as indigenous forests, woodlands and bushlands, farmlands and settlements and forest plantations. The total timber supply between 1995 and 2020 was computed on the basis of the total area under each wood-related land use, the proportion of timber and timber density for each land-use (KFMP, 1994).

Table 2. Accessible sustainable timber supply (000 m^3)

Land use	1995	2000	2005	2010	2015	2020
Indigenous Forest	518	511	509	509	509	509
Woodlands and bushlands	119	126	130	134	138	142
Farmlands and settlements	956	1335	1720	2111	2504	2900
Forest plantations	1,590	1,950	1,802	2,130	2,434	2,861
Total	**3,185**	**3,922**	**4,161**	**4,884**	**5,585**	**6,412**

Timber supply from government managed forest plantations (excluding supplies from private plantations) and farmlands and settlements continue to be the main source of timber in Kenya. The supply from farmlands and settlements increased rapidly from 956, 000 m^3 in 1995 to 1,720,000 m^3 in 2005 and is expected to reach 2,900,000 m^3 in 2020. Supply from these sources was projected to surpass that from forest plantations by the year 2020. The supply from indigenous forests was projected to decrease at a minimal rate from 518,000 m^3 in 1995 to 509,000 m^3 in 2005 and remain constant until 2020. Woodlands and bushlands also increased gradually from 119,000 m^3 in 1995 to 142,000 m^3 by 2020.

The total timber supply was expected to increase gradually from 3.2 million m^3 in 1995 to about 5.0 million m^3 by 2010 then rapidly to over 6.0 million m^3 by 2020 (fig 1). This implies that accessible and sustainable supply of timber would increase by about 50% between 1995 and 2010 and by about 100% between 1995 and 2020. The highest proportion of the timber supplied would be consumed locally, generating enormous quantities of sawmilling wastes and residues.

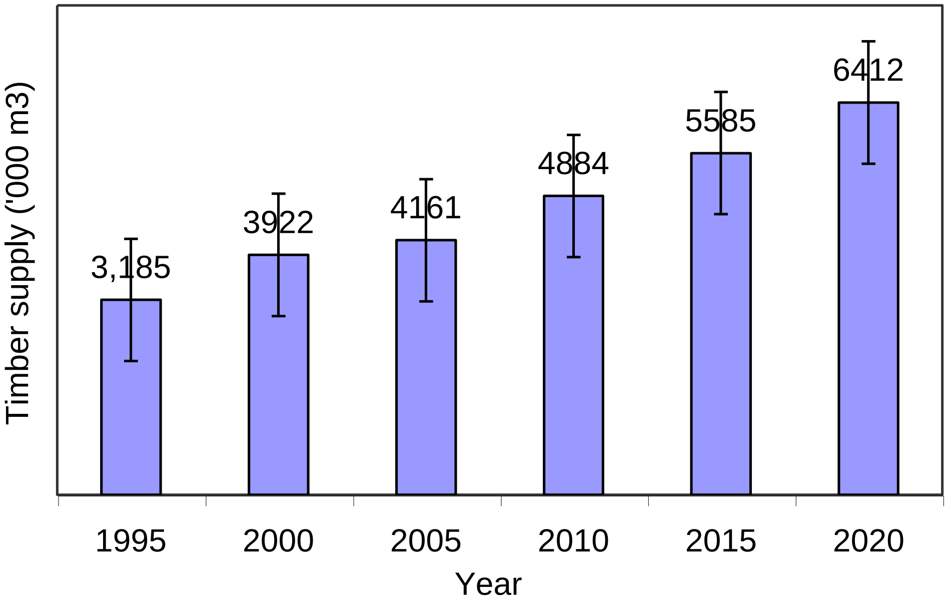

Fig.1. Projected timber supply (KFMP, 1994)

Quantity of bagasse and timber residues

Quantity of bagasse

Table 2 gives 10-year average quantities of cane milled and bagasse generated as well as the proportion of bagasse economically utilised annually per factory between 1994 and 2004. Mumias factory milled the highest average amount of cane delivered, which was almost 2 million tonnes annually compared with about 1.5 million tonnes annually crushed by Chemelil, Nzoia and Sony factories altogether.

Muhoroni factory, although with a milling capacity as high as those of Chemelil, Nzoia and Sony, milled only one half of its capacity during the same period of about 300,000 tonnes annually. Miwani and West Kenya milled the least amount of cane delivered.

The amount of bagasse produced by each factory was proportional to the amount of cane milled. Mumias generated the highest amount of bagasse which was about 700,000 tonnes per year while Chemelil, Nzoia and Sony each generated about 200,000 tonnes of bagasse annually. This was almost three times the quantity of bagasse produced by Mumias factory alone, which used diffuser technology whose sugar extraction was higher than the rest. This quantity was expected to be much higher if the factories were operating at their installed capacities, with a potential of milling 7.7 million tones of cane annually, generating 3.02 million tones of bagasse. However, the current quantity compared closely with that estimated in 1999 by the World Energy Council (WEC, 2000) of 1.7 million tonnes per year.

The amount of bagasse that was economically utilised varied between factories as shown in Table 3. Mumias, Nzoia and Sony economically utilised the highest amount of the total produced while the rest utilised less than 10 % of the bagasse that they generated annually. Most of this was used in boilers to generate process heat and small quantities were sold to nearby agro-chemical industries as sources of heat. The average proportion of bagasse utilised efficiently by all the factories was found to be about 9.6 % which was equivalent to approximately 200,000 tonnes.

Therefore over 90 % of bagasse generated in Kenya was not utilised for any economic purposes. Most of this was transported and dumped within the factories, in the process incurring high transportation costs, loss of several man-hours per year besides posing serious environmental and occupational health and safety hazards through spontaneous incidences of factory fires. The bagasse which do not biodegrade easily emitted pungent foul smell and also formed huge artificial hills.

Table 3. Average cane milled and bagasse generated between 1994-2004

Factory	Cane milled (‘000 t/yr)	Bagasse (‘000 t/y)	Bagasse % cane	Economically utilised, %
Chemelil	596	229	38.5	8.0(18.3)*
Muhoroni	266	113	42.4	6.5(7.3)
Mumias	1,996	735	36.8	15.4(113.2)
Nzoia	446	176	39.5	10.5(18.5)
Sony	498	193	38.8	10.6(20.5)
Miwani	187	77	41.4	8.5(6.6)
W.Kenya	184	70	37.9	8.0(5.6)
Total	**4,173**	**1,593**	**39.3**	**9.6(189.9)**

*Quantity of bagasse (‘000 tons) annually utilised

Sawmilling residues generated

There were about 450 sawmills in Kenya in 1994 with 15 of them categorized as large scale. They accounted for over one-half of the total annual sawnwood output. The majority of the sawmills were medium and small scale whose sawnwood recovery rates ranged from about 20 % to 30 %. The average recovery rate in the country was estimated at about 37 %. This scenario has since changed significantly due to the Government ban on logging from Government plantation forests and stringent transportation regulations even for logs harvested from private farmlands and settlements. Currently, there are few sawbenches and small-scale sawmills operated using logs from privately owned farmlands. However, this situation is expected to change so that there would be sufficient logs from various types of land use following the passing of the forest policy and act (GoK, 1999).

Once the sawmilling industry in Kenya was revitalized, an estimated processing capacity of about 400,000 m^3 of sawnwood would be attained. At an average recovery rate of 40 %, it implies that the sawmilling industry would consume about 1 million m^3 of roundwood annually and consequently generate about 600,000 m^3 of sawmilling wastes annually.

Table 4 gives a summary of sawmilling wastes produced by various sawmill categories. The large-scale sawmills, with better conversion machineries and skilled manpower, had the highest sawnwood recovery rate (41.8 %) followed by medium scale (30.1 %) which were closely followed by small scale sawmills (24.2 %). This was an average sawmilling residue of 67.9 %. Medium- and small-scale sawmills had poorly equipped and unskilled logging crews using poorly serviced and maintained equipments and machines. The quantity of the sawmilling residues followed the same pattern; large-scale sawmills generated the minimum quantity of residues while the small-scale sawmills produced the highest quantity of sawmill residues.

About 5 % of the sawmilling residues produced by the sawmilling industry was economically utilised as animal bedding and in poultry rearing. This quantity was obtained mostly from sawmills that were located in commercial towns where demand was relatively high. Most sawmills situated in the rural areas simply disposed and burnt almost 100 % of their sawmilling residues in dumpsites within the sawmills. This posed serious environmental problems such as fire hazards and human health and safety risks.

Table 4. Summary of average sawmilling wastes produced by sawmill categories

Sawmill Category	Log volume (m^3)	Sawnwood volume (m^3)	Recovery rate (%)	Economically utilised residue, %
L. scale	10.820	4.583	41.8	7.2
Medium "	6.534	2.027	30.1	5.6
Small "	3.277	0.796	24.2	3.5
Average	**6.877**	**2.468**	**32.0**	**5.4**

Table 5 shows projected sawmilling residues based on accessible sustainable timber supply data in Table 2 which was adjusted with the quantity of sawmilling residues produced by the sawmill industry. In 1995, about 2.2 million m^3 of sawmilling residues was produced if the sawmilling industry was operating as usual without the Government ban on logging, increasing to about 2.8 million m^3 and 4.4 million m^3 in 2005 and 2020 respectively. This was about 100 % increase in sawmilling residues in the country, posing various environmental and health and safety challenges. This scenario was most probable due to increased population and rapid economic development in the country with proportional demand for forest-based materials for the construction industry and for joinery and furniture industry.

A projection of the quantity of the residues that was utilised economically upto 2020 is also given in table 5 in brackets. They were computed using the total sawmilling residues between 1995 and 2020 and the average percentages of the economically utilised residues given in Table 4 for each sawmill category. The projection indicated that small quantities of less than 5 % of the sawmilling residues generated were economically exploited over the same period.

Table 5. Sawmilling wastes based on accessible sustainable timber supply ('000 m^3)

Sawmill Category	1995	2000	2005	2010	2015	2020
Large scale	1853.09	2282.60	2421.70	2824.49	3425.07	3731.78
	(133.42)	(164.35)	(174.36)	(203.36)	(246.36)	(268.69)
Medium "	2225.62	2741.48	2908.54	3413.92	3903.92	4481.99
	(124.63)	(153.52)	(162.88)	(191.18)	(218.62)	(250.99)
Small "	2413.47	2972.88	3154.04	3702.07	4233.43	4860.29
	(84.47)	(104.05)	(110.39)	(129.57)	(148.17)	(170.11)
Average	**2169.06**	**2665.65**	**2828.09**	**3319.49**	**3859.14**	**4358.02**
	(117.13)	**(143.95)**	**(152.72)**	**(179.25)**	**(208.39)**	**(235.33)**

Figure 3 also shows the projected sawmilling residues generated by the three categories of sawmills between 1995 and 2020. The quantity of the residues increased with decreasing size of sawmill; small-scale sawmills produced much more residues than the medium and large scale sawmills.

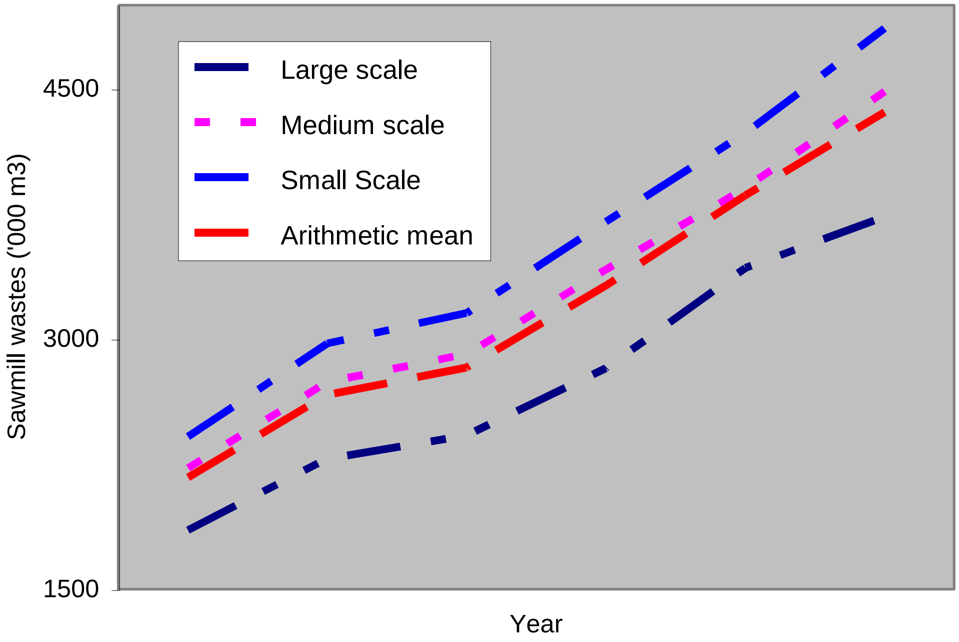

Fig. 3. Projected quantity of sawmilling wastes (1995 - 2020)

An estimate of the quantity of the sawmilling residues generated by the sawmilling industry and the proportion that was economically utilised in Kenya was computed using the current and potential number of sawmills, their conversion capacities and the sawmill residue factors of each category of sawmill (Table 6). Currently there are over 300 sawmills most of which are small scale sawbenches and mobile circular saws compared to about 450 sawmills which consisted of 15 large scale, 155 medium scale and 280 small-scale, before the Government imposed a ban on logging.

Currently, about 830,000 m^3 of sawmilling residues were produced annually mostly by small-scale sawmills compared to about 1.3 million m^3 which could be generated if the sawmilling industry was operating normally. This quantity, whose sole source of saw logs was plantation forests, was insignificant compared to 2.2 million m^3 generated in 1995 as a projection based on accessible sustainable timber supply from indigenous forests, woodlands and bushlands, farmlands and settlements and plantation forests.

Similarly, only about 4.5 % of the total amount of the current and potential sawmilling residues produced was economically utilised. This figure compared well with 5 % that was found when computing sawmilling residues economically exploited based on accessible sustainable timber supply projections of between 1995 and 2020. However, due to rapidly growing local and global interest in biomass residues coupled with environmental concerns and advances in technology, increasing quantities of these residues would be utilised for various modern applications in future.

Table 6. Current and potential sawmilling wastes and economically used proportion per year

Sawmill category	Number of sawmills		Conversion capacity, m^3	Residue per m^3	Sawmilling wastes, m^3		Economically used residues, m^3	
	Current	Potential			Current	Potential	Current	Potential
Large	8	15	10,000	0.58	46,400	87,000	3,341	6,264
Medium	65	155	5,000	0.70	227,500	542,500	12,740	30,380
Small	245	280	3,000	0.76	558,600	638,400	19,551	22,344
Totals	**318**	**450**	**18,000**		**832,500**	**1,267,900**	**35,632**	**58,988**

Model for estimation of residues and their application

Sugarcane bagasse

Fig. 2 gives a linear regression equation:

$$\mathbf{Y = 0.364X + 11.13}$$
$$\mathbf{R^2 = 0.996}$$

developed to estimate the quantity of bagasse (Y) based on random quantity of cane milled (X). The residue index from the mathematical model of 0.364 compared well with the average residue index of 0.39 estimated from data collected over a period of 10 years of cane milling and that reported by Bisanda (2000) of 0.33. Massaquoi (1985) reported a residue index of between 0.1 – 0.3 which implied high efficiency in sugar extraction. However, it was important to specify the confidence intervals for β_o and β_1 at 95 % confidence level and also statistically test the model to ascertain its applicability.

The model efficiency, R^2, which evaluates the performance of the model and is a measure of the strength of the relationship between bagasse (the dependent variable, Y) and cane crushed (the independent variable X) was significantly high at 0.996. This indicated that almost 100 % of the proportion of bagasse generated could be accounted for by the quantity of cane crushed. This was attributed to compaction technology used by all sugar mills except Mumias factory which uses diffuser technology.

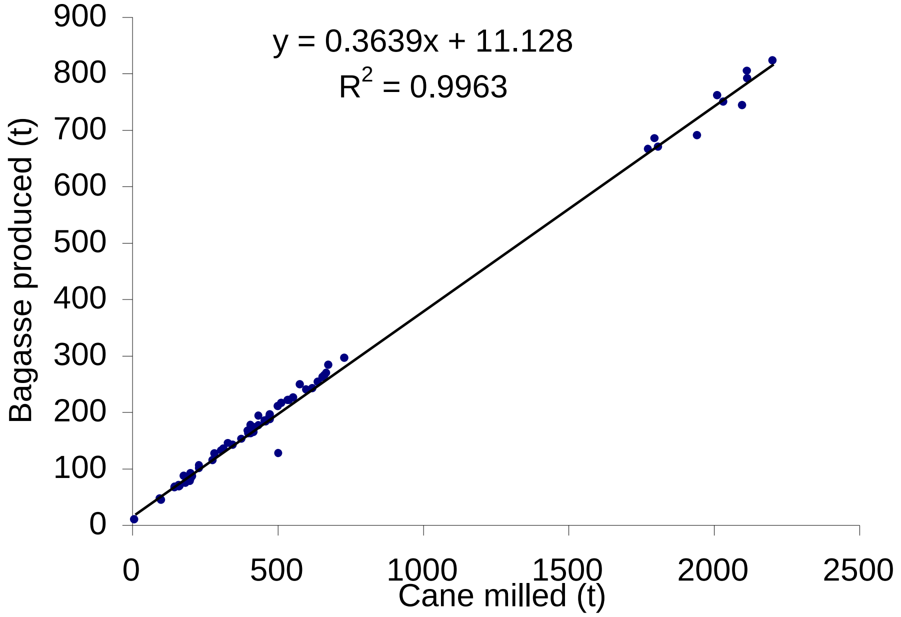

Fig. 2. Relation between cane milled and bagasse produced

The effective application of the model would depend on the confidence intervals for β_o and β_1 of the regression equation at 95 % confidence level and also statistically testing the model using β_1. These were estimated using the formula, *estimate ± standard error* whose components included regression equation, student's t-distribution for $p = 0.05$ with $df = 62$ and an estimated standard error, $S\varepsilon$ (Ott, 1984).

The true values of β_o and β_1 were found to lie within the interval:

$$6.58 \leq \beta_o \leq 15.67$$
and
$$0.36 \leq \beta_1 \leq 0.37$$

The estimated $\beta_{1,}$ which ranged between 0.36 and 0.37, was indicative of bagasse residue index.

The upper limit of 0.37 compared very well with that calculated from data obtained in the field of 0.39 and that computed by the regression equation of 0.36. The model was statistically tested and found that the X variable (quantity of cane) was very useful in predicting the Y variable (bagasse).

Sawmilling residues

The scatter graph in figure 4 gives a linear regression equation:

$$\mathbf{Y = 0.5284X + 0.0418}$$
$$\mathbf{R^2 = 0.8569}$$

that was used to estimate the amount of sawmilling residues generated in sawmills. The coefficient of determination (R^2) gives the proportion of total variability of Y values accounted for by the independent variable X while the remaining proportion ($1 - R^2$) gave total variability of Y values not accounted for by variable X. This proportion indicated a positive linear relationship between X and Y values whenever R was greater than zero (Ott, 1984; Mwambi, 1989). At 86 % coefficient of determination, the model efficiency was satisfactorily high and the regression equation was used with high degree of confidence to estimate the quantity of sawmill residues based on the volume of sawlogs.

The coefficient of X was a strong indicator of the average residue index (i.e. 0.53) for the sawmilling industry, although it varied slightly from one category of sawmill to another. Studies on appraisal and rationalisation gave a milling residue index of 0.68 (Table 4) while that given by KFMP (1994) was 0.63. The two were lower than the residue index derived from the best-fit regression equation of 0.53. The specification of the confidence limits of β_1 catered for disparities due to various other factors that were not addressed by the model.

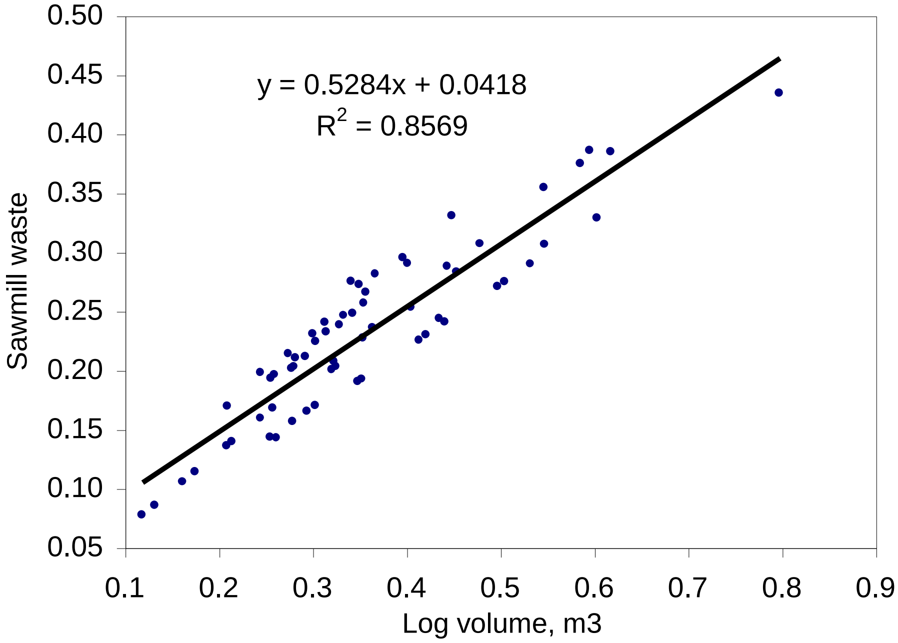

Fig.4. Relation between log volume and sawmill waste

Application of the computer-developed model depended on the confidence intervals for β_o and β_1 of the regression equation at 95 % confidence level and testing the model statistically using β_1 of the regression equation. At $p = 0.05$ and $df = 60$, the true values of β_o and β_1 lied within the intervals:

$$0.032 \leq \beta_o \leq 0.052$$

and

$$0.469 \le \beta_1 \le 0.588$$

The estimated range of β_1 represented the sawmilling residue index. The maximum value of 0.59 compared well with that reported by the KFMP (1994) of 0.63. The small differences were attributed to 14 % proportion of total variability of Y values (sawmilling wastes) unaccounted for by variable X (sawlog volumes) while 86 % of the total variability was accounted for by the independent variable X. The X variable (sawlogs) was found to be very useful in predicting the Y variable (sawlog residues).

The coefficient of determination R^2 could be increased significantly by considering other factors such as log geometry and type, size of sawmill, type of equipments and machines and the level of skills of manpower in the sawmilling industry.

Fig 5 shows the proportion of sawmilling residues computed using the applied model residue index (M_i) of 0.59 and the calculated residue index (C_i) of 0.63 obtained by KFMP (1994). Timber supply projections between 1995 and 2020 in table 2 were also used to show the relationship between the two residue indices. The sawmilling residues increased with increasing quantity of sawlog volume. However, the quantity of sawmill residues obtained using either of the residue index was approximately the same.

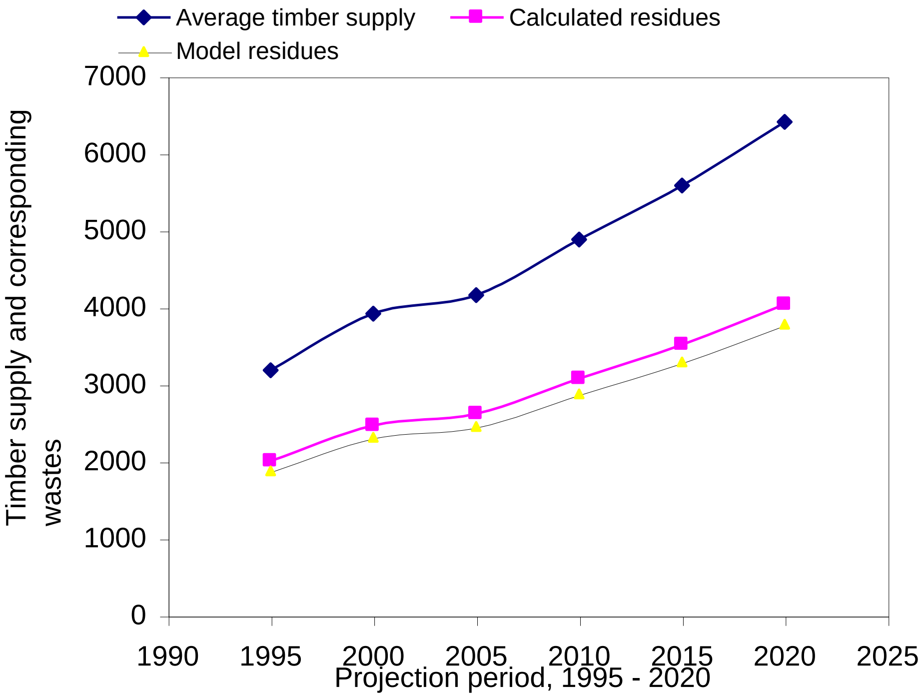

Fig. 5. Application of calculated and model residue index

Currently about 670,000 m^3 of sawmill residues were generated annually compared to 1.04 million m^3 projected if the sawmilling industry was operating normally. This is a conservative figure since wastes and residues from other wood-based industries such as construction industry and furniture and joinery industry were not estimated. However, they were very close to those figures obtained using residue indices obtained from field data.

Conclusions

1. The total area under sugarcane production was 102,952 ha producing 7,743,313 tones of cane per year. Timber production which was highest from farmlands and settlements increased from 956, 000 m^3 in 1995 to 1,720,000 m^3 in 2005 projected to reach 2,900,000 m^3 in 2020.
2. Linear regression equations $Y = 0.364X + 11.13$ ($R^2 = 0.996$) and $Y = 0.5284X + 0.0418$ ($R^2 = 0.8569$) for estimation of bagasse and sawmill residues respectively were developed

Recommendation

The linear regression equations that were developed can be used with high confidence levels for estimation of bagasse and sawmilling residues by investors to quantify raw material availability and since these residues are available in enormous quantities, they are recommended for use in various industrial applications.

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