A SURVEY OF MARULA FRUIT YIELDS
IN NORTH-CENTRAL NAMIBIA

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INTRODUCTION

Study Criteria

The aim of this survey was to measure marula stem densities and marula fruit yields within different land use classifications in North-Central Namibia; "homesteads", "fields", "communal lands" and "protected areas".

In North-Central Namibia (Map 1) there is a long history of intensive marula use. This is also the case with the other study areas in southern Africa. But there are fundamental differences between marula using cultures in the rest of southern Africa compared with the Oshiwambo-speaking population in North-Central Namibia. And these differences, it is believed, have a profound effect on yields (e.g. another study under this project found that Namibian fruits were “significantly larger than those from South Africa, due to their greater pulp mass, especially the flesh/juice component” (Leakey et al in press).

Marula trees in North-Central Namibia have been domesticated for centuries. Today, women own and manage marula trees which compliment the predominantly (wo)man-made landscape. This is a consequence of ecology, farming systems and settlement patterns. This marula fruit yield study was designed with other parts of southern Africa in mind, where there is a different human agent at work. As a consequence, many of the research outputs, such as stem densities within different land use classifications, are not applicable and therefore not included in much detail in this report. Instead, an attempt has been made to quantify (for the first time) Namibian marula yields, to investigate possible regional differences in yield, and to develop simple tools that can be used to predict yields for commercialisation purposes.

Factors Affecting Marula Fruit Yields

Ecologically, North-Central Namibia is a dry, sandy plain comprising mostly moisture- and nutrient-deficient soils. It is important to recognise that this part of Namibia is one of the flattest places on earth, with a typical gradient of 1:10,000 - that’s a drop of one metre for every 10 kilometres - with a general slope north-south. This area comprises an inland delta with raised areas of land between narrow waterways and lake systems that are dry for most of the year. This delta, the Cuvelai drainage system, is fed by summer rains falling locally and to the north on the Sierra Encoco mountains in Angola, slowly flowing with fish and nutrients through the meandering channels of North-Central Namibia and into the Etosha Pan. (See Map 2). Elevated strips of land between waterways have the best soils and it is in these areas where marula trees aggregate naturally. Small changes in elevation have a profound effect on settlement patterns and marula distribution (see Verlinden and Dayot 1999 and 2000). This is why the best land has a long history of settlement and marula use.

In most marula growing areas of southern and eastern Africa there exists a nucleated system of villages, each surrounded by fields, and beyond that, forest land and, perhaps, protected areas. In North-Central Namibia the system of land use is very different.

Firstly, there are no “wild” areas left where marula occurs ‘naturally’, except in the Tsumeb mountainlands and on the escarpment above Ruacana (which were not included in this study because the marula there is not utilised to any significant extent). Secondly, traditionally, and even today, extended families are isolated from one another. Individual homesteads dot the landscape, dispersed every 500 metres or so in a patchwork of farm plots. Until the 1960s
there were no nuclear villages in North-Central Namibia and even today, it is the predominantly rural landscape where marula trees, and a marula industry, are concentrated.

Each homestead comprises huts surrounded by a palisade wall of dried tree trunks. This living area is a breeding ground for marula and other fruit trees. Families gather marula seeds and bring them into the homestead to decorticate, process and consume. In this way, new marula trees (and other fruiting tree species) propagate from discarded seeds by laying claim to corners, cracks and gaps within these palisade walls. Families benefit from the shade and the fruits of these large trees and encourage their growth. There is a direct and positive relationship between the siting of homesteads and the success of new marula trees, not least of which is the fact that the soils of homesites are fertilised by the occupants.

Moreover, when a homestead is abandoned (on the death of the owner or for other reasons) small marula groves, as well as isolated trees, are left behind, to become part of the broader agro-forestry farming system within fields (see Erkilla 2000). When a new homestead is constructed marula trees propagate once again within the safety of the homestead. This process has continued over centuries as the Ovambo population has migrated and spread across the landscape. Today it is estimated that there are more than a million marula trees in North-Central Namibia, more than 95% of which occur within people’s fields. And eight out of every ten of these trees are female, revealing a strong preference for fruit producing trees within fields.

Surrounding each homestead, individual family’s fields (epyà) and semi-wild vegetation (ekove) are cultivated and protected. Most homesteads today are fenced from one another to keep grazing animals out of arable fields. Between fenced farm plots, sections of open access grazing and forest areas do occur, although, as more and more land is fenced off each year with the growth of society, there is less and less “open access” land. In addition, herds of goats and cattle quickly graze any new marula trees (and other tree species) preventing marula from propagating on communal land. Livestock also graze cultivated fields after the harvest, which is why farmers have adopted the practice of protecting marula seedlings with thorn branches (often such trees are named after the person who found them). Even in cases where the seedlings are not actively protected they are only grazed while dormant and are often able to recover when the next rainy season comes. An interesting observed practice is to construct a pig sty under a young marula tree – this provides the pig with some shade, protects the tree from browsers, and fertilises the soil.

Around towns, and areas where soils are fertile, the density of homesteads increases with a concomitant decline in the size of farm plots. In the most fertile parts of North-Central Namibia population densities are quite high (for Namibia), between 100-300 people per square kilometre. In these locations virtually all land is owned, either by the local municipality or by traditional headmen who lease the land to individual farmers and their families.

Marula trees in fields are owned by those families and are managed by women, usually the farmer’s wife or the female head of household. One requirement of this study, therefore, to calculate density of stems within different land use classes (“homesteads”, “fields”, “communal lands”, and “protected areas”), is not applicable in the Namibian context as there are virtually no fruiting marula trees in communal areas and there are no protected areas in the densely populated part of North-Central Namibia where this study took place (refer to Map 2).
As we have stated, marula has been domesticated and integrated into the Ovambo system of farming for centuries. Here farming comprises arable agriculture, agro-forestry and pastoralism. Marula trees prefer the deeper, more fertile soils found on higher ground, the same land traditionally inhabited by farmers for centuries, as it is the best land for farming and above floodwater levels. Indeed, marula trees are traditionally used as an indicator of soils suitable for crop farming. There are also a few situations where marula trees have clearly been introduced into areas where they do not occur naturally, but where the soils are suitable – in such situations the only marula trees are those that grow in homesteads. Only in the far north of the study area, around Ondobe for example, and in isolated pockets across the entire region, do extensive areas of deep soil occur. In these situations a few marula trees do exist outside of farm plots but most are owned and used by families. Most of these marula trees occur in homestead-sized groves, suggesting that they originally grew on farms, before the higher-lying land was expropriated for uses such as townships and roads.

The neo-religious reverence for marula - tree naming, ceremonies, marula festivals, stories, rituals and songs - among the Ovambo population reveals a long association with marula. The local population has a deep knowledge of marula for a myriad of different uses. And because of its many uses a symbiotic relationship has developed between (wo)man and marula. Some women actively transplant young marula trees and protect fruiting trees (see Photo 2). This survey revealed that 49 of the 104 trees recorded had been given names by the household. The names and their meaning in English are included in the data base at the end of this report (refer to Appendix 1). Tree names usually describe the qualities of the fruit, and the name of the person who owned the plot when the tree germinated or the name of the person who found and protected the seedling, again emphasising the relationship between owners and their marula trees.

The women responsible for gathering, processing and preparing marula have both indirect and direct impacts on the selection of fruit trees (e.g. Leakey et al found that fruits processed in South Africa represented the best 84% of the sample population – inferior fruits were discarded, or never harvested) and also a profound impact on the siting, sex, number and, therefore, yield of marula trees in family plots.

Typically, women have 3 to 10 marula trees dispersed within their fields. Some women have no marula at all and others have hundreds of trees. Usually a household will have at least one marula tree. The impact of women (and the local farming system) on marula is most evident by the sex ratio of male to female marula trees in North-Central Namibia. Based on current estimates, and on the results of this survey, eight out of every ten marula trees are female (compared to a ratio of 1:1 in ‘natural forests’ in the Caprivi and in the Kavango Regions where marula trees have not been domesticated) for the simple reason that families desire fruit-bearing trees whilst unproductive male trees are removed, as they can compete with arable crops for precious soil nutrients and moisture.

One plot had 117 trees (with 81 female, 13 male, and 23 trees too young to identify the sex). In addition there were 68 other fruit trees of various types in this owner’s fields. For a single farm to have so many marula trees and other fruiting trees was unique in the drier, poorer soils around Okahao, in the far south of the study area and at the extreme edge of marula’s distribution area in Namibia. In this particular case the farm was originally one plot, which two brothers divided between themselves when they inherited it from their father (a local headman). As they explained, “It was tateku lu (the old man) who started this ‘marula project’. No one else in this area has this many marula trees”. With a circumference of 1780
metres the plot was estimated to be 20 hectares, which calculates to an average of nearly 6 marula trees per hectare, of which 4 were female fruiting trees per hectare. In most plots though, this density will be much lower. And marula trees are concentrated on the best soils and absent in shallower soils.

In Ondobe, in the northern part of the study area, the highest density of human and marula populations can be found. Here, one woman had 112 mature trees within a 1660 metres circumference plot, estimated to be about 18 hectares, of which 91 were female and 21 male, with another 43 too young to identify as male or female. She also had 32 other female fruit trees of various species of which 15 were male. Here the density of marula stems in fields averages nearly 9 per hectare of which 5 are fruiting trees.

**Secondary Objectives**

The study has also been useful for estimating, for the first time in Namibia, the potential supply of marula by developing models using tree diameter (calculated from trunk circumference) and canopy size to predict future yield, based on the yield figures for 2002. Another indirect benefit of this survey has been the identification of cultivars as orchard trees for propagation trials. In addition, the study aimed to test and develop simple indicators (trunk circumference, canopy size, age, health, and alike for local women to be able to monitor fruit yields of their trees in future years. And with a suitable methodology for estimating fruit yields, this study aimed to develop improved prediction models based on the strongest and most reliable correlations identified in this study.

**METHODOLOGY**

**Sampling**

The marula trees chosen for this study were not randomly selected. The results of this study, therefore, are not statistically valid, but they do offer a better understanding of the relationship between tree size and fruit yields as well as the positive impact of farming and domestication of fruit trees on yield.

The choice of trees to measure was a subjective process for two reasons. Firstly, because of the protracted nature of the marula fruiting season, marula trees in North-Central Namibia abscise their fruit between December and May. Only after the first marula trees had dropped their fruit did this study begin. At this time (March), the marula fruiting season was in full swing and some of the early fruiting trees had even finished fruiting. Trees already fruiting could not be included in this survey for the obvious reason that yields would not include all fruit produced within a single season. Similarly, “winter trees” - trees which fruit late in the season (April/May/June) - were excluded from this study as data collection was scheduled to finish in April. The extremes therefore - at the beginning and end - of the season were not included in this research study and only trees that started fruiting in the peak season were included.

The second subjective selection of trees relates to the importance of designing a methodology for weighing fruit yields which mirrors the rhythm of the women’s work. To ensure that data collection did not conflict too heavily with people’s daily routines and to minimise the demands of this research on people’s time, farmers and their wives chose their favourite trees. These were inevitably the trees with the best fruit (sweetest, largest, easiest to decorticate,
most productive). These trees also tended to be located inside or close to people’s homesteads. This subjective selection of trees, therefore, is not statistically sound because it will most likely cause an overestimate of average yield, a bias in favour of the best fruit and the highest yielding trees.

**Data Collection: Weighing and Recording Marula Fruit Yields**

Initially, women were asked to separate the usable fruit and unusable fruit and weigh them individually. In practice, most women did not differentiate between usable and unusable fruit on their recording sheets. Although some women did methodically separate and weigh the two types of fruit, to overcome any confusion, in the final analysis both categories of fruit were combined to give the total seasonal fruit yield. It is this total which is correlated with the different aspects of tree size in the final analysis.

Researchers worked with the women owners of trees. In most instances the matriarch devolved the actual weighing of fruits to younger women in the homestead, the primary marula harvesters and processors in actual practice. Because many older women are semiliterate and are “afraid of this technology” (the weighing scales) younger women and girls of school age were responsible for recording fruit yields on specially designed, simple data sheets. Periodically researchers went back to check if the weighing and recording was going well.

The original intention was to survey 120 individual marula trees spread across the four regions making up North-Central Namibia. In the final instance data was collected from 104 trees, from 20 farm plots in 8 sample sites spread across 3 regions (See Map 2). A total of 16 trees were omitted from the survey because recording forms were not returned. The largest omission was from the Eunda site where Ministry of Agriculture, Water and Rural Development extension officers responsible for conducting the tree survey were unable to carry out the work due to a lack of transport.

Measurements describing different aspects of the tree (fruit yield, trunk size, canopy area, age, height, and alike were collected from most of these trees sampled.

**DATA ANALYSIS**

A significant proportion of the 104 trees surveyed were removed from the final data analysis because the weighing-recording of fruit yields was not completed correctly. Numerous unforeseen circumstances occurred preventing women from completing the weighing process. Typical examples of why sample trees were not completed correctly and therefore excluded from the final analysis include:
* snakes moved into trees preventing weighing
* trees were chopped down after recording began (because they were unsafe)
* some trees were measured for a few days or weeks only, not the full fruiting season because those girls responsible had to go back to school
* yields were recorded incorrectly e.g. a unfeasibly high total yield of 5,000 kilograms was recorded in one instance, inferring this, and other extreme results, were suspect
* recording sheets were lost, incomplete or damaged
* goats ate the fruit meant for weighing
* trees were struck by lightning damaging the tree and the fruit
the quality of fruit was so poor that women stopped harvesting (and therefore weighing) the tree

some trees were too old and did not produce fruit this season

Data cleanup also forced the removal of other trees from the final analysis. Apart from incomplete yield figures for a number of trees, often one aspect of a tree was left out of the original tree survey (tree height, trunk size, canopy size, age and alike. In these instances as well, the relationship between that particular tree characteristic and its yield could not be analysed simply because the data was missing. Finally, ‘outlier values’, extreme values, in the data sets were scrutinised and in some instances removed (particularly if, after going back to the original recording sheets, they were considered errors) otherwise results would be skewed towards these extreme values. It must be noted that marula trees do naturally experience considerable variability in their size and appearance, as well as total fruit yields over a season. This natural variability was respected. Trees with extremely high or low yields, or extremely large or small physical characteristics (trunk, canopy, height, age, and alike were included in the final analysis because it is precisely this variability which we are trying to understand to predict fruit yields.

Factors Affecting Fruit Yield and Indicators Measured

Soil types and land forms combined with rainfall play a key role in marula fruit yields. Within the scope of this study it was not possible to conduct a temporal/spatial study of rainfall and its effect on fruit yields. Similarly, it was not possible to classify soil types and associated land forms to understand how soil fertility and drainage affects fruit yield. Soils do vary enormously within people’s fields and farm plots as well as between regions. Soils often vary over space of a few metres. And individual trees tap different soil types by extending over a wide area. The researchers conducting this marula study were not trained in soil analysis in the field. This study recommends a deeper analysis to test the relationship between rainfall and various soil/land classifications which, it is believed, are primary factors effecting fruit yield. Working with local farmers and their wives to classify soil/land types would be a good starting point. It would be extremely useful to include an assessment of soil depth above the water table, and to correlate this to time of fruiting and fruit yield.

Another variable which farmers mentioned affected fruit yield is the occurrence and severity of a natural plant parasite of the mistletoe family, Erianthemum dregei (Loranthaceae). From the survey it appears that marula trees most affected by parasites occur in and around towns and in the southern part of the study areas (the Okahao and Ondangwa sites on the extreme natural range of marula in Namibia. See Map 2). Perhaps their prevalence is due to environmental stress, such as drought and poorer soils, making them weaker and more susceptible to disease, such as parasites. Birds, the host and transport agent for the parasite, congregate in towns in southern regions because there is more food and more fruit trees in these locations compared to the surrounding, open, bare land. Birds in the forested regions in the far north of the study area, on the other hand, have a richer choice of trees to feed from and roost in, making the incidence of parasites in people’s fields much lower. Photos 4, 5 and 6, show young and old trees affected by this plant parasite.

In fruiting trees the size of the canopy (width x height in this survey) and the diameter of the trunk (at 50 cm above ground level in this survey) are traditionally good indicators of the productive capacity of a given tree. These relationships were measured in the field and statistically tested using a simple correlation between canopy size and total fruit yield of trees as well as trunk size and fruit yield.
The significance of this correlation (between canopy size, as well as trunk size, and fruit yield) was tested using simple regression analysis. It should be noted that the physiognomy of marula trees varies enormously from tree to tree. Typically, marula trees have between one and three stems (main trunks). In the final analysis these trunks were combined in order to give a total trunk size. In the same way canopy size and its condition varies considerably from tree to tree, most notably with age and health (old and sick trees have a relatively thin canopy which “look like an old man’s hair” according to one farmer). Trees affected by parasites also have a thinner canopy cover.

Women were asked the age of each tree in order to test the relationship between age and yield. This seemed an appropriate idea because locally this concept would be easily understood. If age did correlate closely with fruit yield it might be a simple and cheap means of monitoring and predicting fruit yields in the future. Unfortunately, respondents in too many instances were unsure of the age of trees, particularly the largest trees, many of which were thought to be more than 100 years old because they were known to be older than any living person in the area. The age of these oldest trees were estimated based on known events and people of the past and are probably within 10-20 years of their true age. Even so, according to this survey, age was not a reliable indicator of fruit yield.

As we have mentioned, a number of factors affected the reliability of fruit yield values used in this study. Below are some more factors which caused specific fruit yield results to be excluded from analysis:

* The quantity of usable and unusable fruit is unknown. Bad and damaged fruits were almost certainly included in the final analysis whilst in other instances bad fruit was ignored by harvesters.
* Unmeasured fruit almost certainly fell onto piles of fruit already measured meaning the actual number of fruits was higher than recorded.
* Fruit fly adds dramatically to the quantity of fruit which perished. Towards the end of the season these unusable fruit are often ignored by harvesters and excluded from the survey yields figures.

Within this survey, although it was attempted, there is no reliable record of the proportion of useable and unusable fruit within the total fruit values. Women did mention that towards the end of some fruiting seasons there can often be a glut of fruit; women cannot process all that is available. Perished fruit is ignored and left to rot. It is believed, therefore, that the quantity of unusable fruit is quite high in some instances and yields should not be seen as the exact amount of fruit produced by trees.

The size and quality of fruits varies considerably from tree to tree. Some trees produce exceptionally large fruit (averaging 60 grams plus) whilst others produce tiny fruits (less than 10 grams). Exceptional fruit trees are well known locally. And some male trees produce a small number of fruit each year (see Photo 10) while some female trees produce fruit intermittently and not every year. One tree included in this survey suddenly started fruiting for the first time when it was more than 40 years old. The owner explained that she thought it was a male until it unexpectedly started fruiting and, in 2002, produced more than 1,000 kilograms of fruit. This broad temporal variability - the occasional fruiter, the infertile and the exceptionally fertile - was not captured within this study.
As we have mentioned, rainfall is a primary determinant of yield. And Namibia is prone to extreme variations in rainfall; year to year and place to place. A typical example of this is a comparison of rainfall patterns this year (2002) compared with last year and its suspected effect on the two fruiting seasons. Rainfall was good initially this year (2002) but quickly died off. As a result, most marula trees fruited early and most had finished by the beginning of May, 2002. Last year (2001), on the other hand, the rains came late and fell heavily at the end of the season, continuing even after May. Similarly, the fruiting season was late. How rainfall effects yield cannot be tested in a single year in a survey such as this. The results of this year, therefore, are not indicative of other seasons. In a few cases the trees and their fruit characteristics were known to the researchers from work done in the 2001 season and – especially in the case of late fruiters – these trees were observed to have smaller and less juicy fruits than in 2001. The overall effects of the early cessation of the 2002 rains on yields cannot be quantified accurately, except to state that late trees had fewer and drier fruits in 2002 than in 2001.

**RESULTS**

**Analysis of the Sample Population: Averages**

Below is a description of the ‘average tree’ based on the results of this survey (See Appendix 2). Sample sizes are given:

<table>
<thead>
<tr>
<th>Tree characteristic measured</th>
<th>Sample size</th>
<th>Tree average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total fruit yield (2002)</td>
<td>56</td>
<td>596 kilograms (std. dev. 465kg)</td>
</tr>
<tr>
<td>Average fruit mass</td>
<td>49</td>
<td>30 grams</td>
</tr>
<tr>
<td>Canopy size (w x h)</td>
<td>56</td>
<td>45 square metres</td>
</tr>
<tr>
<td>Trunk diameter</td>
<td>90</td>
<td>67 centimetres</td>
</tr>
<tr>
<td>Tree height</td>
<td>100</td>
<td>10.2 metres</td>
</tr>
<tr>
<td>Tree age</td>
<td>65</td>
<td>53 years</td>
</tr>
</tbody>
</table>

The total fruit yield of individual trees for the 2002 season varied from a few kilograms (from a tree which was fruiting for the first time), to a high of 2,860 kilograms, (from one very impressive, 17 and a half metre high, 80 year old tree called "Nangubu", meaning, “in the thorn brush fence”). Of the 11 fruiting trees in this woman’s fields, this exceptionally large tree was the owner’s favourite because of its large shade area, its prodigious yield and the exceptional size of its juicy, sweet fruit. Among the discarded data were records of trees bearing up to 5,000 kg of fruit, which – although discarded – is not impossible, as there are records from Botswana of some trees bearing up to 6 tons of fruit in a single season. Other extremes include very old trees (more than 100 years old), and very young trees (producing fruit for the first or second time). The results of the survey indicate that very young and old trees often net less than 100 kilograms in a season. Of the 56 trees measured for yield the average was 596 kilograms, and includes both useable and unusable fruit. The high standard deviation – 465 kilograms - reveals wide variability in fruit yields between trees. The median yield is 482 kilograms and the mode was 100 kilograms. Calculating the average mass of individual fruits was done by the women by weighing 150 fruits and dividing the net weight by 150. Of the 49 trees measured the average fruit size was 30 grams. Although the scales used were not sufficiently accurate to make these results
reliable, what the results do show is the wide variability in fruit mass between individual trees. The trees in Photos 7 and 8 produced fruit of around 50g in mass. Unfortunately, these particular fruit perished before they were weighed properly. Leakey et al (in press) recorded a mean fruit mass of 26.68g for Namibian marula, excluding the highly exceptional “Namibian Wonder”, which had a mean fruit mass of 69.9 g. Photo 10 shows small and unusable fruit produced by (some) male trees.

Trees as young as 5 years old are producing fruit, although this is an exceptional example. (The next youngest tree bearing fruit in this survey was 10 years old – grafted trees have, however, been reported to fruit after three years). Six trees were estimated by their owners to be more than 100 years old, and recorded as such. As mentioned earlier, most of these very old and very young trees produced only a few fruit but were included in the analysis because of this natural skew. The average age for trees in this survey was 53 years. There was a weak statistical relationship between the ages of trees and their yield (with a correlation coefficient of 0.22 for the sample population of 46 trees).

The height of fruiting trees was calculated using an abney level and a simple formula based on distance and angle to the bottom and top of each tree, respectively. Trees varied from 3.99 to 21.43 metres high with an average of 10.2 metres for the 100 trees measured.

Analysis of the Sample Population: Correlation Coefficients

Throughout the analysis a simple correlation formula (R) was used to test the relationship between any two given parameters: in this instance, tree height and fruit yield. This same formula was used throughout this analysis to test the relationship between other variables, such as tree age and fruit yield, tree girth and fruit yield, tree canopy size and fruit yield, etc, to give a correlation coefficient between 0 and 1.

As a rule of thumb a simple correlation (R) of 0.5 reveals a statistical relationship but not a very strong one; it explains half the relationship between the two variables; 1.0 shows a perfect correlation and 0 indicates no relationship at all. For example, the simple correlation coefficient (R value) for tree height and fruit yield was 0.56 (n=100) and shows a relationship between the two variables; tree height being a determinant affecting tree yield.

The relative importance of the R value depends on the sample size. The larger the sample size, the lower the value of R that can be accepted as indicating a significant relationship. R is the index of the variability accounted for around the mean relationship between two measures (e.g. fruit yield and stem circumference). The real interpretation of the R value depends upon its associated P value. P value indicates the statistical significance, i.e. the statistical probability of obtaining the relationship measured by R by mere chance. The greater the sample size the lower the theoretical probability of this happening, and hence a lower R value.

International convention in biological science is that P must be 0.05 or less to be acceptable, indicating that only 5% of the time will we have said there was a significant relationship when it was actually not so. (In medical sciences it is 0.01 or less).

1 A simple correlation R-value of 0.7 can also be expressed, and corresponds to, a multiple R² value of 0.5.

It should be noted that no detailed analysis of standard error or the residual were done in this study although figures are included in the statistical tables included in Appendices 5 and 6 for reference.
When studying natural phenomena, a simple correlation (R value) of 0.6 to 0.7 reveals a satisfactory correlation (although this is dependent on the sample size and associated P value). As we have explained, one of the goals of this study is to try and develop prediction models based on the most reliable variables measured. With a satisfactory correlation we can perform simple regression to make predictions. Only variables known to have the strongest relationship with each other can be employed to generate prediction models. For example, estimating fruit yield from the age of a tree will not produce a reliable prediction model. Later we will see that tree girth and canopy size have the strongest and most reliable relationship with fruit yield and it is these parameters that are used to develop a prediction model (refer to Appendices 5 and 6).

Logically, canopy size (width x height x depth of an ellipse to nearest half metre) is a good indicator of fruit yields, where a thick, healthy, expansive leaf crown produces more fruit than a small, sparse, unhealthy canopy. In forestry inventories, trunk diameter is traditionally a relatively simple parameter to measure. This study measured only width x height to give a two-dimensional, cross-sectional area for canopy size. This is why canopy size in this report is measured in square metres, not cubic metres. Based on the entire sample population, canopy size and trunk diameter were analysed to see if they had a convincing statistical relationship with fruit yields.

Canopy size (height x width) varied considerably, from 3 to 231 metres$^2$. Even within this large spread, the results of this survey highlight a good correlation between canopy size and fruit yield (See Figure 1 below). Out of the 56 trees measured there was a correlation coefficient of 0.67 with an acceptable P value of $< 0.05$. This indicates a significant relationship between the size of a marula tree’s canopy and its fruit yield, even with extreme values included. The scatter graph below shows this relationship; a generally linear relationship with extreme values as outliers located on the edges of the graph. Examples of outliers are highlighted with grey star icons on the graph. (The data set for this graph is included in Appendix 3).
The girth of trees was measured and analysed to see if there was a direct relationship between the size of a tree trunk and fruit yield. The correlation coefficient for the sample population of 67 trees measured was 0.59 which ($P < 0.05$) indicates a significant relationship. It should be noted that even with extreme values included in these calculations, of which there were 11 (16% of all trees measured), there was still a strong relationship recorded between the size of a tree’s trunk and its fruit yield. For example, some trees with large trunks had low fruit yields mainly because they were very old and virtually infertile. And some small trees, mostly those fruiting for the first or second time, also produced very low quantities of fruit. Even with this variability included within calculations there does appear to be a strong relationship between the size of a tree’s trunk and its fruit yield. The scatter graph below shows this relationship; a generally linear distribution with extreme high and low values appearing as outliers, depicted on the graph as grey star icons (the data set for this graph is included in Appendix 4).
Simple Correlation Coefficient = $0.59$  

P value = $< 0.05$

**Analysis of each Region**

To provide a more detailed picture of the sample population, an analysis of the relationship between canopy size and fruit yields, and trunk size and fruit yields, was conducted for each of the three administrative regions within the study area (see Map 2).

**An Analysis of the Relationship between Fruit Yield and Canopy Size by Region**

The figures below indicate that the Omusati Region has a very strong correlation between canopy size and fruit yield; 0.9 is a very strong relationship for a natural phenomenon such as this. Ohangwena has a weaker (but still significant) relationship of 0.4 and Oshana has a good relationship of 0.59. Within the population average of 0.67 then, there is considerable variability between each of the regions.

<table>
<thead>
<tr>
<th>Region</th>
<th>Sample Size</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omusati</td>
<td>22</td>
<td>0.90</td>
</tr>
<tr>
<td>Ohangwena</td>
<td>12</td>
<td>0.40</td>
</tr>
<tr>
<td>Oshana</td>
<td>22</td>
<td>0.59</td>
</tr>
</tbody>
</table>

The graph below and data set (included in Appendix 3) show that the Omusati Region is dominated by a few large trees and many small trees. Within this variability though is a
strong, linear correlation. Based on the Omusati sample of 22 trees the Region has a few large, old trees producing a lot of fruit, (the largest with a canopy of 145 metres and a fruit yield of 2055 kg), but the region is characterised by relatively small trees producing average yields. Typically, trees have a canopy of 5-35 metres, producing between 25-400 kilograms of fruit. The exceptionally high correlation of 0.9 shows that there is little variability in yield when trees are the same size. One exception was a tree with a canopy size of 27 metres² producing just 7 kilograms of fruit during the entire season. This tree is typical of the natural variability within the marula population throughout the study area in the sense that it is a very old tree and, although large to look at, has a sparse canopy and numerous broken branches, some of which are hollow. Its old age makes marula yield difficult to predict; according to farmers, older trees fruit well in some years and poorly in others, such as this year, 2002.

Figure 3: Fruit Yield Prediction Model based on Canopy Size for Omusati Region

![Fruit Yield Prediction Model](image_url)

Simple Correlation Coefficient = 0.90
The distribution of points on the graph for Ohangwena above shows the (almost) random relationship between yield and canopy size in this Region. (The data set for Ohangwena is included in Appendix 3). The high variability in fruit yields between trees of the same size is revealed by the low correlation coefficient of 0.40. This region sampled mostly medium and large trees with a high variability in fruit yield within these classes. For example one large tree with a canopy size of 66 metres² produced 1650 kg fruit whilst a slightly larger tree with a 77 metre canopy produced just 424 kilograms, that’s about 25% the yield of a tree the same size. One medium-sized tree with a 54 metre canopy produced 1170 kilograms. And the tree with the largest canopy of the entire sample population, 231 metres in size, produced fewer fruit, just 1130 kilograms in all. This variability is compounded by the relatively small sample size in Ohangwena (n=12), where extreme values have a strong influence on the overall trend.

The Oshana Region had a good correlation of 0.59 calculated from 22 trees sampled. All of the trees measured were small or medium with a canopy size less than 55 metres. Large variations in fruit yields did occur though. For example, five trees had a canopy size of 33 metres but their fruit yields varied from 395 to 1310 kilograms (the data set for this graph is included in Appendix 3).
Comparing the three regions, Oshana has the most productive trees for their size, followed by Omusati and then Ohangwena. More importantly, small trees in Ohangwena produce quite reasonable yields. But the rate of yield increase is low where even a big increase in canopy size relates to a small increase in yield. This is shown by the relatively flat prediction line in Ohangwena compared with Omusati and Oshana. These two regions experience small trees with small yields but, as the tree size increases, so yields improve dramatically. This is particularly the case in the Oshana Region where a small increase in tree size corresponds to a significant improvement in fruit yield. Based on subjective field observations, the inverse seems more likely. Personal observations and discussions with local marula producers indicate that the biggest marula trees and the highest fruit yields are experienced in Ohangwena. This is related to the soils and rainfall which tend to be better in Ohangwena. It would be expected, therefore, that tree size and fruit yields would also be better in Ohangwena, which is not the case according to these data sets.

**An Analysis of the Relationship between Fruit Yield and Trunk Size by Region**

Based on the correlation coefficient of 0.59 for the entire population (where n=67) there appears to be a good relationship between the size of a tree’s trunk and its fruit yield. Further analysis by region allowed comparison of this relationship in more detail (data sets are included in Appendix 4)

<table>
<thead>
<tr>
<th>Region</th>
<th>Sample Size</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omusati</td>
<td>19</td>
<td>0.76</td>
</tr>
<tr>
<td>Ohangwena</td>
<td>16</td>
<td>0.24</td>
</tr>
<tr>
<td>Oshana</td>
<td>32</td>
<td>0.56</td>
</tr>
</tbody>
</table>
If we compare each of the three regions on the graphs below it is clear that there is a well defined relationship between trunk size and fruit yields of trees in the Omusati and Oshana Regions. The Ohangwena Region, once again, has a weak relationship of 0.24.

Figure 6: Fruit Yield Prediction Model From Trunk Circumference in Omusati Region

The Omusati Region experiences a generally linear relationship with two extreme values: 2.95 metre trunk producing 7kg and 3.45 metre trunk producing 2055.5kg (grey star icons on the graph). (The data set for this graph is included in Appendix 4).

With a low correlation coefficient of 0.24 there is little point in plotting a graph or developing a prediction model for the Ohangwena Region. The error is just too high. For example, one tree with a trunk circumference of 2.45 metres produced a yield of 400 kilograms whilst a tree of similar size - a circumference of 2.54 metres - produced 1,650 kilograms, more than four times as many fruit. To compound the variability experienced in Ohangwena is its small sample size, just 16 trees, which further increases any differences between trees. This compares with a much lower variability in Omusati (where n=19) and Oshana (where n=32) with correlation coefficients of 0.76 and 0.56, respectively. (The data set for this graph is included in Appendix 4).

The Oshana Region does have some extreme variability within the general trend. The two largest trees (grey star icons on the graph) are virtually the same size (3.54 m and 3.86 m) but produced very different yields (2,862kg and 739kg, respectively). As well, the graph also shows quite high variations in fruit yield from small and medium sized trees. (The data set for this graph is included in Appendix 4).
Comparing the two regions, Omusati and Oshana, they experience a similar (almost identical) relationship between fruit yield and trunk size. A small increase in trunk size produces similar improvements in yield.

**Prediction Models**

**Description and Explanation of Results**

The data sets on canopy size and trunk size were considered reliable enough to develop yield prediction models from the survey data. Each of the graphs describing regional data sets above includes a line showing the predicted fruit yields for each region. The only exception is the exclusion of a prediction model based on trunk circumference data in the Ohangwena Region. Here the data was considered to be so random and the correlation so poor, 0.24, that any prediction would have been little more than guesswork. (For reference purposes this data set and a scatter graph for Ohangwena is included in Appendix 4).

To minimize potential errors the prediction models below are derived from the total sample population. Data sets, regression outputs and scatter graphs for yield predictions using canopy size are included in Appendix 5. Data sets, regression outputs and scatter graphs for yield predictions based on trunk size are included in Appendix 6.

Using a simple linear regression function, two separate models were developed. These models are based on x and y axis coefficients (refer to Appendix 6 for details) calculated from, firstly, canopy size and yield data (with a correlation of 0.67), and secondly, from trunk size and yield data (with a correlation of 0.59). To make predictions of natural phenomenon it is, as a rule of thumb, considered wise to have a good correlation coefficient of at least 0.6.
Fruit Yield Prediction Model Using Canopy Size

The graph below shows the predicted marula fruit yield using measured yields and associated tree canopy sizes.

Figure 8: Fruit Yield Prediction Model Based on Canopy Size For All Regions

Simple (linear) correlation coefficient = 0.67
Nonlinear (curve) correlation coefficient = 0.79

Evidence from marula harvesters, as well as personal observation, suggests that the relationship between canopy size and fruit yield is not linear: smaller and medium sized fruiting trees produce relatively more fruit than very large trees. There is no doubt that examples of trees with large canopies can produce high yields of more than 2,500 kilograms but it appears, both from anecdotal evidence and from the results of this survey that yields do not increase in a linear fashion. Rather, as trees grow in size, yield tapers off.

A ‘Curve Expert’ package was applied to test this hypothesis. It was found that as canopy size increases so yield improves relatively slowly. The best fit curve\(^2\) produced a concave curve, describing a non-linear relationship between canopy size and fruit yield (refer to the graph above). With this curve formula applied there was an improved correlation coefficient, 0.79, compared with simple (linear) correlation of 0.67.

\(^2\) The curve is defined as \(y=a*e^{(b/x)}\) where; \(y=\text{yield}; a=1538.66; b=-31.06\) (from the Excel package); \(x=\text{canopy size}\)
**Fruit Yield Prediction Model Using Tree Circumference**

The graph below shows the predicted fruit yield using measured tree trunk size. (Refer also to Appendix 5 for data sets, regression analysis output and prediction model statistics).

Figure 9: Fruit Yield Prediction Model Based on Trunk Circumference For All Regions

![Graph showing fruit yield prediction model](image)

Using measured tree circumference sizes and related yield the regression analysis and the Curve Expert package both produced a prediction model with a straight line. Based on the results of this survey a linear relationship best represents the effect of trunk size on fruit yields.

**CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH**

This study is the first of its kind to try to quantify marula fruit yields in North-Central Namibia.

Not surprisingly, the results of this survey reveal a direct relationship between tree size (trunk, canopy and height) and corresponding fruit yields.

As a starting point a random sampling method is recommended to ensure data collected is statistically valid. This data is not statistically valid because of the sampling method employed (refer to section on Methodology above) but there does appear to be a strong relationship between observed fruit yields and trunk size and fruit yields and canopy size.
Canopy size has a non-linear (curved) relationship and trunk size experiences a linear relationship.

Although the survey data used is considered reliable it is a small sample (less than 100 trees) of the population (estimated to be more than a million trees). In future it is recommended that a larger sample of trees be measured from a smaller number of locations, to minimize costs and to improve the reliability of data collection: it is quicker and easier and cheaper to train, say, three field workers (women harvesters) than numerous assistants spread across a large geographical area (as was the case with this survey). And better to gather very detailed data from specific sites than superficial data from a number of locations.

For example, the data from Ohangwena is suspect in that it does not correlate closely with what is known about marula trees in this important marula growing area. The results from Ohangwena have relatively low correlations and, more importantly, marula yields: tree size differs markedly from the results of the other two regions.

With a larger sample of trees and a more reliable data set to work from it is recommended that a multiple regression analysis be employed. This will enable researchers to test the relationship between more than two variables using, for example, trunk circumference, canopy size and tree height together with measured fruit yields to predict potential fruit yields with greater accuracy. This might improve the correlation coefficients, but does require more sophisticated software and a better understanding of the potentials and pitfalls of statistics. In this study we have only conducted simple regression using two tree parameters at any time: canopy size and yield; and trunk size and yield. This could be a worthwhile student project, unless there is funding available to conduct more detailed survey work through other organizations such as CRIAA SA-DC.

It is recommended that the prediction models developed here should be tested, refined and adapted using new data from future fruiting seasons. As they stand at the moment, these models are prototype predictions and have not been tested in the field. It could be the case that these results mask the true relationship between tree size and fruit yield; just because they fit the data sets of this survey does not mean they are true. It is simply the case that most of the basic data is statistically reliable and there is consistency in the results.

As well as tree size and fruit yield this study recommends a deeper analysis to test the relationship between rainfall and various soil/land classifications which, it is believed, are primary factors effecting fruit yield. Working with local farmers and their wives to classify soil/land types would be a good starting point. It would be extremely useful to include an assessment of soil depth above the water table, and to correlate this to time of fruiting and fruit yield.

It is hoped that in the future planners and researchers could estimate fruit production from marula trees in North-Central Namibia cheaply and quickly. This is important within the broader marula industry because it is important to estimate the potential production of fruit in a given area. If we can develop simple and effective prediction models based on a measured characteristics of marula trees (height, canopy size/health, trunk size, and alike, it will be relatively easy and cheap to estimate marula yield once the size and number of trees is known. Further down the line this could enable planners to accurately estimate the sustainable supply of marula fruit products to local and growing overseas markets. Currently there is no estimate of fruit yields or the potential (sustainable) supply of marula to these markets.
These are very preliminary figures, but based on the results of this survey, and supported by recent studies, the average marula tree produces 596 kilograms of fruit. Combined with (conservative) figures of one million marula trees (Botelle 2001), of which 80% are estimated to be female (Botelle 2001; Hangula 2000), the total marula fruit yield for the North-Central Regions is likely to be in the order of 450,000 to 500,000 metric tons per annum. This constitutes a huge potential resource.

It is recommended that the Directorate of Forestry in Namibia carry out an inventory of marula trees to find out how many there are. This project should begin in the most important marula growing area of Namibia, the North-Central Regions, and extend to the Kavango and Caprivi Regions.

**Winners and Losers in the Commercialisation of Marula**

Anecdotal and scientific evidence (Botelle, 2001; Leakey et al, forthcoming, and other research papers within this FRP research project) reveal a positive relationship between the local human population and fruiting (female) marula trees in North-Central Namibia.

Over centuries, intensive use and selection of the best marula fruiting trees has had a direct and positive impact on the marula resource. Today, fruiting marula trees have been integrated into local farming systems and domesticated; 95% of all marula occur in people’s fields, with an average of 4-5 female trees per hectare. The best marula trees (those with the most desirable fruit) have been planted and/or protected to the point that they now occur throughout the region, particularly on the most productive farmland.

With the commercialisation of marula throughout the late 1990s, more and more local farmers and their wives are protecting and planting marula trees. And there are plans within Namibia’s Directorate of Forestry to actively propagate high-yielding marula cultivars with exceptional fruiting qualities. As far as the marula resource is concerned then, they are one of the winners of the commercialisation of marula with better quality fruiting trees being planted more intensively throughout the region, particularly in people’s fields and on the best soils.

Another winner must be the local farmer who can now sell marula fruit products for the first time to outside buyers at a reasonable price which is guaranteed through an international fair trade agreement with The Body Shop International, based in the UK. Urban populations, outside of marula growing areas, within Namibia are also able to buy marula products for the first time. They are also winners in the commercialisation of the marula trade. And overseas consumers are benefiting from the commercialisation of marula. They can now buy products they have never before seen or used before. The chain of positive spin-offs occurs at all levels.

The principal losers are the (non-fruiting) male marula trees which have seen a relative decline in numbers, although this is not a direct result of the commercialisation of marula but a longer term trend within the local farming system to select productive trees and reduce non-productive trees from arable fields which may compete with crops. Other potential losers are marula growing areas in northern Namibia – the Kavango and Caprivi Regions for example – which have so far been left out of the newly established international marula trade. As well, local producers within the North-Central Namibia not yet part of the commercial chain have not benefited directly from the commercialisation of the marula industry.
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