Estimating Fruit Yield from *Vitex payos* (Lour) Merr. in Semi-arid Eastern Province of Kenya: Application of Allometric Equations

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Abstract: *Vitex payos* (Lour) Merr. is a common species in the semiarid areas of Eastern Kenya. It is a favoured species and is frequently maintained in homestead plots and arable fields in an agroforestry situation. Although, the abundance and popularity of *Vitex payos* has led to the commercialisation of its fruits, their quantities to sustainability support cottage industries in the rural areas has not been considered. Vitex payos trees were surveyed during fruit season and the quantity of fruits for 120 trees distributed on farm lands and bushlands in three districts counted per tree. Mean fruit yield was significantly higher from farm trees (>6145 fruits per tree) than trees in bushlands areas (<4154 fruits per tree), even after accounting for differences in tree size. Few cases of trees with over 21000 fruits were also recorded from both land uses. Although, the majority of the trees produce <5000 fruits per tree per year, through purposeful selection of germplasm in its wide natural range, production could be increased up to four fold. A fairly accurate prediction of fruits per tree and consequently the quantity available from the farms could be achieved through use of a combined logarithmic and inverse transformation equations using the crown diameter and the tree height. However, considering that the *Vitex payos* grows in more diverse dryland areas in Kenya including the Eastern, Coastal and Central regions, it is prudent to collect more data from all these areas and test the validity of the equation developed in this study for wide-scale application as a management tool.

Key words: Allometric equations, indigenous fruit trees, *Vitex payos*, wild fruits, Kenya

INTRODUCTION

Indigenous fruit trees play a key role in supporting livelihoods of many poor people in sub-Saharan Africa providing a range of products such as fruits and edible and cosmetic oils. Among the food producing fruits, fruit pulp remains the most important component. One such resource in the drylands of Kenya is *Vitex payos* fruit that most subsistence farmers collect for home consumption and subsistence sale in local markets during the fruit ripening seasons. However, lack of productivity and yield data constrains sustainable exploitation of the fruits from this indigenous tree. An estimate of the expected fruit yield is therefore, important for promoting sustainable fruit harvests use and commercialization. Wong *et al.* (2001) opined that there are no specific methods for quantifying non wood forest products (e.g., fruit yields).

Depending on the ecology of the tree, objective of the study and the tree tenure, a number of methods could be employed to quantify the fruit yields.

One interesting method is the sampling technique which collects individual tree variables and relates particular characteristics using regression models (Gregoire and Valentine, 1996; Gregoire *et al.*, 1995; Chapman *et al.*, 1992, 1994). The main drawback to this technique however, remains the acquisition of the values to apply in the specific technique. Different studies have tried to approach the problem differently guided mainly by the fruit characteristics such as their colour, tree height, sample size required and the resources and time available to carry out the work. These studies included the use of frame and image (Huddleston, 1971), scanning both the tree canopy and forest floor (Musila and Leonhartsberger, 2003) and placing of fruit traps below fruiting trees (Zhang, 1995).

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In addition, other methods such as visual ranking of trees and assigning relative fruit available (Peres, 1994), aerial photography (Jansen *et al.*, 2008) visual counting of fruits on tree canopies (Chapman *et al.*, 1992; Jansen *et al.*, 2008) and counting the number of pericarp segments from fruits in sample plots located below the crown of trees (Snook *et al.*, 2005) have been used. Shackleton *et al.* (2002) marked some trees and regularly counted the fallen fruits throughout the fruiting season. Jessen (1955) proposed the use of random branch sampling to estimate the fruit yields on a tree. Marshall modified Jessen's method by systematically selecting branches from the whole canopy. Todd (2001) counted fruits on the ground and up the tree at a single visit at the peak of fruit season to estimate fruit production per tree.

The appropriateness of using a specific approach however, depends on the architecture of the tree and the phenology of the species. Trees with a dense crown and green fruits when ripe are normally difficult to sample from the ground as many fruits remain covered by the foliage. Some of these methods also give inaccurate estimates because of the nature of fruiting of the tree species, the way the fruits are utilized by the animals and season in which the survey is done. For example, Parrado-Rosselli *et al.* (2006) observed that the use of fruit traps did not accurately reflect the fruiting patterns observed in the forest canopy. Fruits trapped were those that had not been eaten by frugivores and depending on fruit density in the canopy and the population of frugivores, quantities trapped varied.

Regular collection and counting of fruits require close supervision of the activity to ensure all fruits are collected. Todd (2001) noted that some fruits could be removed by people or animals and thus caused an underestimation in their study. However, some of these methods have been used to estimate fruit quantities of indigenous fruit trees such as *Sclerocarya birrea* (A. Rich) Hochst. Anacardiaceae (Shackleton *et al.*, 2002), *Allanblackia stuhlmannii* (Engl.) Engl. (Clusiaceae) (Mathew *et al.*, 2009) and *Astrocaryum standleyamum* L.H. Bailey (Arecaceae) (Jansen *et al.*, 2008). Muchiri and Chikamai (2003) pointed out that the most accurate means of determining fruit yield was to climb the tree and count the fruits directly.

This study was therefore, geared towards developing simple and effective fruit yield prediction models based on easy-to-measure tree variables such as height, canopy size-surface area or volume and trunk diameter and evaluating variation in *Vitex payos* fruit production in three districts and under different land uses (farms and bush/fallows) in the drylands of Kenya. Two hypotheses were tested. Firstly that tree measurable parameters are not correlated to the fruit yield of individual trees. Secondly that there is no variation in fruit production in different districts and under different land uses (farms and bush/fallows).

MATERIALS AND METHODS

Study area: The study was carried out in three districts namely Mbeere, Mwingi and Kitui, all of which are located in Eastern province of Kenya (Table 1). The three districts are characterized by low soil fertility, low and erratic rainfall and experience frequent droughts. Annual rainfall distribution is markedly seasonal with 80% of the total rainfall falling in two wet seasons: March to May and October to December.

The soils in Mbeere are a mixture of chromic cambisols, rhodic ferrasols and luvisols with varying degree of stoniness, rockiness and soil depth. The Mwingi soils are red sandy, loamy sandy with patches of black cotton soils. The soils in Kitui are mainly loamy sandy in low-lying areas while along seasonal rivers; the soils are sandy clay loam and low in fertility. The three districts were selected because of the large number of *Vitex payos* trees retained on farms. A reconnaissance survey was undertaken in each of the districts jointly with extension staff from the ministries of agriculture and forestry to establish the availability of the species and to determine and select specific areas where fruits trees were abundant on farms.

Sampled trees and direct total fruit count: From each district, twenty *Vitex payos* fruit trees were randomly sampled from cultivated farms and fallow (bush) lands thus making a total of 120 trees. Individual selected trees had their main and secondary branches marked up to the terminal branches the sites of fruit production. To capture

Table 1: Location of the study districts, their mean annual rainfall and temperatures

District	Latitude (S)	Longitude (E)	Area (km²)	Average annual rainfall (mm)	Average temperature (°C) Minimum	Maximum	Elevation (m.a.s.l)
Mbeere	00°20'-00° 50'	37°16'-37° 56'	2093	640-1100	14-22	25-32	1180
Mwingi	00°03' 01° 12'	37°47'-38°57'	10030	600-1100	14-22	26-34	1140
Kitui	00°04' 03°00'	37°45' 39°00'	20402	500-1050	16-28	32-34	895

accurate numbers of fruits per tree, fruits were counted when the majority had matured but not ripened. This, unlike other previous studies ensured the fruits had neither fallen nor been eaten by frugivores.

Fruits were counted on each terminal branch by either climbing the tree to access those in the canopy or using a raised ladder for those on the surface of the crown and from the ground for those on lower side of the canopy. Fruit numbers were recorded for each terminal branch separately and summed for each branch and a grand total for each tree obtained by summation. In addition, tree dendrometric variables such as height, girth at breast height, crown diameter and crown depth were measured. For the few trees with forks below 1.3 m, the circumference of each fork was measured and their sum computed into diameter of an individual tree (Miller and Dietz, 2004).

Assessments on crown diameter were made in two perpendicular directions through the base of the tree and the mean of the two calculated. Crown depth, a parameter used in calculating both the crown volume and surface area of individual trees was calculated by subtracting the height to the lower side of the crown from tree height. Crown volume (cvol) and crown surface area (csa) were computed based on the assumption that crowns were more or less hemispherical (cvol = 2/3 ($\pi r^2 h$) and csa = $2\pi rh$ where r is the crown radius h is the crown depth and π = 3.14). Five trees were selected from each land use in every district and kept as independent data. These were not used in equation development but were utilised to test the strength of the relationships developed.

Data analysis: Data were analysed using Statistical Package for Social Scientists (SPSS) version 16. Differences between sites were examined using Analysis of Variance (ANOVA) after testing for normality. The relationship between the tree attributes and fruits per tree were determined using bi-variate correlation. The relationship between fruit yield and individual tree attributes or combined were determined through linear regression. To test the relationship between tree attributes and fruit yield per tree, Pearson correlation coefficients were calculated (Foster, 2008).

The number of fruits per tree was log transformed and the tree attributes were square rooted and inversely transformed. For significant ANOVA results, subsequent pair-wise comparisons were examined using Tukey's post hoc test. To detect differences between land use (farms and bush/fallow) an independent sample t-test was carried out. The power of regression equations were compared by their r-values. Coefficients of each equation were used to estimate fruits of independent trees. Using t-test, the values obtained through different equations were compared against the actual number of fruits. Their deviations were also calculated to establish their magnitude from the true value.

RESULTS

Direct fruit count: Dendrometric variables of the sampled trees for direct fruit count across the three districts (Mbeere, Mwingi and Kitui) and the two land uses (farms and bush/fallow) are shown in Table 2. There were significant differences in *Vitex payos* tree height, diameter at breast height, crown diameter and crown volume between districts with p values ranging between 0.018 and 0.048 (Table 2). Mwingi district had trees with significantly higher values than those in Kitui in all tree parameters except diameter at breast height which the latter had the highest value. *Vitex payos* trees in Mbeere district were not significantly different from those of either Mwingi or Kitui.

Tree crown depth; crown surface area and fruit number per tree and per unit volume of crown were not significantly different across all districts. All the tree variables were also not significantly different between the two land uses. However, fruit numbers per tree and per unit of canopy volume were significantly different (p = 0.041 and 0.014, respectively) (Table 2).

Mean number of fruits per tree from farms was 6145±729, varying from 316-22068 while the mean number of fruits for trees in fallow/bush land was 4154±624 and varying from 179-21523. The number of fruits per tree were positively skewed with majority of trees recording <5000 fruits and ranged from 179-22068 per tree (Fig. 1). The mean number of fruits did not vary significantly among

Table 2: Descriptive statistics of fruit trees and fruit yield in districts and land uses in Eastern province, Kenya (mean±sem)

Tree characteristic	Districts				Land uses			
	Mwingi	Mbeere	Kitui	p-value	Farm	Bush	t-value	Overall
Fruits per tree	5900±880	3609±574	5940±986	0.082[NS]	6154±729	4154±623	0.041*	5150±489
Height (m)	6.09±0.28	5.47±0.24	5.18±0.17	0.023*	5.61±0.18	5.54±0.21	0.249[NS]	5.58±0.14
Diameter (cm)	17.1±1.10	18.9±1.00	22.5±2.2	0.048*	18.4±0.9	20.5±1.5	0.250[NS]	19.5±0.9
Crown diameter (m)	6.25±0.33	5.76±0.26	5.22±0.21	0.031*	5.66±0.18	5.83±0.27	0.599	5.75±0.16
Crown surf area (m²)	39.33±4.20	29.87±2.66	29.86±2.27	0.055[NS]	33.72±2.87	32.72±2.87	0.873[NS]	33.02±1.86
Crown depth (m)	3.74±0.22	3.19±0.23	3.53±0.17	0.175[NS]	3.63±0.17	3.34±0.18	0.228[NS]	3.48±0.12
Crown volume (m³)	47.27±7.42	30.91±3.40	28.0±3.25	0.018*	34.02±3.64	36.77±4.88	0.653[NS]	35.39±3.03
Fruits (m⁻³)	143±14	184±41	224±28	0.158[NS]	226±28	142±18	0.014*	184±17

*significant at p = 0.05, NS indicates not significantly different at p = 0.05

the districts-ranging from 5940±986 for Kitui, 5900±880 for Mwingi and 3609±574 for Mbeere (Table 2). Exploration of the data showed that there were extreme cases of trees with high number of fruits in all districts and land uses (Fig. 2). There were significant differences in number of fruits per tree and per unit volume of canopy between trees on farms and bushes (Mann-Whitney Z = -2.377, p = 0.017 and -2.223, 0.026, respectively).

Relationship between fruits per tree and tree dendrometric parameters: The number of fruits per tree was positively and significantly correlated with total tree height, crown diameter, crown surface area and crown volume (r-values ranging between 0.320 and 0.436; p<0.001) (Table 2). Correlation coefficient for diameter at breast height and number of fruits was positive but not significant (Table 3). Trees on farms had their fruit counts poorly correlated to tree parameters such as height and crown diameter (Pearson's correlation coefficient = 0.123 and 0.285, respectively). Those in fallow/bushland were however strongly correlated to the two tree parameters with values of 0.688 and 0.591, respectively. Regressing fruit number against all the tree variables yielded Eq. 1 with r-value of 0.512 and p<0.001. Individual independent variables' p values were not significant and ranged from 0.080-0.688 (Table 4). These variables were
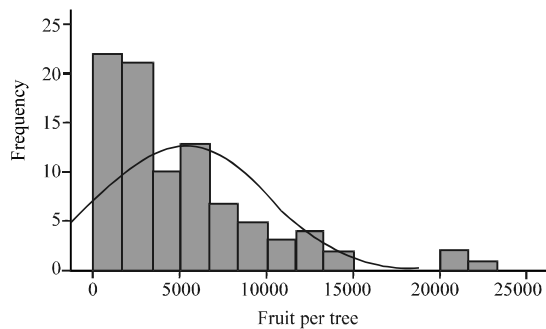
however, correlated among themselves (Table 3) and therefore causing an inflation of their variances. This was evidenced by the high variance inflation factors of each coefficient (Table 4). Eq. 1, therefore suffered from multi-collinearity and thus the need to combine some variables or remove others altogether as predictor variables:
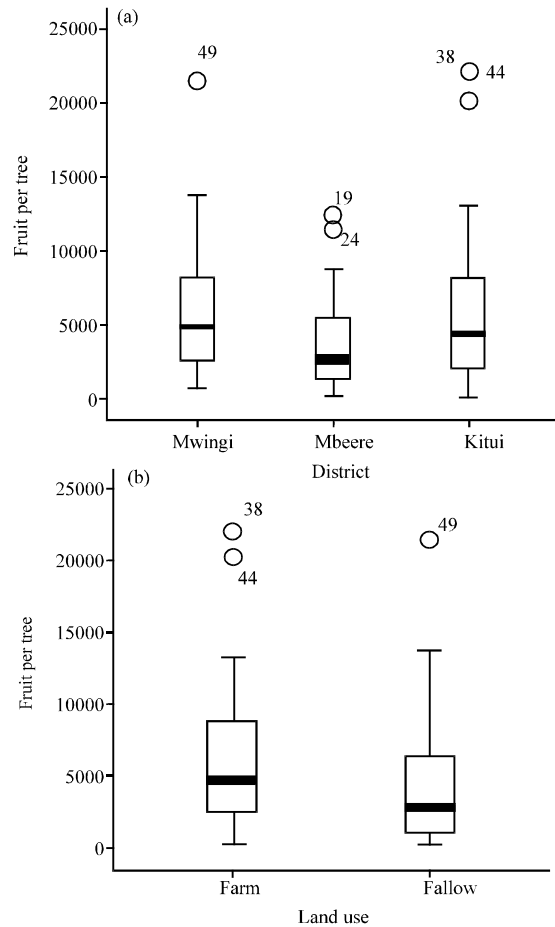

Fig. 2: *Vitex payos* fruits per trees distribution in three districts and two land uses in the dry lands of Kenya

Fig. 1: Tree distribution against number of fruits per tree in the dry lands of Kenya

Table 3: Pearson's correlation coefficients of tree variables

	DBh (cm)	Tree height (m)	Crown diameter (m)	Crown surface area (m²)	Crown volume (m³)	Number of fruits
Dbh (cm)	1.000	0.363**	0.486**	0.456**	0.428**	0.126
		<0.001	<0.001	<0.001	<0.001	0.236
Tree height (m)		1.000	0.669**	0.861**	0.783**	0.397**
			<0.001	<0.001	<0.001	<0.001
Crown diameter (m)			1.000	0.848**	0.887**	0.416**
				<0.001	<0.001	<0.001
Crown surface area (m²)				1.000	0.970**	0.492**
					<0.001	<0.001
Crown volume (m³)					1.000	0.475**
						<0.001

**Correlation is significant at p = 0.01 level, Dbh = Diameter at breast height

Table 4: Coefficient estimates, Standard Error of the Mean (SEM) and significance value (p) and variance inflation factor for Eq. 1

	Regression coefficients					
Statistics	b_0	b_1	b_2	b_3	b_4	b_5
Coefficient value	2116.040	-590.377	-79.395	-53.838	250.835	260.769
SEM	3628.910	719.379	59.670	79.670	141.769	646.778
p-value	0.561	0.414	0.187	0.501	0.080	0.688
Variance inflation factor		4.782	1.393	27.813	33.216	5.168

$$y = b_0 + b_1*ht + b_2*dbh + b_3*cvol + b_4*csa + b_5*cdia \qquad (1)$$

Where:

ht = Tree height (m)
dbh = Diameter at breast height (cm)
cvol = Crown volume (m^3)
csa = Crown surface area (m^2)
cdia = Crown diameter (m)
b_0-b_5 = Regression coefficients

Coefficients b_2 and b_4 had absolute values greater than their standard errors of the means while b_0, b_1, b_3 and b_5 had smaller values (Table 4). The latter coefficients encompassed zero and thus were not significant in the equation. The variance inflation factor of b_3 and b_4 were highly inflated while crown volume and crown surface were highly correlated (p = 0.970) (Table 3), thus causing multi-collinearity when the two were included in the equation. Using a stepwise approach to regress all independent variables as in Eq. 1, diameter at breast height, tree height, crown diameter and crown volume were excluded as independent variables. Equation 2 with an r-value of 0.436 and p<0.001 was realized with crown surface area as the only independent variable:

$$y = 880.853 + 129.280*(csa) \qquad (2)$$

However, considering correlation coefficient between fruit numbers per tree and crown diameter and that between fruit number and crown surface area (0.492 against 0.416) (Table 3) together with the associated ease of measuring the crown diameter, a linear Eq. 3 using crown diameter as predictor variable was developed with an r-value of 0.416 and p<0.001.

$$y = -2110.418 + 1263.412*(cdia) \qquad (3)$$

Plots of regression residuals from these equations have fan-like shape which indicates lack of normal distribution of fruit numbers (Appendix 1). Further, inspection of residuals showed three trees whose fruit numbers were poorly predicted. Trees with large number of fruits (above 20,000 fruits per tree) were characterized by excessively high residuals in all three equations-potential outliers. Omission of the three trees in analyses improved r-value in Eq. 2 (0.468) but caused a decline in
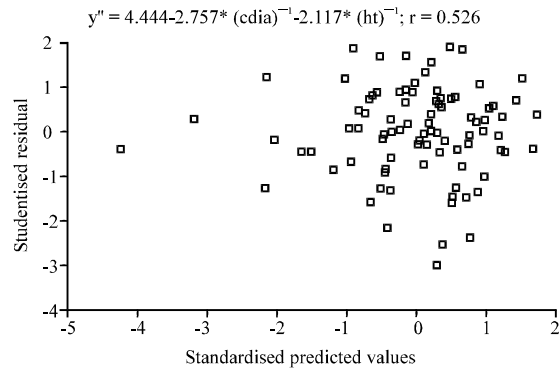

Fig. 3: Plot of studentised residuals against standardised predicted value from Eq. 4. y = logarithm of fruits per tree; cdia = mean crown diameter (m); ht = tree height (m)

Eq. 1 and 3 with r-value equals to 0.492 and 0.409, respectively while distribution of residuals remained with fan-like shape (Appendix 1). Numbers fruits per tree were log base 10 transformed while predictor variables were square rooted and inverse transformed.

Equations with inverse transformed variables had higher r-values than those with the square root transformation and the untransformed ones. Plot of regression-studentised residuals against standardized predicted values were scattered around the origin thus indicating normalization of the fruit data (Fig. 3). Equation 4 with inverse transformed crown diameter (cdia^{-1}) and tree height (ht^{-1}) values was the most appropriate equation with an r-value of 0.526:

$$y' = 4.444 - 2.757*(cdia^{-1}) - 2.117*(ht^{-1}) \qquad (4)$$

where, y' is the logarithm transformed number of fruits per tree. Using an independent data set (30 trees), the four equations were used to estimate the fruit population and the estimates correlated with the actual fruit count. Pearson's correlation coefficients and the p-values are shown in Table 5. All the equations estimated mean fruit numbers of the independent tree population that were significantly correlated to the mean of the actual number of fruits (Table 5). Results of pairwise comparison of the actual number of fruits per tree and those predicted using the four equations are shown on Table 5. Equation 3 and

Table 5: Correlation coefficients, p-values and t-value of paired difference of fruit count and fruits predicted by different equations

Actual fruit number against	Paired samples correlations		Paired difference	
	Correlation	p-value	t-value	p-value
Equation 1	0.531	0.003**	7.130	0.001***
Equation 2	0.468	0.009**	5.360	0.001***
Equation 3	0.454	0.012*	1.740	0.093[NS]
Equation 4	0.467	0.009**	0.288	0.775[NS]

Where NS = Not Significant; *significant at $p \leq 0.05$; **Significant at $p \leq 0.01$, ***significant at $p < 0.001$

Table 6: Percent discrepancy of fruit estimation of all independent tree data and tree data with >2300 fruits per tree from fruit count

Equation	Percent deviation	
	All data	Trees >2300 fruits
1	582	162.0
2	486	125.0
3	262	30.0
4	135	-9.4

4 predicted numbers that were not significantly different from the actual numbers on independent tree (Table 5) and thus most reliable. While the p-values compare the variance of the mean of actual and predicted fruit numbers the t-value compares the variances of predicted and counted fruit number of individual trees.

Equation 1 and 2 though with the highest correlation coefficients were poor predictors of fruits of independent trees. Equation 3 and 4 predicted fruits per tree whose population mean value and individual tree values were correlated closely to the actual values (Table 5).

To compare these equations, percent discrepancies (fruit count minus fruit estimate divided by fruit count multiplied by 100) were computed and their direction noted to detect any trend (Table 6). All the equations generally over estimated the number of fruits of independent data. Equation 4 gave the best estimate compared to other equations. In all equations, it was found that trees with <2200 fruits had huge deviations of >100%. Removal of these trees from the data reduced the deviation in all cases. However, while the first three equations overestimated the fruit count, Eq. 4 underestimated the fruit number with a 9.4 mean deviation from the counted value (Table 6).

DISCUSSION

Fruit production: One of the objectives of this study was to determine if there were variations in *Vitex payos* fruit production in different districts and under different land uses. Statistically, there were no significant differences in fruit production among trees in different districts. Conversely, there were significant differences between land uses with trees on farms producing more fruits than unmanaged trees in the bushes. Studies elsewhere (Shackleton *et al.*, 2002; Botelle *et al.*, 2002) have shown significant variation in fruit production among trees from different regions and land use systems. In another note, Botelle *et al.* (2002) reported that differences in soil type and land forms combined with annual rainfall play a significant role in influencing fruit production of *Sclerocarya birrea* trees. The level of management of fruit trees in different localities on the farm have also been reported to significantly influence the level of competition for available resources such as nutrients among trees (Shackleton *et al.*, 2002; Botelle *et al.*, 2002).

In the present study, trees sampled in the three districts were found in sites characterised by sandy soils and erratic bimodal rainfall patterns. Perhaps, the commonality of these sites' characteristics could be responsible for the uniformity of fruit production across the three study districts. Trees on the farm produced more fruits as observed in other studies. Fruit production on the farms was almost 50% more than in the unmanaged bushes. Leakey *et al.* (2002) documented a fivefold difference in fruit yield between *Sclerocarya birrea* trees on farm and on communal land. The differences were attributed to the influence of altered environment and therefore reduced competition (Shackleton, 2004) and retention of the better trees on farmland during bush clearance for agricultural production (Leakey *et al.*, 2002).

Tree dendrometric variables such as height, diameter at breast height, crown diameter and volume were found to be significantly different among districts (p<0.05) between Mwingi trees and those of Kitui. Mbeere trees were not significantly different from either Mwingi or Kitui trees. Mwingi trees possessed significantly larger crown diameter and crown depth, the two factors that influence amount of fruits produced (Miller and Dietz, 2004). These contrasted with Kitui trees which had the lowest crown diameter and intermediate crown depth. While trees from the two districts produced relatively equal number of fruits per tree, those from Mwingi had large crown volume and low fruit production per unit volume of canopy and the opposite was true for Kitui trees.

It is possible that majority of Kitui trees were mature, with high diameter at breast height and thus high fruit production. Mbeere trees on the other hand had the least mean crown depth and moderate crown diameter. This could have been as a result of heavy pruning of trees on farms to reduce shade on associated crops while big trees in fallow/bush land were cut for fuelwood for curing tobacco and brick baking.

Trees on farms produced significantly higher number of fruits per cubic metre of canopy than trees in bushes (t = 0.014) as well as overall fruit count per tree (t = 0.041). While all surveyed trees on average yielded 25.80 ± 2.45 kg of fruit, those on farms yielded 30.79 ± 3.65 kg and in bushes 20.81 ± 3.43 kg (each fruit on average weighs 5.01 g). After taking account of the tree size by considering the fruit yield per unit volume of crown, fruit production was high on the farms (1.13 ± 0.14 kg m^{-3}) and

low in bushes (0.92±0.87)-approximately 20% difference. This however did not account for the region in the crown that is void of fruits (Miller and Dietz, 2004). The higher fruit density on trees on farm land than in bushes implies *Vitex payos* trees could benefit from improved management on farms through increased productivity.

In addition, the current difference in fruit yield of trees under the different land uses indicates that *Vitex payos* may have undergone some level of unintended selection by the local communities. This also implies that fruit yields realized from the *Vitex payos* could be further improved through deliberate selection of superior germplasm. Some of the sampled trees had over 20,000 fruits per tree.

Such trees were found in Mwingi and Kitui districts and on both farms and bushlands. Therefore, an expanded survey of the species' natural range should be carried out to identify such germplasm that could play an important role in enhancing fruit production in the domestication process for the species.

Relationship between fruits per tree and tree dendrometric parameters: The relationship between the number fruits per tree and tree dendrometric parameters was reasonably expressed by a linear logarithmic function. Log transformation of fruits per tree regressed against the inverse of the tree parameters resulted in a normalised plot of residuals (Osborne, 2002) as well as marginal increase in the r-value. Most studies relate the parameter of interest in this case fruits with diameter at breast height (Makishima, 2005; Jian *et al.*, 1994; Lamien *et al.*, 2007; Muchiri and Chikamai, 2003). However, diameter largely reflects the age of a tree which at an advanced stage is accompanied by reduced crown growth vigour due to a decline in photosynthesis rate and eventually fruit production (Stoffberg *et al.*, 2008; Binkley *et al.*, 2002).

Relationships between fruit yield and the various tree parameters were of moderate strength with r-values <0.6 even when all variables were used as predictors. Crown surface area gave the best prediction of fruit yield followed by crown volume with r-values difference of 0.017 between them. This could be associated to the fact that most fruits are produced near the crown surface rather than inside. However, measuring crown diameter as a field exercise is easy as opposed to computing the crown surface area and volume from crown diameter and estimate of crown depth.

The use of crown diameter and tree height, two parameters that are easy to measure, gave equally good relationship with fruit yield. Untransformed data however, produced residual plots that indicated a trend violating the assumption of normality. The critical purpose of these equations is however, to predict fruit numbers of independent trees. Muchiri and Chikamai (2003) working on baobab found fruit counts were better estimated by diameter at breast height than either tree height or tree crown diameter. They also found a relationship between fruit count and tree height and fruit count and projected crown area. The r^2 values of the two relationships were low and thus weak. Other studies (Miller and Dietz, 2004) found significant relationships between diameter and fruit production.

In the present study however, diameter had a weak relationship with fruit count and therefore was a poor fruit predictor. Unlike other studies (Miller and Dietz, 2004), crown diameter together with tree height had a strong relationship with fruit count and thus was applicable for *Vitex payos* fruit estimation.

In a related study, Foster (2008) indicated that the abundance of fruits is highly correlated with size of tree crown and the foliage density. A pair wise comparison of the estimated and actual fruit per tree revealed no significant difference thus indicating reliability of the equation.

CONCLUSION

The increasing awareness and commercialisation initiatives based on limited information on fruit production should be of great concern. The promotion of successful cottage industries in rural areas is dependent upon adequate resources to meet anticipated demand (Shackleton, 2004). It is necessary therefore, to predict with some accuracy the resources available, otherwise the cottage industries may be frustrated and ultimately the rural populations as well. From this study, it has been shown that *Vitex payos* trees vary greatly in terms of fruit production.

The majority of the trees produce <5000 fruits per tree per year but through purposeful selection of germplasm in its wide natural range, production could be increased up to four fold. Prediction of fruits per tree and consequently the quantity available from the farms could be achieved through use of a combined logarithmic and inverse transformation equations using the crown diameter and the tree height. However, considering that the *Vitex payos* grows in more diverse dryland areas in Kenya including the Eastern Coastal and Central regions, it is prudent to collect more data from all these areas and test the validity of the equation developed in this study.

assistance during the field work. Researchers are highly indebted to the rural communities in Mbeere, Mwingi and Kitui districts, Eastern Kenya for freely sharing with us their valuable knowledge. Financial support for the study was provided by the Leverhulme Trust, UK through Bangor University, UK under a research project on Impr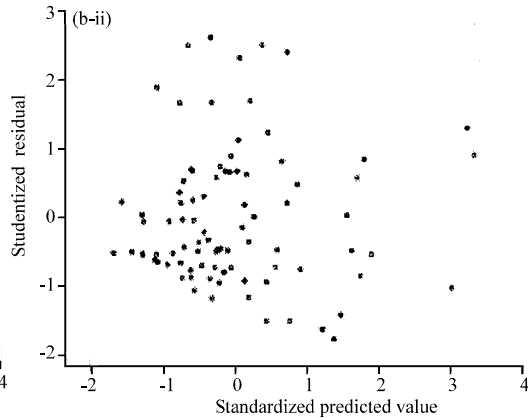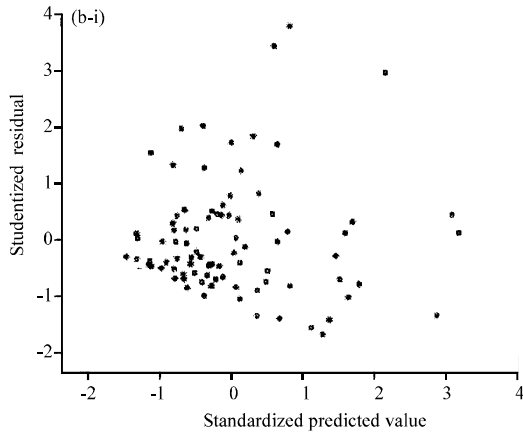oved Management and Utilisation of Eastern Africa Indigenous Fruit Trees (Contract No. F/00174/K) and Kenya Government through KEFRI Dryland Programme.

APPENDIX
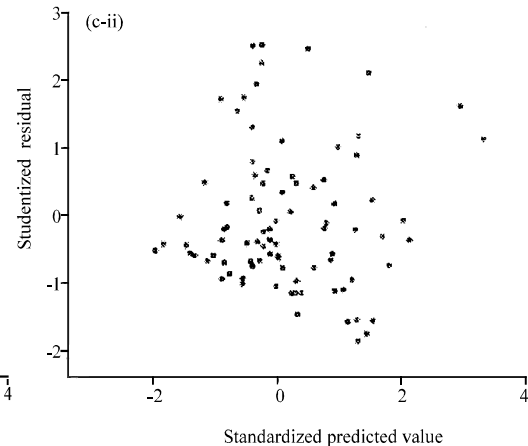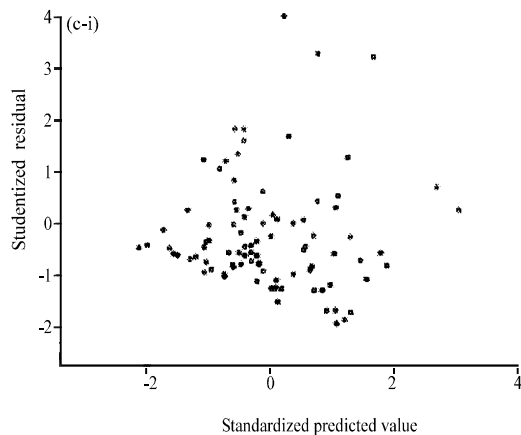
Appendix 1 Scatter plots of studentised residuals against standardized predicted values Eq. 1, a) all
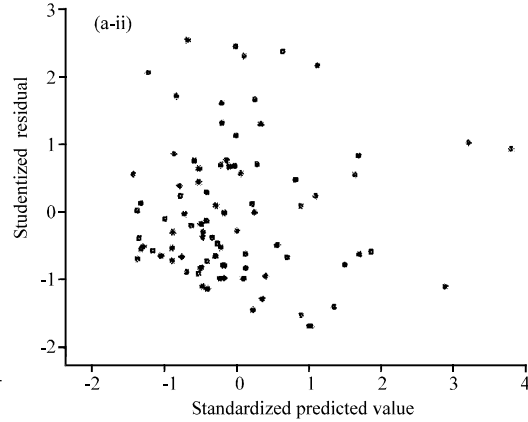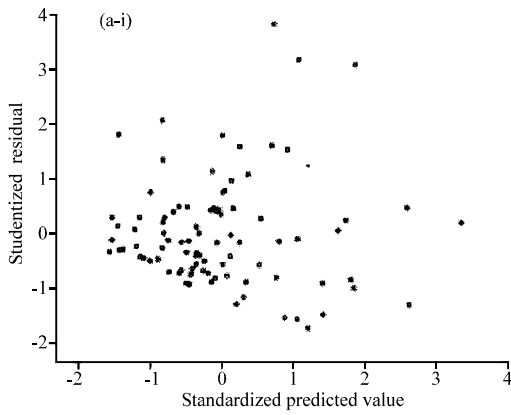
$y = 2116.036 - 590.377*ht - 79.395*dbh + 260.769*cdia + 250.835*csa - 53.838*cvol: r = 0.512$

$y = 880.853 + 129.280*csa: r = 0.492$

$y = -2110.418 + 1263*cdia: r = 0.416$

variables, b) crown surface area and c) crown diameter as independent variable. Plots (a-i), (b-i) and (c-i) used data from 90 fruit trees and; (a-ii), (b-ii) and (c-ii) used 87 trees data after omitting 3 trees-outliers.

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