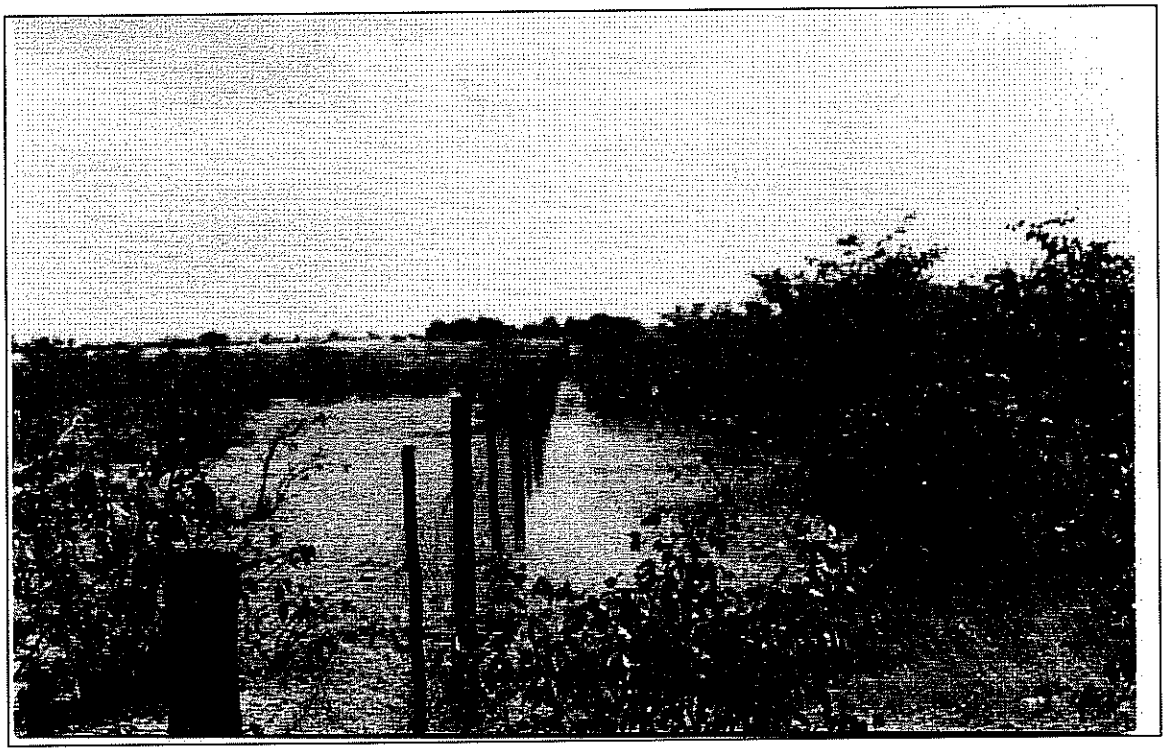
MOPANE SHRUBLAND MANAGEMENT TRIAL at DAPP-Onambelela

DRAFT REPORT

RESULT FOR 1995-2002 Measurements & Treatments



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SUMMARY

Being an important tree species in Namibia both for human beings and other living organisms, *Colosphospermum mopane*, has been under enormous pressure over the past few decades. Areas what in the past have been covered by most valuable, productive and tall mature mopane trees are now extensively covered by least productive, crooked, stunted and slow growing mopane shrubs, which are useful only for household uses such as fuelwood. Due to these pressure of mopane in Namibia, it was recognised that there is an urgent need to address this problem by setting up trials which would look into an efficient way of managing both remnant mopane shrubland and mature mopane stands in a sustainable manner in order to cater the needs of local people while at the same time trying to reduce the incidence of over harvesting mopane stands. A trial titled 'Mopane Shrubland Management Trial' was set up at Onambelela in Omusati region in the year 1995 with aid and participation of local community. Four different treatments have been applied and their effects on the growth of mopane have been studied and evaluated over the past eight years (1995-2002). The results have demonstrated that thinning mopane stands, can actual increases the productivity of the mopane shrubland land while at high density the productivity of mopane stands can be reduced.

1. Introduction

Colophospermum mopane (Kirk ex Benth.) Kirk ex J. Leonard, commonly known as mopane, is an important tree species in Namibia. It stretches southwards from Kunene River towards the Ugab and northeastward towards Namutoni. Small patches are also found in Caprivi (Lewis, 1991 and Mapaure, 1994). It is a multipurpose tree species and it is extensively used in Namibia especially in the northern part of the country. There, people use the branches of mopane for firewood, for making grain granary, for roof frames and for fencing. The barks are used for tying kraal fences and hut frames together and to hold grass on roof (Rodin, 1985). The stems (small, medium and larger) are used for axe and hoe handles, for pestles, for mortals and for fencing and building poles (Gelens, 1999). You can also get medicine from the bark, roots and gum; tannin from the bark and resin from the seeds (Timberlake, 1999). The dead roots are harvested, sandblasted and marketed as ornaments (Piepmeyer, 1999).

The population in the northern part of the country (now comprised of 4 region: Omusati, Oshana, Oshikoto and Ohangwena) has been increasing from 230,000 to 550,000 between 1960 and 1990 and as a result there has been an increase in the number of homestead in the region (Conroy, 1999). Increases in houses number have enormously caused pressure on *C. mopane*, as many people have become more and more relying on mopane products for their daily subsistence. This in return caused mopane deforestation and what has been a tall mopane trees is now an area extensively covered by mopane shrub land.

C. mopane is not only an important tree species for human beings but also to many animals and some insects. Livestock such as goats and cattle as well as wild animals such as elephants have been reported to enormously browsing on mopane leaves and branches especially when grass is scarce during drought periods or dry seasons (Styles, 1993). Also the mopane worms, a caterpillar of emperor moth (*Imbrasia belina*), which is the most important food for many people in Southern Africa, feed on the nutritious leaves of mopane (Styles, 1994). In most cases, when people harvest the mopane worms, they tend to break or cut off the mopane branches in order to reach for the worms and this can also happen when animals browse on mopane. In the process, the growth of mopane trees is highly disturbed and slowed down.

Because of this increasing importance of mopane to human beings as well as to other living organisms and because of the impacts these living things have on mopane, an idea of establishing at trial, which aims to find proper way of managing mopane in Namibia was initiated. This trial was titled "Mopane Shrubland Management Trial" and was established in 1995 at Onambelela-Ombalantu in Omusati region. The main objective of the trial is to assess the growth and yield of mopane shrub when protected and managed along with the lines, which give products desirable to local farmers. The trial is comprised of four treatments, in which the control is included.

Since the establishment of the trial, the effect of treatments on the growth of mopane has been evaluated. Any differences or similarities, which occur, as a result of these treatments are what this report is about.

2. Site Description

2.1 Location

The Mopane shrubland management trial is situated at Onambelela, which is in the central part of Northern Namibia and it is about 8 km southeast of Outapi-Ombalantu in the Omusati region **(See Map 1 and 2)**. It is located at 15°10' E and 17°35' S and at an altitude of 1100 m above sea level (Gelens, 1999). The trial site covers an area of about 20 ha.

Figure 1. **Map of north-central Namibia showing the location of the trial site**

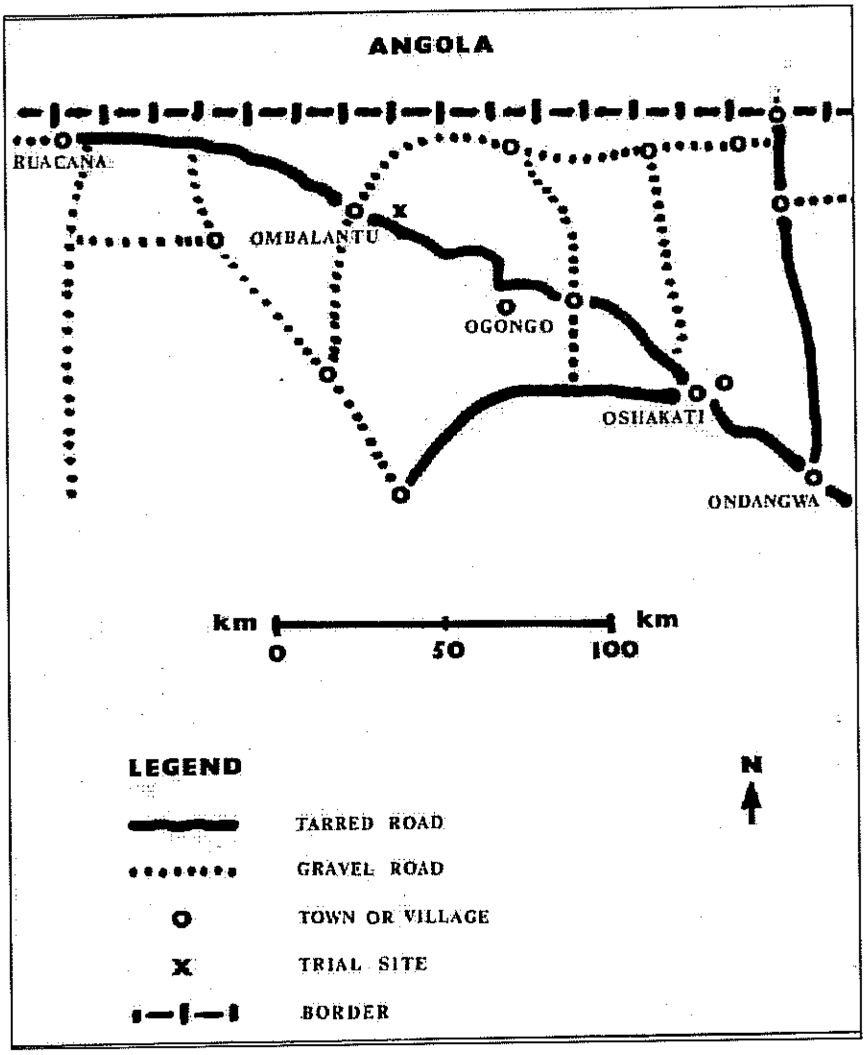
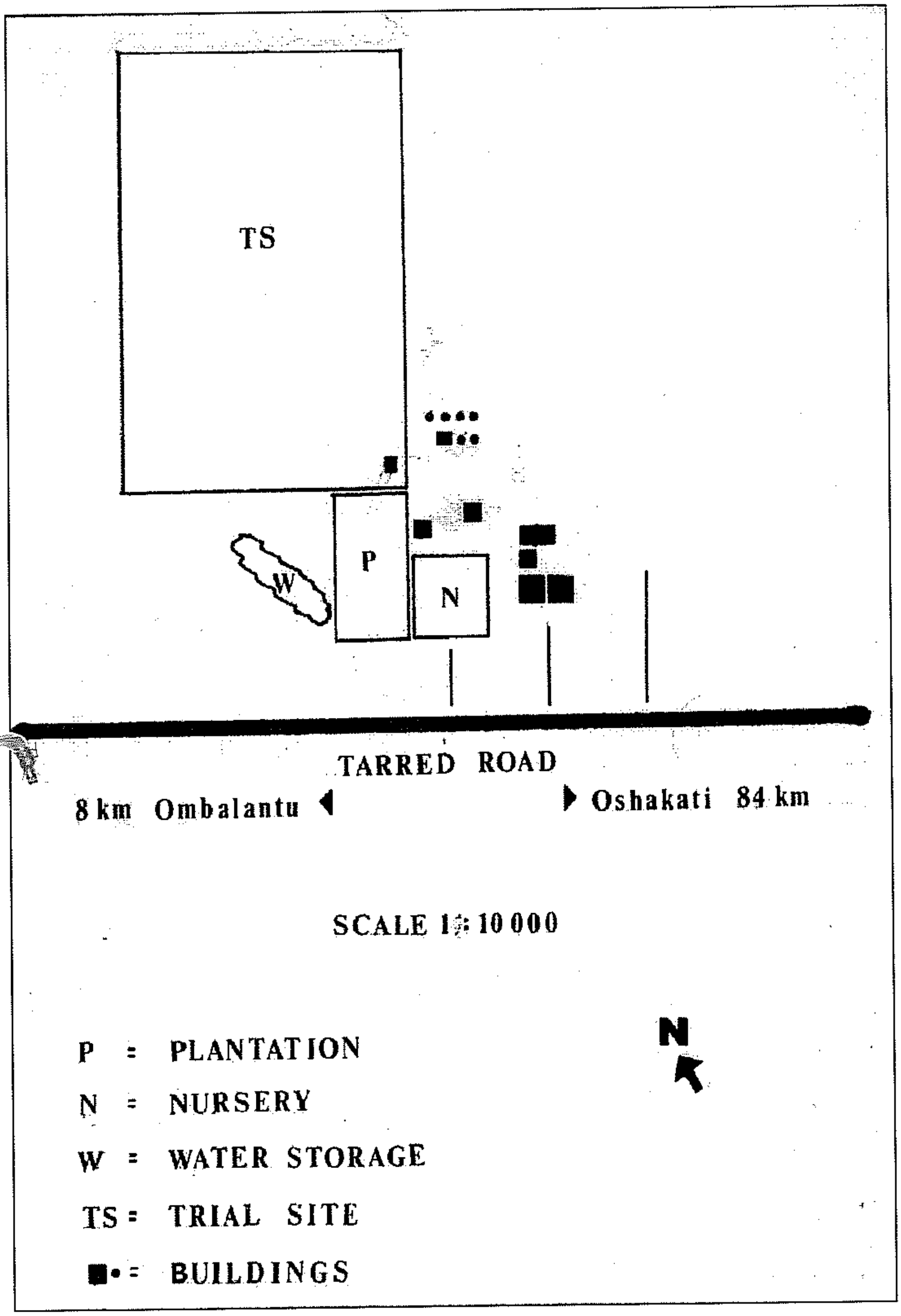


Figure 2. Map of the Development Aid from People to people (DAPP) premises showing location of the trial site



2.2 Vegetation

According to Timberlake (1999) and Styles (1993), mopane appears to be a dominant species where it is growing together with other woody species. Some observers stipulated that the dominant nature of mopane is due to the fact that its aggressive shallow roots out competes other species or is due to the unsuitability of the soil for other species or is due to some chemical factor (Timberlake, 1999).

At Onambelela, the trial site, *C. mopane* is the dominant (cover about 75% of the area) species, growing in association with other local species such as *Terminalia pruniodes, Commiphora africana, Dichrostachys cinerea* and *Acacia* species. The other area of approximately 25% is tree less and is covered with the grass most of the time (Gelens, 1999).

2.3 Soils

Timberlake (1999), Styles (1993) and Cole (1982) stated that mopane is commonly found on depositional clay-rich soils as well as on other clay-rich soils such as terminalia, drainage lines and exposed illuviated clay horizon of granite duplex. Gelens (1999) reported that the substratum over the whole of north-central Namibia, on which mopane is growing, is 'Kalahari' sandstone.

The soil at the trial site was identified as solonetz according to the FAO / UESCO World Soil Map. The effects of solonetz soil in the growth of plants is said to be detrimentally especially if there is high amount of exchangeable sodium in the soil and can restrict the growth of the roots (Gelens, 1999 and Kreike, 1995). However, *C. mopane* is able to survive in such a soil but only in the form of shrubs. The soil profile at the site shown in Figure 3 indicates that the topsoil, which is about 25 cm in depth, is brownish in colour and is overlying a greyish B-horizon, which covers a distance of about 35 cm in the profile. The change between A-horizon and B-horizon is said to be abrupt.

Table 1 summarises the results of soil analysis done at the Agricultural laboratory in Windhoek. The result in the table has indicated that B-horizon tends to have more contents of Sodium (Na), and Magnesium (Mg) than other horizons. Potassium (K) and Calcium (Ca) tend to increase with the soil depth. There is no trace of Phosphorus (P) in A and B1 horizons and it occurs only in small quantity in B2 and C horizons. The pH also increases with the soil depth. According to Fraser et al. (1987) high content of magnesium and calcium in the soil can restrict the growth of mopane to shrub form.

Figure 3. Soil profile at mopane trial site at DAPP-Onambelela

Table 1. Results of analysis of soil samples taken from mopane trial site

Horizon	**A**	**B1**	**B2**	**C**
Depth	00-15 cm	15-30 cm	30-50 cm	50+ cm
% Sand	93	88	82	81
% Silt	0	0	2	3
% Clay	7	12	16	16
Texture class	Sand	Sand	Loamy sand	Loamy sand
P (ppm)	0	0	2	1
K (ppm)	127	133	182	229
Ca (ppm)	367	1174	1400	6274
Mg (ppm)	199	1080	1224	1160
Na (ppm)	86	1861	3725	1903
pH	5.0	6.5	8.0	

2.4 Climate

Mopane is normally associated with zones having annual rainfall ranges between 400-700 mm, but it can also grow in area with annual rainfall below 100 mm and above 800 mm (Timberlake, 1999). The rainfall in Namibia is variable and Omusati region is not an exception. The average annual rainfall for Ombalantu recorded in 1955/56 to 1984/85 is about 425 mm per year. The average temperature is at least 20°C while the maximum temperature can be as high as 40°C in hot summer. The minimum temperature can also fall below 0°C in coldest months (Gelens, 1999). According to Cole (1982), mopane is sensitive to low temperature and it rarely survives the temperature that falls below 15.5°C or where light frosts occur during the winter months.

The rainfall at Onambelela (a trial site) has been recorded since the year 1997-2002 (no rainfall data was available for the year 1995-1996). The average annual rainfall over this period was 408 mm. This average rainfall is nearly similar for aforementioned Ombalantu average annual rainfall, an area within which the trial site is located.

Figure 4. Annual rainfall at DAPP-Onambelela, the mopane trial site

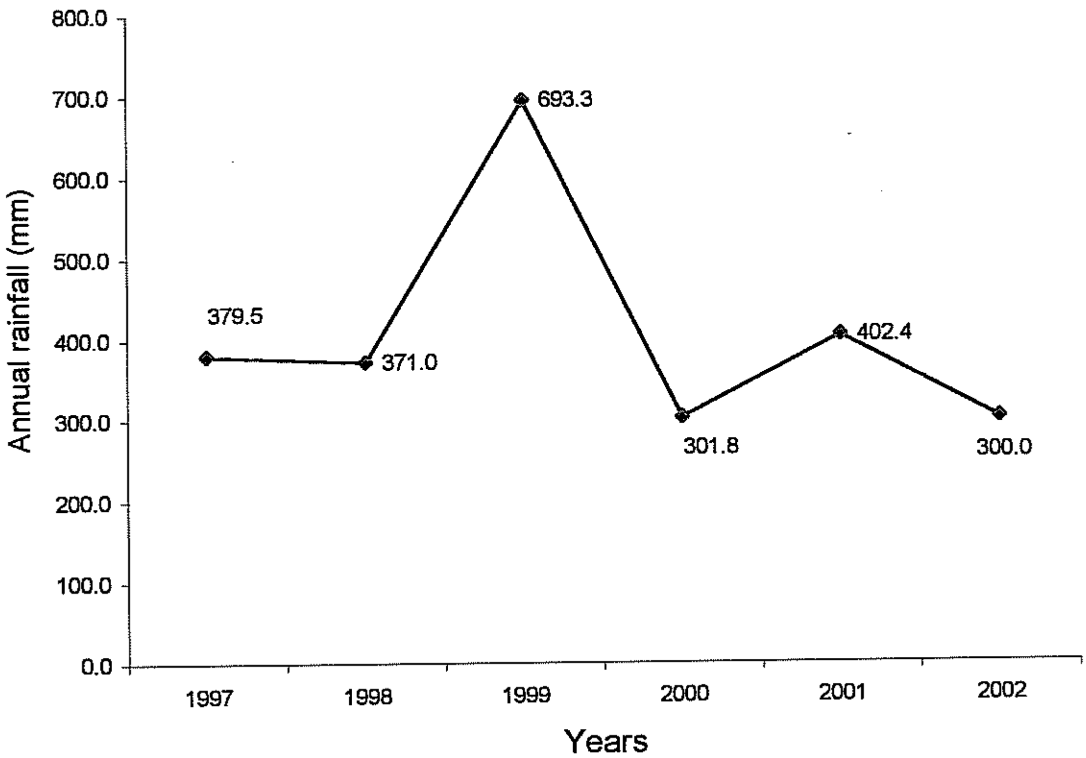
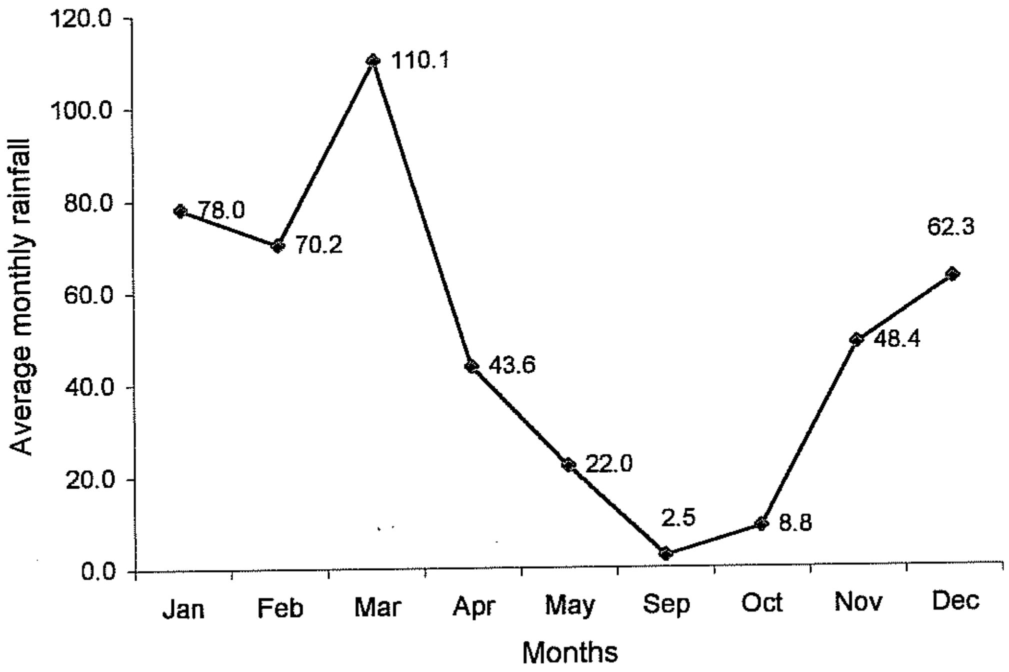


Figure 4 illustrated that the annual rainfall during this respective time was variable and this feature is typical for Namibia's rainfall condition. The highest rainfall was received in the year 1999, while the lowest rainfall was in the year 2002.

Additionally, the average monthly rainfall over 6 years period at Onambelela was also calculated and is demonstrated in Figure 5. The highest and lowest average monthly rainfall over this period was obtained in March and September respectively. No average monthly rainfall was recorded in June, July and August and the one recorded in September and October was insignificant.

Figure 5. Average monthly rainfall over the period of 6 years at DAPP-Onambelela



2.5 The relationship between mopane growth and the climate and the soil

Mopane's distribution can be influenced by moisture availability expressed through altitude, rainfall and soil texture. It can occur as a tree in savanna woodland or as a shrub in low tree and shrub communities (Cole, 1982). Where mopane grows as a shrub, that area is usual hotter and dryer or the site has moisture content which accumulates on shallow soils over an impervious bedrock or impervious layer of transported clay (Cole, 1982 and Dye and Walker, 1980).

At Onambelela, mopane is in the form of a shrub. However according to the information gathered from the community, mopane at this site was once in the form of a tree and many wild animals used to be seen here in large numbers (Gelens, 1999). It can therefore be stipulated that during that time when mopane was in the form of a tree, the soil at the site was deep and more fertile than now. This is likely to be so as trees allow more grass to grow in between than shrubs do and grass can protect the soil from wind and water erosion and therefore improving the structure, depth and texture of the soil. Hence the reason that mopane at this site is now found in the form of the shrub can be attributed to heavy cutting and browsing by livestock. Cutting down mature trees induces heavy coppicing, which may out-compete grass. Less grass means soil erosion by both wind and water is increased. Erosion removes the top rich soil and leaves heavy subsoil, which most of the time is sodic. A lot of sodium in the soil encourages dispersion of clay soil. Dispersed clay particles clog up the soil, therefore prevents water infiltration and encourages run-off. This in turn encourages stunted growth of the coppiced shoots due to restricted root growth.

3. Experimental Design

Mopane Shrubland Management trial was designed with the involvement of the local community in the vicinity of Onambelela. The local people provided crucial information such as how they traditional manage mopane, what type of products they get from mopane and at what time and size they harvest the mopane products. This traditional information from the local people together with other information gathered from literature was then used to make a decision on which treatment was to be used in a trial. The four treatments were then decided upon and they are as follows:

- Treatment 1 (T1): This is a control treatment, that means the trees are left to grow without any thinning or harvest (no cutting);
- Treatment 2 (T2): First, shoots are singled to one leading shoot plus continuous removal of all regrowth;
- Treatment 3 (T3): Continuous removal of the material when it reaches a certain standard minimum size;
- Treatment 4 (T4): First, shoots are singled to one leading shoot plus continuous removal of the material when it reaches a certain standard minimum size.

The minimum size in T3 and T4 is when the shoots reach a height of 2 m and a diameter of 2 cm at the base. These are the minimum sizes estimated the shoots to have when the local people harvested them for uses such as building, fencing and when making ropes and basket.

There are 20 plots all together as indicated in Figure 6 and each plot measure 0.5 ha. The aforementioned treatments were replicated 5 times on these plots. The treatments had been allocated to the plots in a random way as seen in Figure 7. There are 3 circular subplots coded A, B, C in each plot and these were also randomly placed in plots as demonstrated in Figure 8. Each subplot measure 200 m^2 with a radius of 7.98 m and they are 60 subplots altogether. To make it easier to recognise each subplot from one another, a big-creosoted pole with a number and a code on it has been placed at the centre of each subplot. A number is painted white and represents a plot number while a code is painted red and it represents a subplot.

Every shrub in each subplot has been given a number written on a metal tag (For example 1, 2, 3, etc). For easy allocation of the first shrub during measurements, a white dot has been painted on a pole, which is at the centre of the subplot. The nearest shrub in the direction of the white dot represents the first shrub in a subplot. The marking was done in an anti-clock way until all shrubs inside the circle were marked. The distance between shrubs was set at 1 m, as this is how farmers do it when they manage their mopane.

A tag was attached to any shoot belonging to a particular shrub. However subplots on which T4 was applied, a tag was always attached to a leading shoot. In addition, all shrubs in the circle were painted white while those outside the subplot remained unpainted. Shrubs, which appeared after the establishment of the trial, were painted a different colour and their numbering system also differed. For example the first recruits, appeared after the establishment of the trial were numbered 11, 12, 13 etc. and were painted blue on their stem. The next will be marked 21,22,23 etc. and will be painted a different colour on their stems. This makes it easier to recognise the shrubs, which regenerate at different times.

Figure 6. Map of the trial site showing the location and the number of the treatment plots

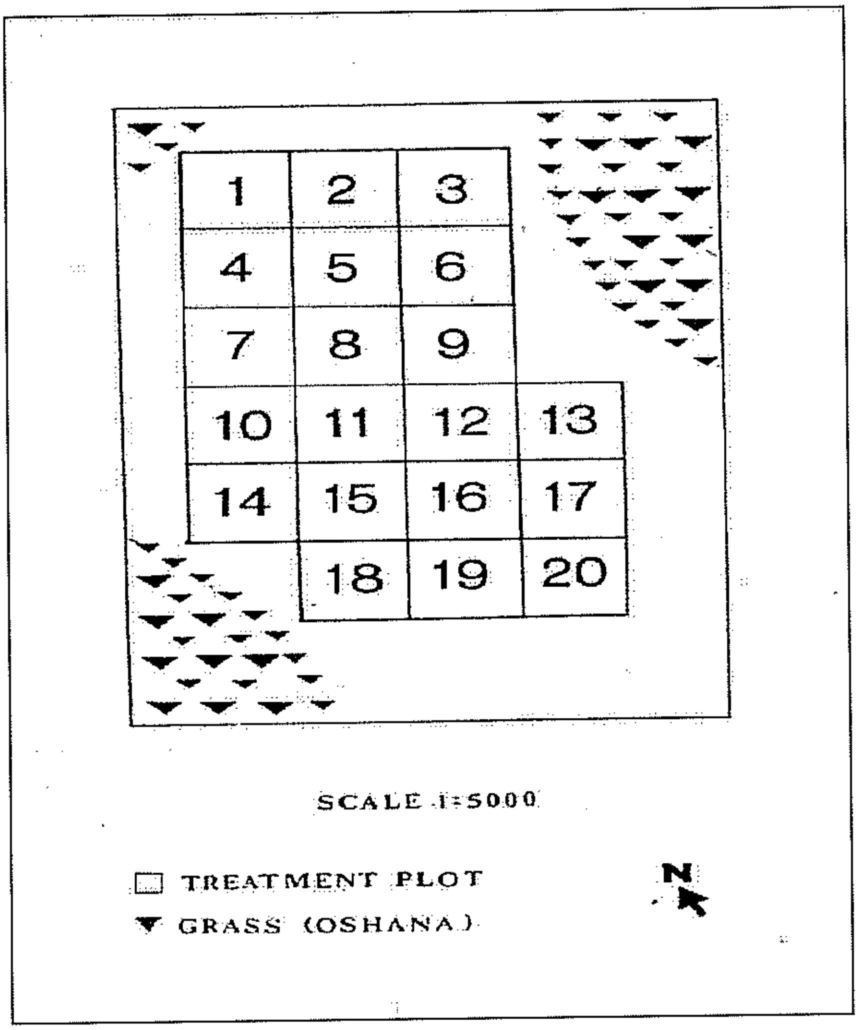


Figure 7. Map showing the allocation of the treatments to the treatment plots

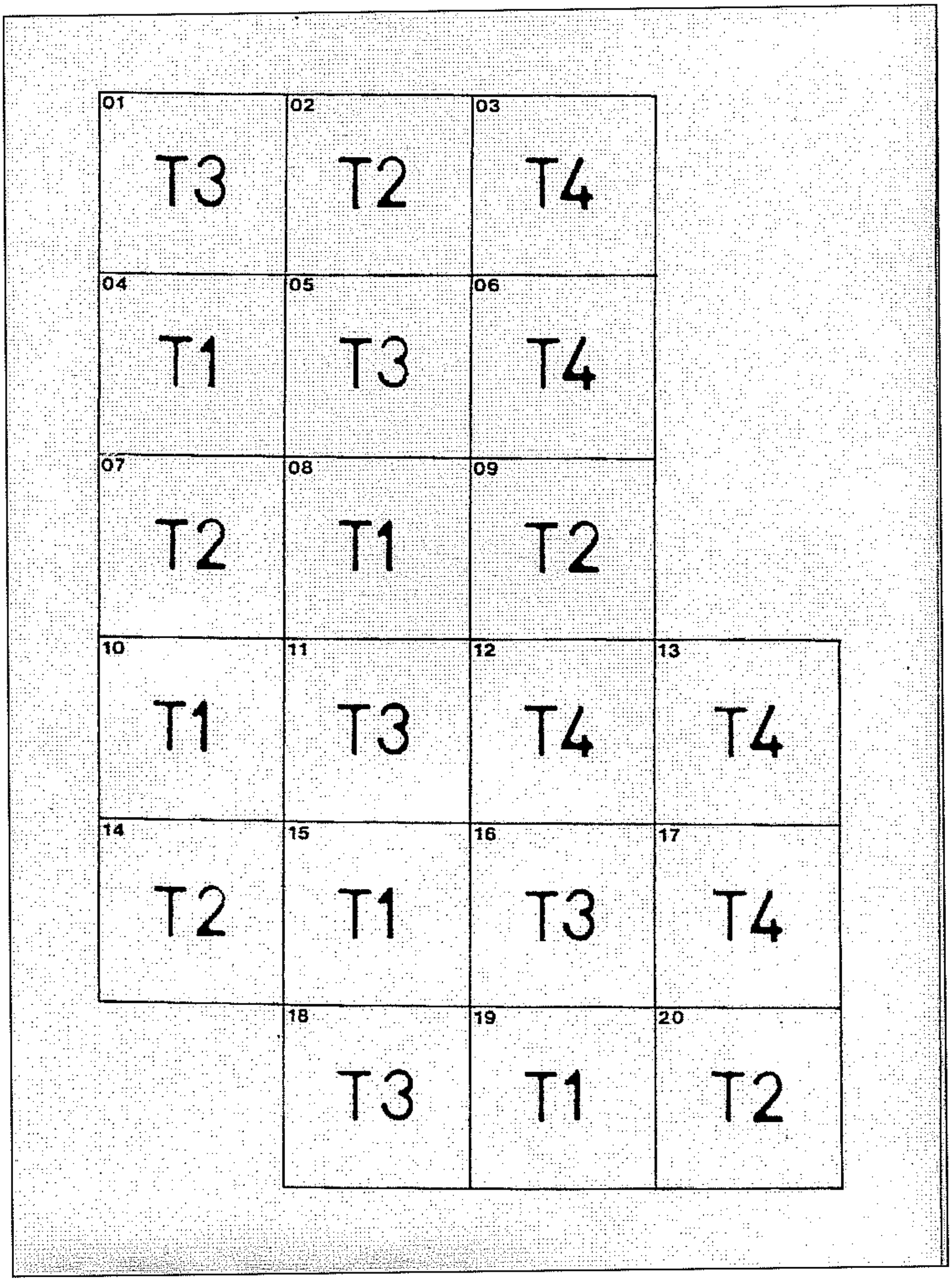
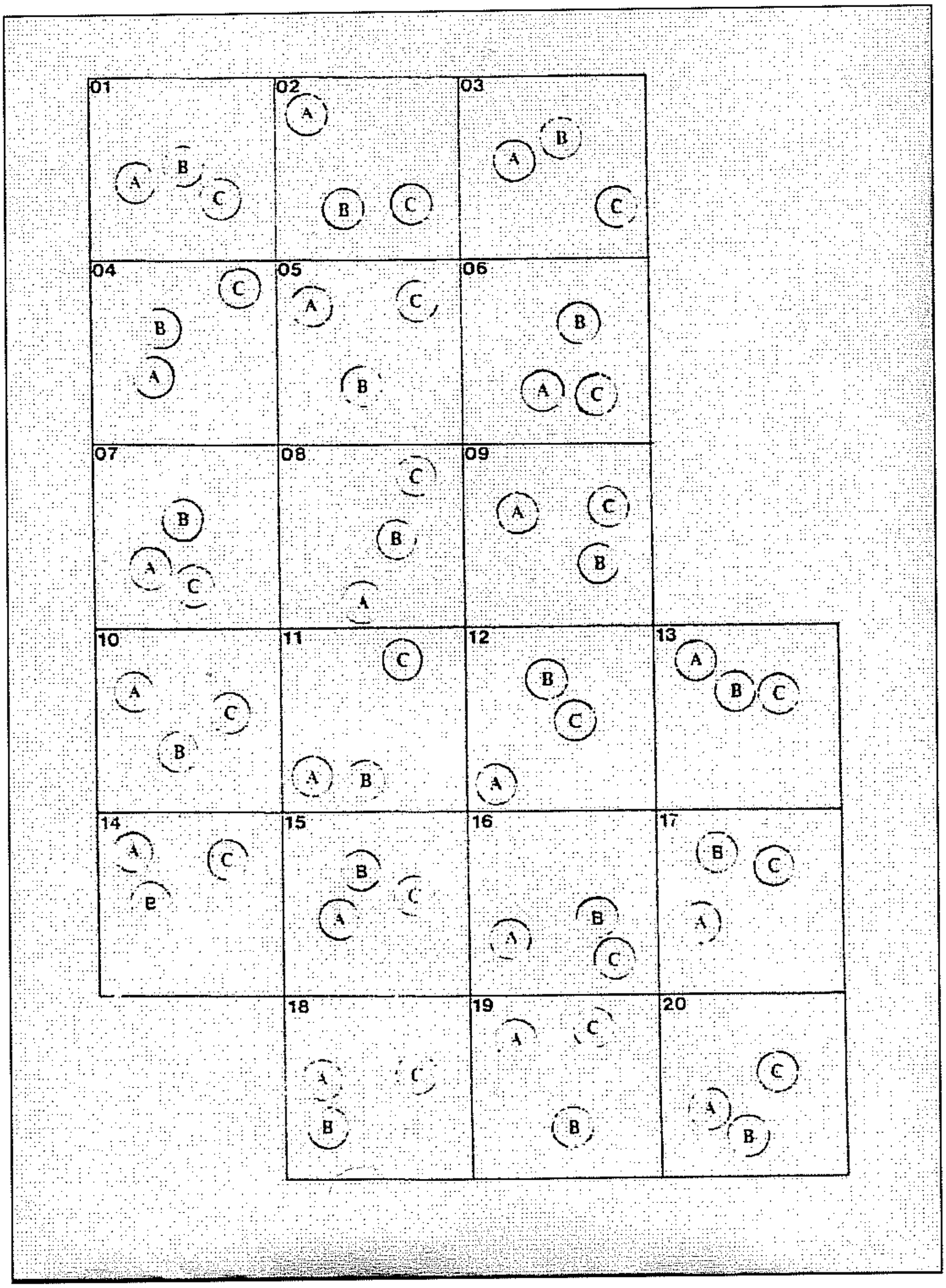


Figure 8. Map showing the location of the measurement sub-plots within the treatment plots



At the time of measurement only shrubs inside the subplots were measured while during treatment application, all shrubs in a plot were treated in order to attain the uniformity of the plot. The variables measured and recorded in each year in every subplot were height, diameter, the numbers of shrubs and the number of shoots. During treatment application, the height, diameter and fresh weight of the removed shoots were measured and recorded. The diameter was measured at 10 cm above the ground and at a later stage when the trees are big, it will be measured at breast height, which is 1.30 m from the ground. Only shrubs, which were 75 cm, or more, were measured. Measuring sticks were used to measure the height while callipers were used to measure the diameter. T4 and T3 are applied only if the shoots reach a minimum specific height and diameter otherwise they will not take place.

In the first two years of the trial establishment, measurements were done in June while the treatments were carried out in October. However this was only followed in the first two years of the trial establishment. It was realised that it was more economically to carry out measurement and treatments at the same time around June-July. This helped to cut down on fuel and subsistence and travelling allowances costs.

After measurement, parameters such as volume and basal area were calculated using the following formula:

$$\text{Volume} = ((pi * d^2) / 4) * \text{form factor of } 0.46$$

$$\text{Basal Area} = (pi * d^2) / 4$$

Weight of the standing biomass was also calculated by using simple regression analysis model between fresh weight and volume or basal area. The analysis of the results and most of the graphs was carried out using Minitab 13 Software package while Microsoft Excel was used to process the data and for few graphs and calculations.

4. General measurements and treatments in 1995-2002

The first measurements and treatments were carried out in 1995 in the first two weeks of June and 2nd and 3rd week of October respectively. The aim of the first measurement was to make an assessment of the conditions of the stand before any treatments were carried out. Knowing the condition of the stand before any treatments were carried helped the assessor to determine whether treatments would have any effects on the growth of the stands. In the first assessment, all shrubs or shoots in the measurements subplots were measured and counted. A team of two people did the work (Gelens, 1999).

As from the year 1997 upwards, measurements and treatments were done at the same time as it was realised that carrying out these activities at different times was too costly. However instead of two people, two teams of 3 people carried out these activities within a week for the whole trial plot. One team of three people normally did not cost a lot in terms of subsistence and travelling allowances as they were normally from the same region in which the trial exists.

The measurement were done in such a way that one person was taking the height measurement, the second person was responsible for the diameter measurement, while a third person was recording both height and diameter readings. Measurements were always done in an anti-clockwise starting from first shrub up to the last shrubs. Care was always taken during measurement, not to measure the shoots twice as this was likely to be done. This was prevented from happening by also measuring the shoots of each shrub in a circle way and care was always taken to remember the first measured shoot.

In 2002, the recording sheet was changed a bit by adding some information such as Year, Date, Subplot Number, Treatment, Recorder (Name) and Page Number, which were missing in the previous recording sheet. **(See Appendix 1 for updated recording sheet).** This was done, as it was realised that in the previous years some of these information were not recorded properly in the recording sheet and this sometimes made it difficult to know for example which year the measurements were taken and who to contact in case of some inquiries.

During treatment application such as thinning and pruning, a group of about 10 local people were always used to carry out the duties. Outside the measurement subplots, they used a particular rod or stick to decide whether a shoot will be removed or not. In some cases they used their extended arm to decide upon these. These local people have been doing these jobs since the beginning of this trial and they are most experienced in this particular job. Shoots inside the measurement subplots, which were to be removed were measured first and then marked with a coloured ribbon to make it easier for the local people to spot them and cut them down. Secateurs and pruners were used for pruning and thinning.

The local farmers' participation in carrying out treatments was rewarded with few Namibian dollars as well as with the authorisation to collect all the harvested shoots for their domestic utilization. At first, these local people were rewarded with the harvested shoots only, however, it was decided that to increase their moral in the management of the trial, it was good to give them incentive in form of cash. This in addition, will also improve their livelihood.

The data were entered in the computer using the format that will make it easier to process and analyse data obtained in different years at the same time. The example of the computer raw data entry sheet is indicated in **Appendix 2**.

5. Results of measurements and treatments of mopane trial-1995- 2002

The results presented in the following subsections in the form of tables and figures are the mean values per hectare only of the number of shrubs, number of shoots, mean volume and basal area per hectare and mean height and diameter per subplot for all 60 subplots pooled together in case of the whole trial plot and for all 15 subplots pooled together in case of the treatment subplots. The basic total number of shrubs, number of shoots, total volume and basal area for each measurement subplots are indicated in **Appendix 3** while other descriptive statistics relating to the mean value for the above mentioned variables and for fresh standing weight are found in **Appendixes 4-8 and Appendixes 9-10** respectively. All the results for the year 1999 was left out because measurement in this year was not taken as it was supposed to be, for example only one shoot was measured at each shrub in T1 and T4 subplots instead of all.

5.1 Results for the whole trial plot

Table 2. Changes in the mean number of shrubs and shoots, mean volume and basal area per hectare and mean height and diameter per treatment subplots for the whole trial plot

		Mean number of shrubs	Mean number of shoots	Mean height (cm)	Mean diameter (mm)	Mean volume (m^3)	Mean basal area (m^2)
1995	BT	988	6635	109.8	16.2	0.87	1.53
1995	AT	988	3569	111.4	16.6	0.50	0.86
1996	BT	1024	4510	118.0	16.7	0.74	1.16
1996	AT	1023	4200	118.2	17.2	0.73	1.13
1997	BT	894	3015	118.6	20.7	0.72	1.15
1997	AT	*	*	*	*	*	*
1998	BT	896	2956	121.7	21.4	0.78	1.21
1998	AT	*	*	*	*	*	*
2000	BT	983	4372	132.5	19.1	1.12	1.49
2000	AT	982	4249	130.2	18.8	1.03	1.40
2001	BT	997	4683	134.1	20.3	1.37	1.83
2001	AT	997	4652	133.6	20.3	1.35	1.81
2002	BT	1042	6275	130.2	17.0	1.33	1.75
2002	AT	1041	6180	129.0	16.8	1.28	1.69

KEY
AT After thinning
BT Before thinning
* No thinning was done

5.1.1 Shrubs and shoots

Figure 9. Changes in the mean number of shrubs of mopane per hectare for trial plot as a whole over 8 years period

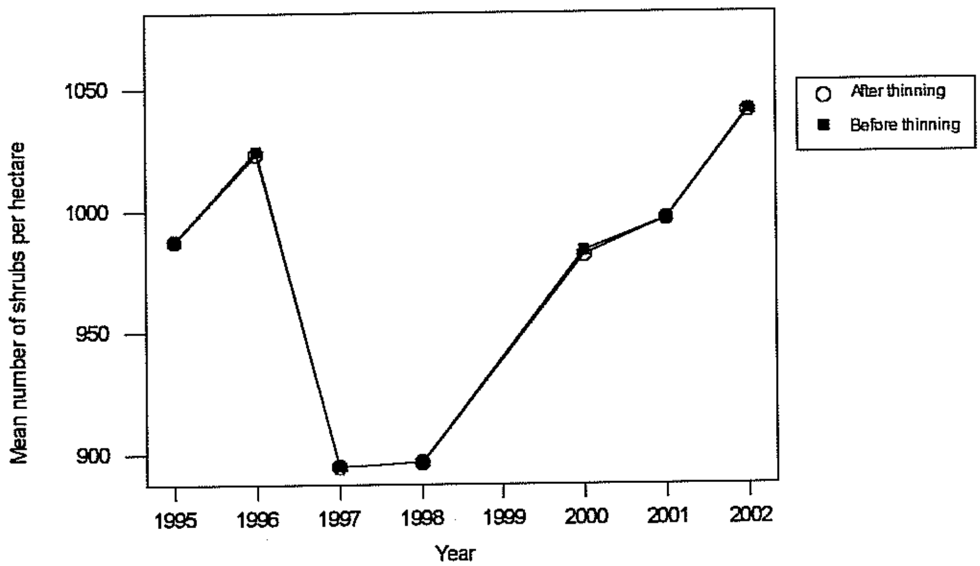
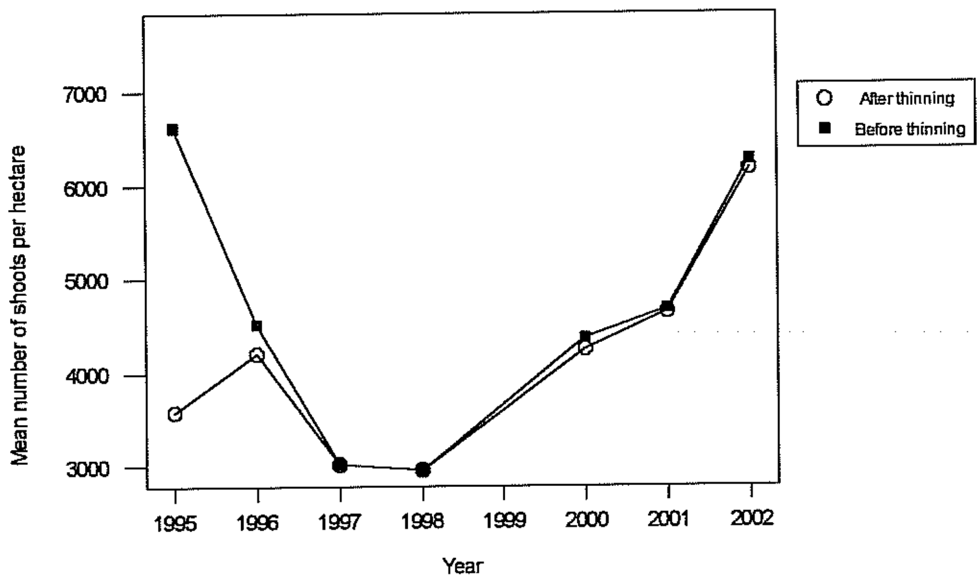


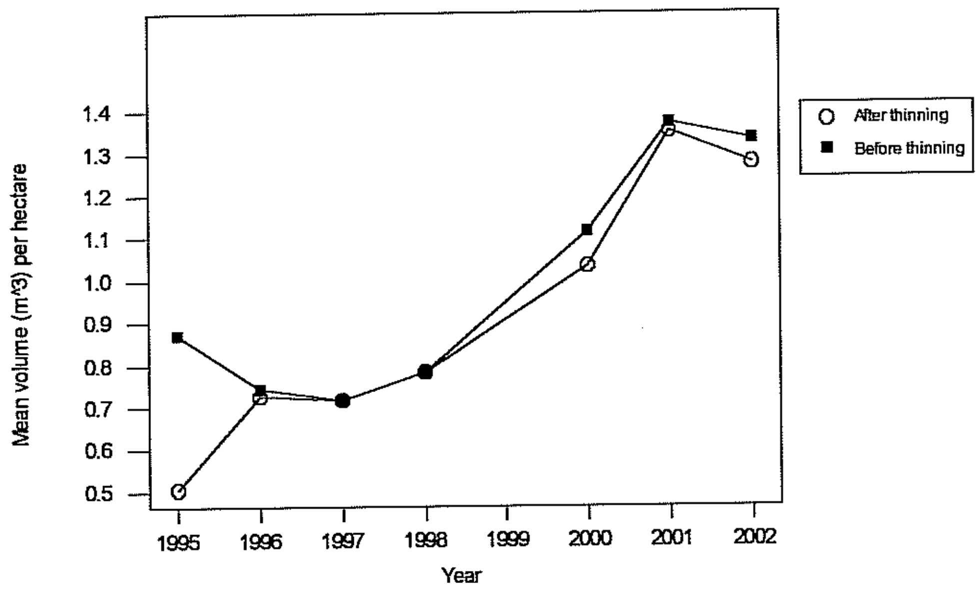
Figure 10. Changes in the mean number of shoots of mopane per hectare for the trial plot as a whole over eight years period



The mean values for the number of shrubs and number of shoots are presented in Table 2 and Figure 9 and 10. The number of shrubs before and after thinning in each year remains almost the same. Figure 10 shows that the first thinning carried out in 1995 dramatically reduced the number of shoots, however, the number of shoots went up again in 1996. In 1996 and 2000 up to 2002, only a small portion of the shoots was thinned out from the whole trial plot during treatments. Strangely, both the number of shrubs and shoots in 1997 and 1998 was very low but started to increase again since then. It is not known what causes this sharp fall of these variables in these years.

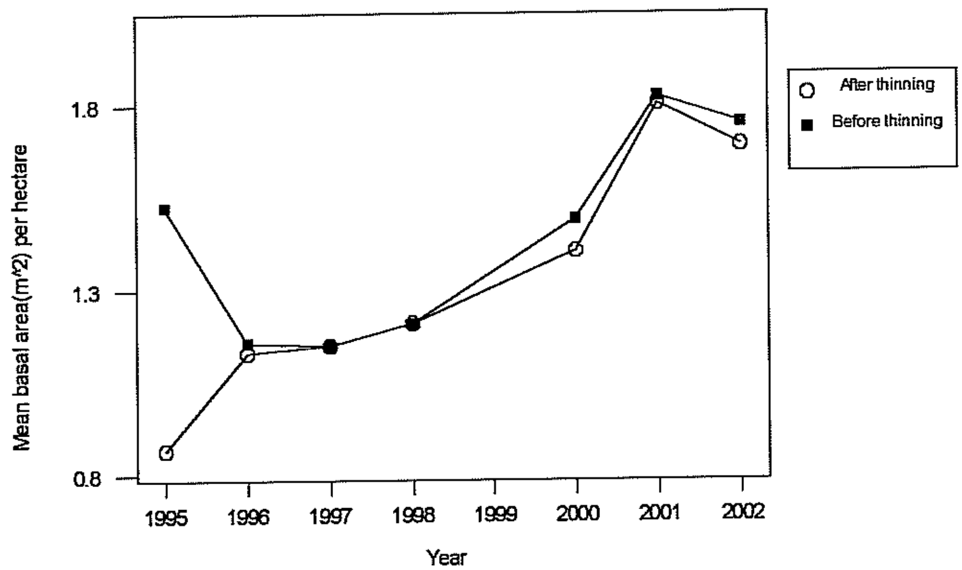
5.1.2 Volume and basal area

Figure 11. Changes in the mean volume of mopane per hectare for the trial plot as a whole over eight years period



As for the number of shoots, thinning done in 1995 also reduces the mean volume and the mean basal area of the whole trial plot as shown in Figure 11 and 12. However, these variables sharply increased again in 1996. This sharp increase in mean volume and basal area in 1996 is attributed to profusely coppicing of the stumps thinned in 1995 and also due to the appearance of new shrubs with new shoots, that were not present or recorded in 1995. Despite sharp increase in the mean number of shoots in 2002, the mean value for volume and basal area fell in this year. This sharp fall is probably due to the fact that the diameter measurement in 2002 was done at 30 cm from the ground instead of 10 cm as usual because of the confusion that occurred.

Figure 12. Changes in the mean basal area of mopane per hectare for the trial plot as a whole over eight years period



5.1.3 Height and diameter

Figure 13 and 14 illustrates the mean height and diameter per subplot over the period of 8 years. In 1995 and 1996, the mean height and mean diameter went up after thinning while it went down in 2000 up to 2002 after thinning. The reason why thinning in this particular years caused different outcomes in the mean value of height and diameter per subplot is because, in 1995 and 1996, thinning removed big portion of small sized shoots and left the bigger one, while in 2000 up to 2002, thinning removed large sized shoots. The mean diameter in 2002 went down sharply compared to any other year. The reason why the mean diameter in this year is low compared to others is probably because in 2002, there was large proportion of small sized shoots and also that the diameter was measured a little bit higher compared to other years.

Figure 13. Changes in the mean height of mopane per subplot for the trial plot as a whole over 8 years period

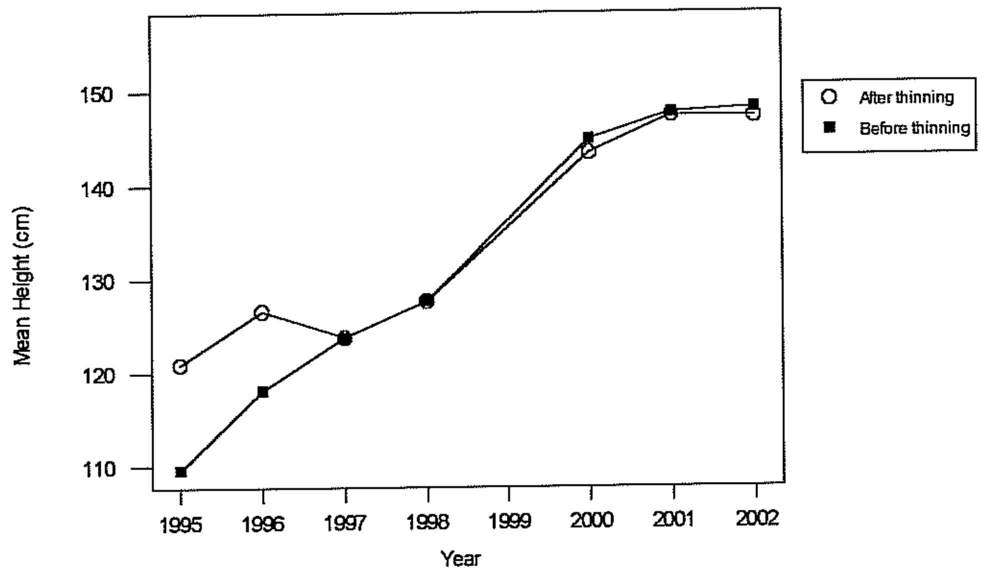
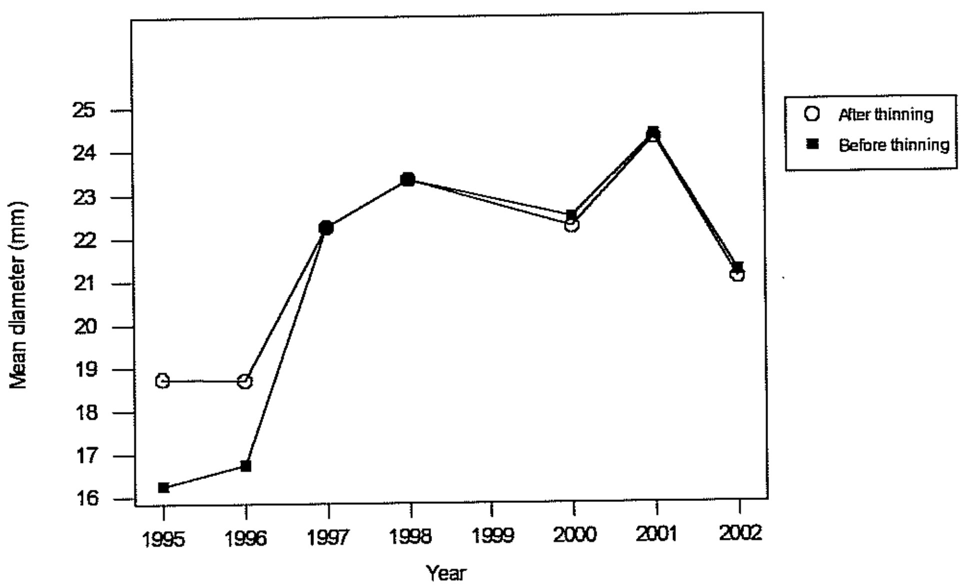


Figure 14. Changes in the mean diameter of mopane per subplot for the trial plot as a whole over 8 years period



5.1.4 Volume and basal area increment for the whole trial plot

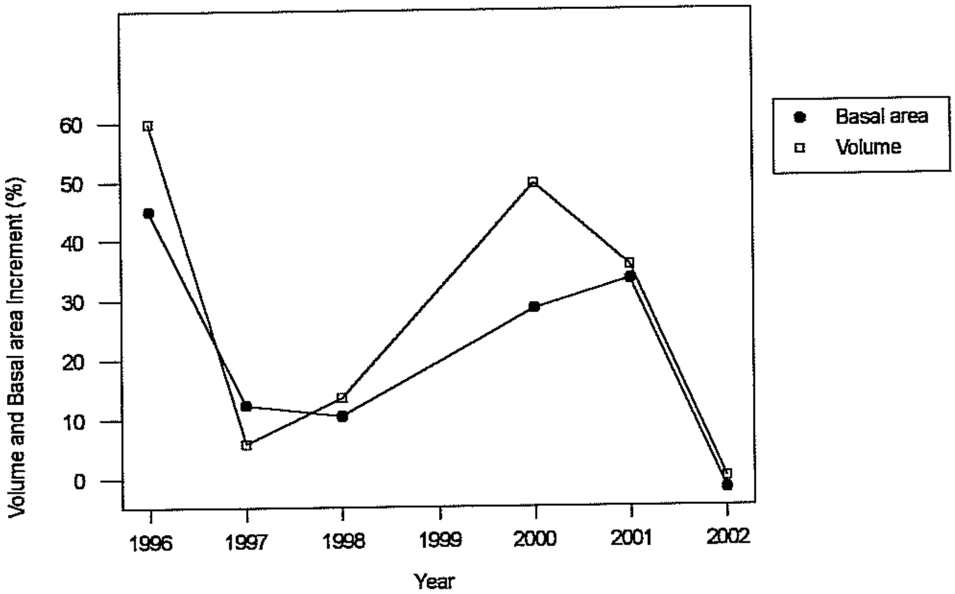
The relative growth rate for both volume and basal area was highest in the year 1996 and lowest in the year 2002 as shown in Table 3 and Figure 15. The growth rate largely went down in the year 1997; significantly improved in the year 2000 and fell sharply again in the year 2002. There was hardly any growth in volume and basal area in the whole trial plot in the year 2002. In addition, Figure 15 indicated that the volume increment was visibly higher in all years (except in 1997) compared to basal area increment.

Table 3. The mean volume and basal area increment (%) of mopane for the trial plot as a whole

Year	Volume increment (%)	Basal area increment (%)
1995-1996	59.7	45.0
1996-1997	5.8	12.2
1997-1998	13.4	10.4
1998-2000	49.4	28.5
2000-2001	35.6	33.2
2001-2002	0.0	-1.9

Key
- The growth goes down

Figure 15. Mean volume and basal area increment (%) of mopane for the whole trial plot in the year 1996-2002



5.2 Results for the four treatments subplots

5.2.1 Shrubs

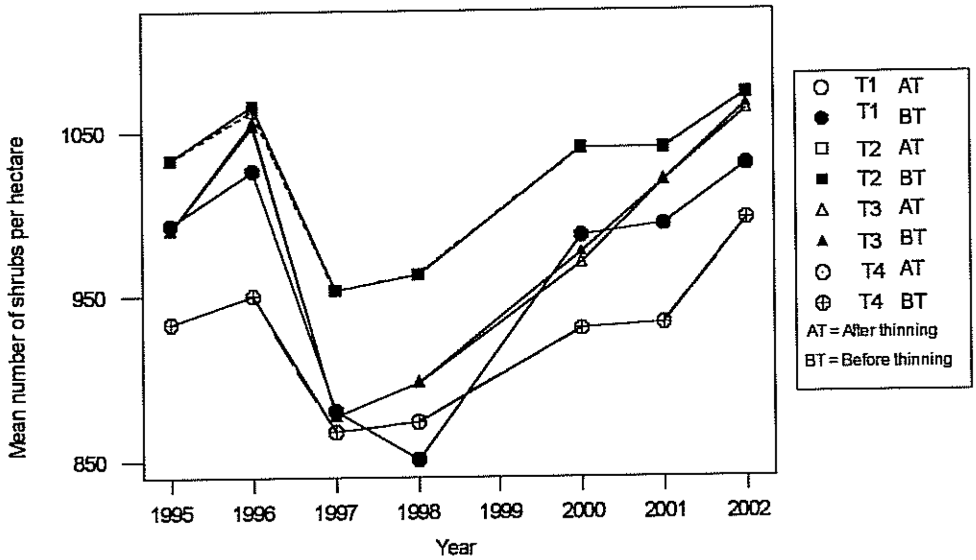
Table 4. Development of number of shrubs per hectare for T1 to T4 measurement subplots during the period of 8 years (measurement for the year 1999 is excluded)

		Year						
Treatment	Number of shrubs	1995	1996	1997	1998	2000	2001	2002
1	BT	993	1027	880	850	987	993	1030
2	BT	1033	1063	953	963	1040	1040	1073
3	BT	990	1057	877	897	977	1020	1067
3	AT	990	1057	877	897	970	1020	1063
4	BT	933	950	867	873	930	933	997

<u>KEY</u>
AT After thinning BT Before thinning

The number of the shrubs in the treatment subplots had been fluctuating since the beginning of the trial as shown in Table 4 and Figure 16. T2 subplots had the highest number of shrubs since the beginning of the trial in 1995 while T4 subplots had the lowest. All treatments subplots had few shrubs in the year 1997-1998. The last measurement done in 2002 demonstrated that all the treatment subplots had more shrubs than they had at the beginning of the trial.

Figure 16. Development in the mean number of shrubs of mopane per hectare for four treatment subplots



5.2.2 Shoots

Table 5. Development of mean number of shoots per hectare for T1 to T4 measurement subplots during the period of 8 years (measurement for the year 1999 is excluded)

		Year						
Treatment	Number of shoots	1995	1996	1997	1998	2000	2001	2002
1	BT	5287	6110	3657	3070	4100	5100	6973
2	BT	6807	2247	953	963	1040	1040	1073
2	AT	1033	1063	*	*	*	*	*
3	BT	7023	7250	4683	4353	6737	6443	7043
3	AT	**	7190	**	**	6247	6353	6740
4	BT	7423	2437	2767	3437	5610	6150	10010
4	AT	933	**	**	**	**	6113	9933

KEY
AT After thinning
BT Before thinning
* Thinning was done but shoots did not reach the measurable size
** No thinning was done

Figure 17. Development in the mean number of shoot of mopane per hectare for four treatment subplots

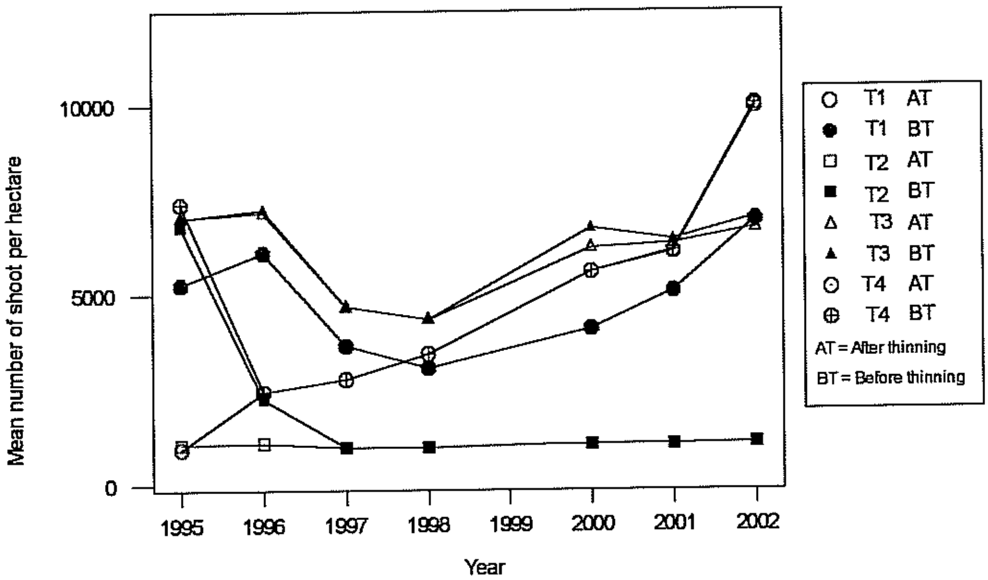


Table 5 and Figure 17 demonstrated the development in the number of shoots in 4 treatments subplots from the year 1995-2002. The first thinning done in 1995 in T2 and T4 subplots with the purpose of leaving only one leading shoots at each shrub heavily reduced the number of shoots in these subplots. There was no thinning done in T3 subplots in the year 1995 as shoots in these subplots hardly reached the measurable size.

From the year 1997-2002, the number of shoots in T2 subplots remained roughly the same but increased in T4 subplots and kept inconsistently changing yearly in T1 and T3 subplots. No thinning was done in T1 subplots, as these were controls subplots.

5.2.3 Height

Thinning done in 1995 in T2 and T4 subplots and that done in 1996 in T2 subplots did not only reduce the number of shoots but also brought some changes in the mean height of the shoots in these treated subplots. The removal of small sized shoots in T2 and T4 subplots drastically increased the mean height of the shoots as seen in Table 6 and Figure 18. However, profusely coppicing of the stumps thinned in 1995 brought down the mean height of shoots in T2 and T4 subplots in 1996.

In addition, the mean shoot height in T2 subplots after thinning in 1996 was significantly high compared to other treatments subplots and had been on increase since the year 1998-2002. The mean shoot height in T1, T3 and T4 subplots had not been changing that much and did not significantly differ. It is also worth to mention that removing small and bigger shoots from subplots appeared to increase and decrease the mean height respectively.

Figure 18. Development in the mean height of mopane per subplot for four treatments

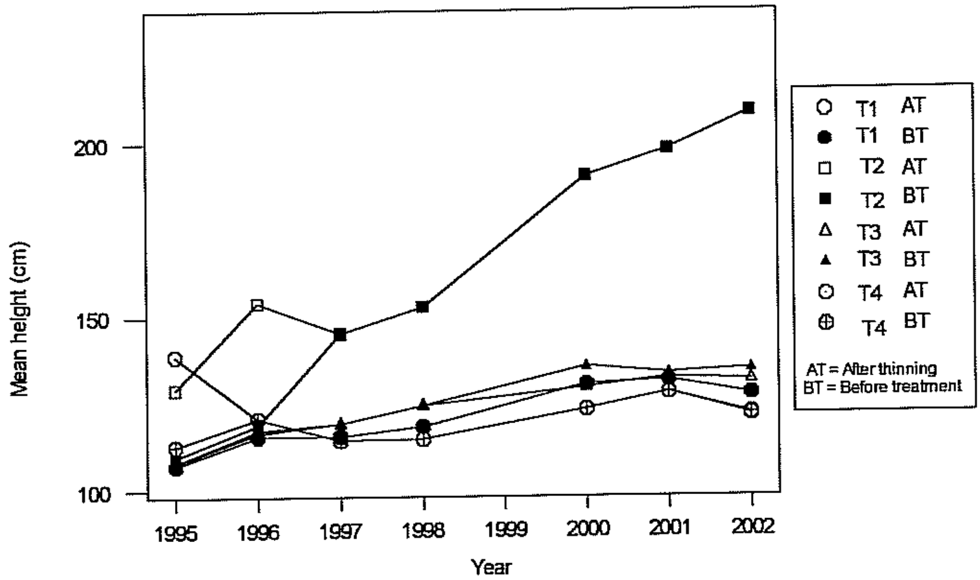


Table 6. Development of mean height (cm) per subplot for T1 to T4 measurement subplots in 1995-2002 (excluding the year 1999)

		Year						
Treatment	Height	1995	1996	1997	1998	2000	2001	2002
1	BT	107.3	115.4	115.2	118.6	128.7	130.3	126.9
2	BT	109.5	118.9	143.4	151.5	187.8	194.9	204.9
2	AT	128.1	152.4	*	*	*	*	*
3	BT	108.6	117.1	119.2	124.4	135.4	132.9	132.9
3	AT	**	116.1	**	**	129.6	131.9	129.7
4	BT	113.1	120.8	113.5	112.9	121.4	128.1	122.5
4	AT	137.5	**	**	**	**	127.6	121.9

KEY
AT After thinning
BT Before thinning
* Thinning was done but shoots did not reach the measurable size
** No thinning was done

5.2.4 Diameter

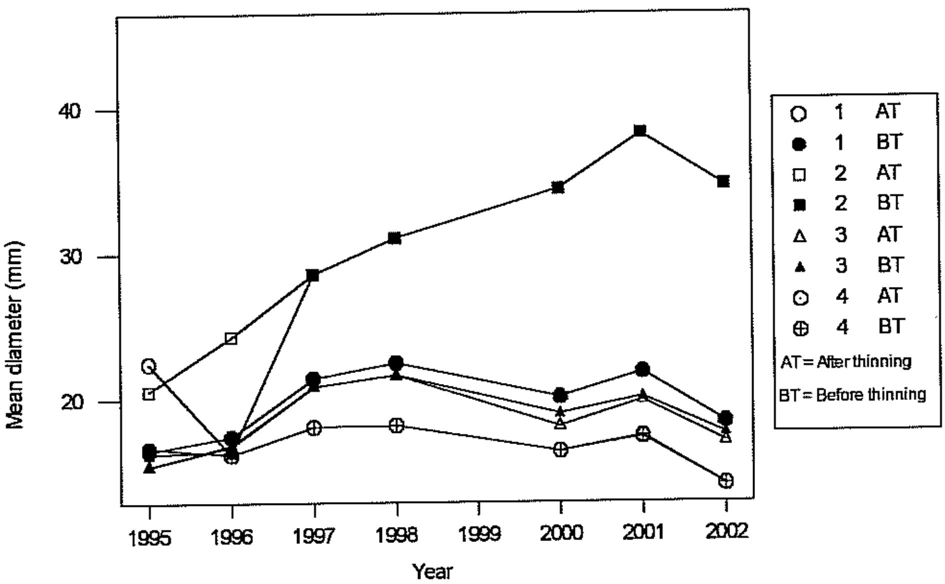
The mean diameter in the treated subplots was affected by thinning in a similar manner as the mean height of shoots (compare Figure 18 and 19). As for the mean height, removing small sized and larger sized shoots in the subplots improved and worsened the mean diameter of shoots respectively.

Table 7. Development of mean diameter (mm) for T1 to T4 measurement subplots during the period of 8 years (measurement for the year 1999 is excluded)

		Year						
Treatment	Mean diameter (mm)	1995	1996	1997	1998	2000	2001	2002
1	BT	16.4	17.3	21.2	22.3	19.8	21.5	18.2
2	BT	16.2	16.4	28.3	30.9	33.9	37.5	33.9
2	AT	20.5	24.2	*	*	*	*	*
3	BT	15.4	16.8	20.7	21.7	18.9	19.7	17.3
3	AT	**	16.7	**	**	18.1	19.6	16.8
4	BT	16.6	15.2	17.4	17.5	16.2	17.1	14.1
4	AT	22.2	**	**	**	**	17.0	14.0

KEY
AT After thinning
BT Before thinning
* Thinning was done but shoots did not reach the measurable size
** No thinning was done

Figure 19. Development in the mean diameter of mopane per subplot for four treatment



5.3.5 Volume and basal area

The development of the mean volume and basal area of the shoots before and after thinning is illustrated in Table 8 and 9 and in Figure 20 and 21. Figure 20 and 21 demonstrated that the mean value of volume and basal area in 1995 was also reduced heavily after thinning in T2 and T4 subplots. Continuously thinning of the T2 subplots each year made these subplots to have the lowest mean volume and basal area, while T1 and T3 subplots maintains the highest mean volume and basal area as no heavy thinning was done in these subplots at the beginning of the trial except small portion of thinning in T3 subplots in 1996 and 2000-2002.

Coppicing of the thinned stumps in T4 subplots kept the mean volume and basal area of shoots in T4 subplots above that in T2 subplots but well below that in T1 and T3 subplots. Moreover, the shoots mean volume and basal area in T1 subplots had been generally decreasing since 1997-2000, but surprisingly increased sharply in 2001 and progressively in 2002. In addition to that, in 2002, T1 subplots had the highest shoot mean volume and basal area compared to other treatment subplots. The shoots mean volume and basal area in T2 and T4 subplots had been gradually increasing since thinning recovery in 1995 except when it went down in T2 subplots in 2002.

There was also a reduction in shoot mean volume and basal area in T3 subplots in 2002. The reason why the shoots mean volume and basal area in these specific treatment subplots in this particular year decreased was because the shoot mean diameter in these subplots drastically went down while the shoots mean number remain almost unchanged compared to the previous year. Although the shoots mean diameter in T1 and T4 subplots in 2002 also went down, this did not affect their shoots mean volume and basal area as in T2 and T3 subplots due to the fact that their shoots mean number kept on increasing. Briefly, the reason why the shoots mean diameter in all treatments subplots unexpectedly decreases in 2002 is because, the diameter measurement in this year was done at 30 cm above the ground instead of 10 cm as it should be.

Figure 20. Development in the mean volume of mopane per hectare for four treatment subplots

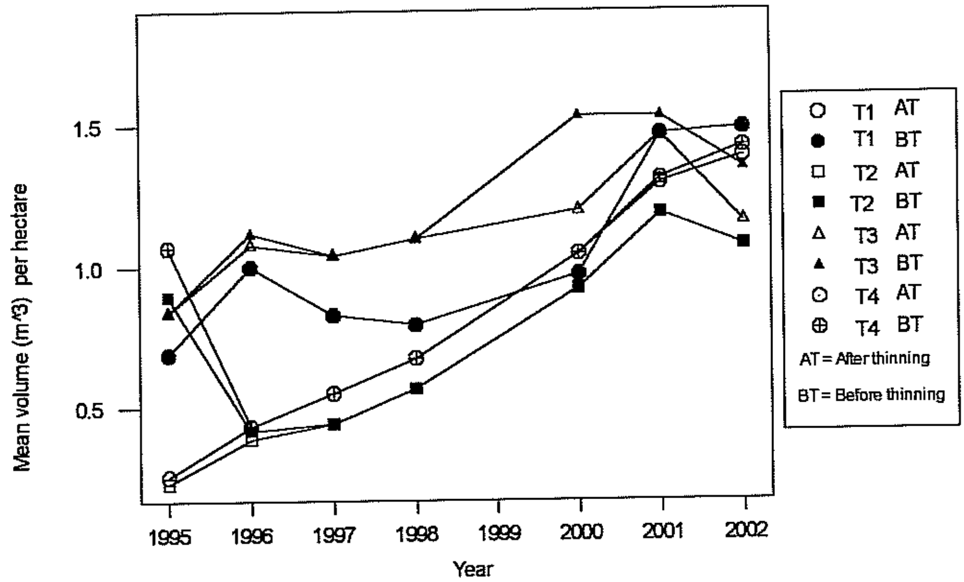


Figure 21. Development in the mean basal area of mopane per hectare for four treatment subplots

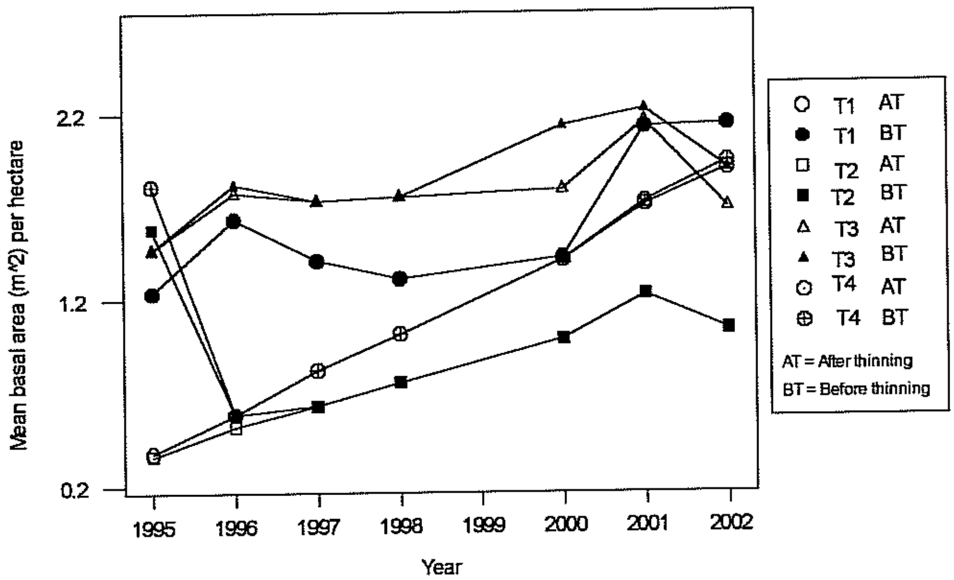


Table 8. Development of mean volume (m^3) per hectare for T1 to T4 measurement subplots during the period of 8 years (mean of 15 subplots)

		Year						
Treatment	Mean Volume	1995	1996	1997	1998	2000	2001	2002
1		0.68928	0.99812	0.82540	0.79199	0.96901	1.46545	1.48726
2	BT	0.89727	0.41804	0.44381	0.56399	0.92017	1.18727	1.07173
2	AT	0.23157	0.39025	*	*	*	*	*
2	Removed	0.66570	0.02812	*	*	*	*	*
2	% Removed	74.6	6.7	*	*	*	*	*
3	BT	0.83452	1.11819	1.03907	1.09922	1.53061	1.53072	1.34901
3	AT	**	1.07998	**	**	1.17335	1.46721	1.15601
3	Removed	**	0.06369	**	**	0.35726	0.13609	0.19300
3	% Removed	**	5.6	**	**	23.3	8.9	14.3
4	BT	1.06765	0.43528	0.55278	0.67406	1.04319	1.30965	1.42337
4	AT	0.25683	**	**	**	**	1.29481	1.38940
4	Removed	0.81082	**	**	**	**	0.07419	0.07278
4	% Removed	75.9	**	**	**	**	5.9	5.1

KEYS

AT After thinning
BT Before thinning
* Thinning was done but shoots did not reach the measurable size
** No thinning was done

Table 9. Development of mean basal area (m^2) per hectare for T1 to T4 measurement subplots during the period of 8 years (measurement for the year 1999 is excluded)

		Year						
Treatment	Mean basal area	995	1996	1997	1998	2000	2001	2002
1		1.24280	0.63117	1.41442	1.31486	1.42692	2.12703	2.13618
2	BT	1.58049	0.58768	0.62827	0.75446	0.98736	1.22310	1.03867
2	AT	0.36414	0.51886	*	*	*	*	*
2	Removed	1.21635	0.06977	*	*	*	*	*
2	% Removed	76.9	11.9	*	*	*	*	*
3	BT	1.47086	1.81807	1.72898	.75030	2.13590	2.22506	1.90238
3	AT	1.47086	1.77838	1.72898	1.75030	1.76659	2.15828	1.69725
3	Removed	**	0.06616	**	**	0.36931	0.14309	0.20513
3	% Removed	**	3.6	**	**	17.3	6.4	10.8
4	BT	1.80935	0.58679	0.82261	1.01571	1.41363	1.72707	1.93544
4	AT	0.38186	**	**	**	**	1.71185	1.89960
4	Removed	1.42749	**	**	**	**	0.07608	0.07680
4	% Removed	78.9	**	**	**	**	4.4	4.0

KEYS
AT After thinning
BT Before thinning
* Thinning was done but shoots did not reach the measurable size
** No thinning was done

5.3.6 Volume and basal area increment for four treatments subplots

Table 10. Mean volume and basal area increment of mopane per hectare in the four treatment subplots in the year period 1995-1995 to 2001-2002

Year period	Treatment	Volume increment (%)	Basal area increment (%)
1995-1996	1	45.3855	32.3057
1995-1996	2	84.6365	65.5764
1995-1996	3	36.3287	25.1476
1995-1996	4	72.4744	56.9942
1996-1997	1	-16.2658	-12.7492
1996-1997	2	15.5552	23.1102
1996-1997	3	-3.3684	-2.8232
1996-1997	4	27.3228	41.4307
1997-1998	1	-3.4463	-5.9172
1997-1998	2	26.5303	19.5337
1997-1998	3	6.8338	2.392
1997-1998	4	23.7538	25.5733
1998-2000	1	27.4261	12.0937
1998-2000	2	67.5036	33.5474
1998-2000	3	42.3933	24.4942
1998-2000	4	60.2557	43.9445
2000-2001	1	52.8075	51.1508
2000-2001	2	30.3648	25.2152

2000-2001	3	28.4416	24.5025
2000-2001	4	30.8991	32.059
2001-2002	1	3.2007	1.9622
2001-2002	2	-8.0953	-13.9594
2001-2002	3	-6.8045	-10.8012
2001-2002	4	11.7417	15.1534

Figure 22. Mean volume and basal area increment (%) of mopane for four treatment subplots in the year period 1995-1996 to 2001-2002

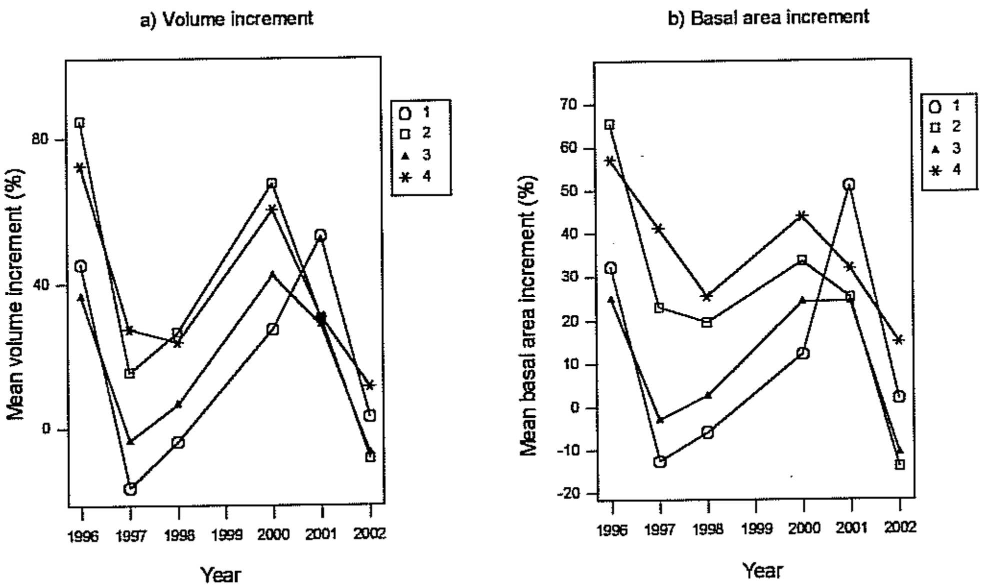


Table 10 and Figure 22 indicate the shoot mean volume and basal area increment percentage in four treatment subplots in the year period 1995-1996 to 2001-2002. Figure 22 evidently shows that the growth rate in T2 and T4 subplots stayed on top of that in T1 and T3 subplots since the year 1996 until the year 2000. However in the year 2001, the growth rate was largest in T1 subplots than the rest. The increment for all treatments subplots to a great extent went down (with negatives values in some subplots) in 1997 and 2002. The reduction in the shoot mean number in 1997 and error in point of diameter measurement in 2002 could be a contributing factor to such sharp fall in mean volume and basal area increment in all treatment subplots. Furthermore, there was an error in taking measurement in the year 1999 because it was only one shoot measured at each shrub specifically in T1, and T4 subplots instead of all shoots. Therefore, the inclusion of mean values of volume and basal area obtained in this specific year was avoided in growth increment calculation in order to justify the validity and accuracy of the trial results.

5.4 Results for comparing leading shoots' growth in T2 and T4

Emphasis was made to compare the growth of the leading shoots in T2 and T4 measurement subplots. This comparison aimed to see whether there was any differences for the mean values of the number of shoots, volume, basal area, height and diameter in subplots where treatment 2 and 4 have been applied in the period of 8 years. T2 and T4 subplots had been treated equally at the onset of the trial, whereby only one leading shoot was left at each shrub. However, in the subsequent years, all the regenerating shoots in T4 subplots had been allowed to grow until they reach a certain harvestable size while in T2 subplots, all the regenerating shoots were thinned out every year. It was hypothesized that, the coppice shoots in T4 will at a certain time slow down the mean growth rate of the leading shoots. Figure 23 shows the mean number of leading shoots in T2 and T4 subplots while Figure 24 and 25 illustrate the development in the mean values of height, diameter, volume and basal area.

Figure 23. The development of mean number of shoot per hectare of the leading shoots in T2 and T4 subplots

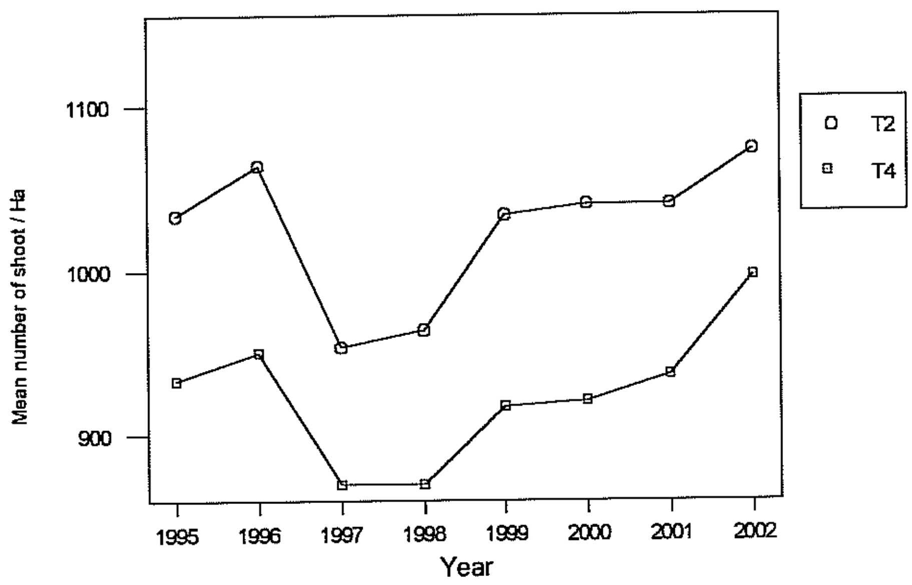


Figure 26 demonstrates the mean volume and basal area increment in each year in these particular subplots. All the above-mentioned variables for T2 and T4 subplots are summarised together in Table 11.

Figure 24. Changes in mean height and diameter of the mopane leading shoots in T2 and T4 subplots

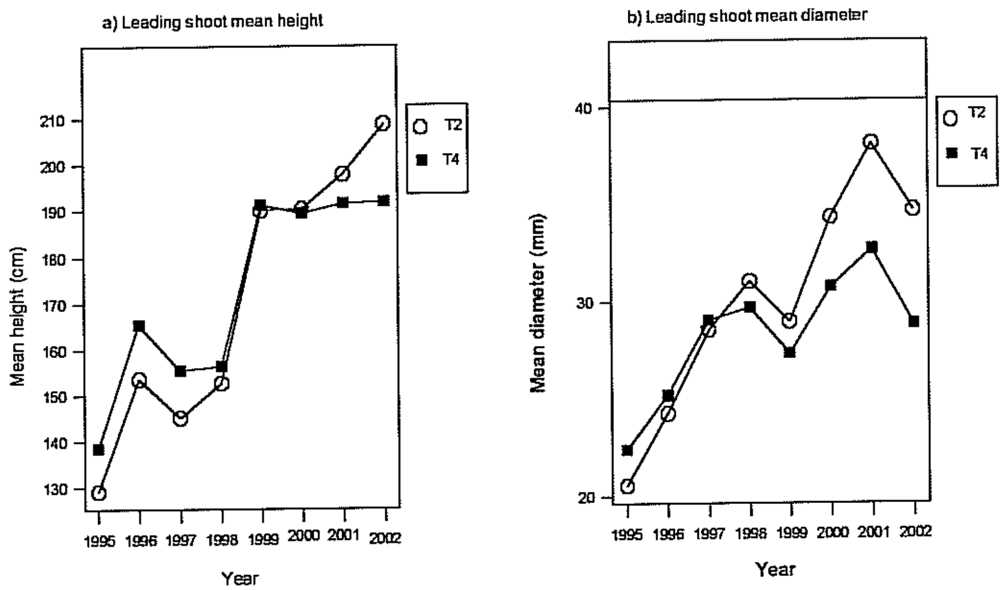
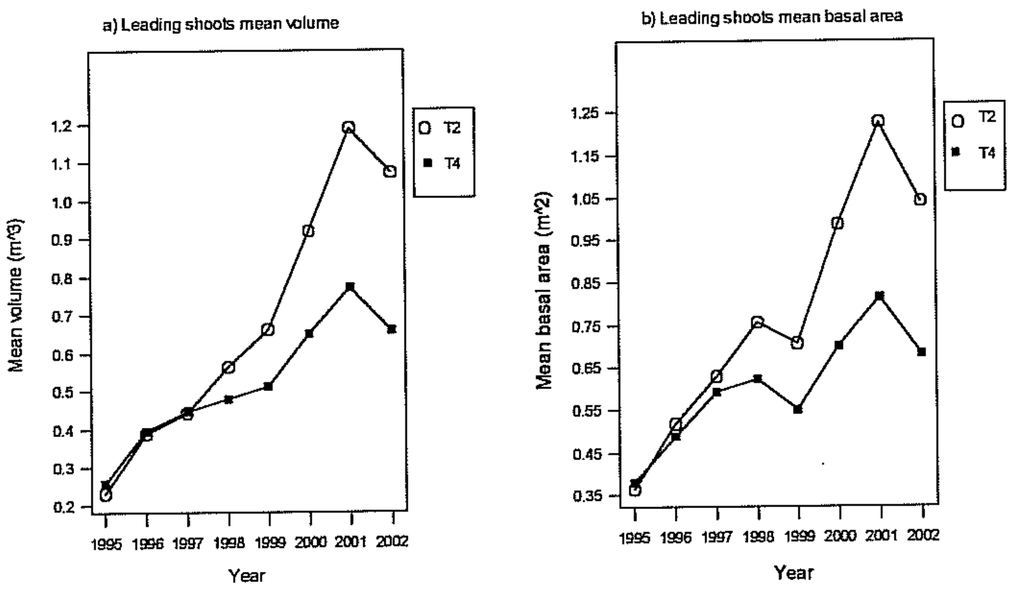


Figure 25. Development of mean volume and basal area of mopane leading shoots in T2 and T4 subplots

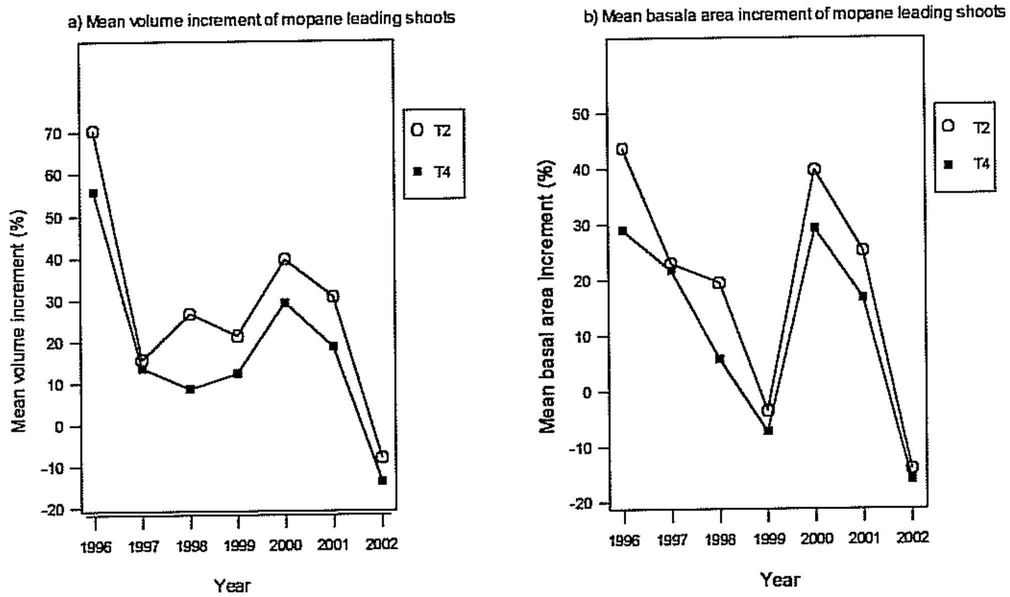


Thoroughly assessment of Figure 24 and 25 reveals that the mean height and diameter in T4 subplots was higher compared to T2 subplots in the first three years. In addition to that, there was no apparent variation between T2 and T4 subplots for mean values of volume and basal areas in those first three years. However, since the year 1998 upwards the mean values of all the measured variables in T2 subplots began to go above those in T4 subplots and this divergence appeared to become large as the years advance.

Table 11. The effects of treatment 2 and 4 in the growth of the leading shoots in T2 and T4 subplots

Year	Treatment	Mean volume	Mean basal area	Mean height	Mean diameter	Mean shoot
1995	2	0.23157	0.36414	129.2	20.6	1033
1995	4	0.25683	0.38186	138.6	22.5	933
1996	2	0.39025	0.51886	153.8	24.3	1063
1996	4	0.39434	0.48735	165.4	25.2	950
1997	2	0.44381	0.62827	145.3	28.6	953
1997	4	0.44788	0.5934	155.3	29.1	870
1998	2	0.56399	0.75446	152.7	31.0	963
1998	4	0.48041	0.62318	156.4	29.7	870
1999	2	0.6613	0.70646	190.2	29.0	1033
1999	4	0.51213	0.5504	191.3	27.3	916
2000	2	0.92017	0.98736	190.4	34.3	1040
2000	4	0.64839	0.70013	189.5	30.8	920
2001	2	1.18727	1.2231	197.8	38.2	1040
2001	4	0.76872	0.81427	191.6	32.7	936
2002	2	1.07173	1.03867	208.8	34.7	1073
2002	4	0.65599	0.68017	191.8	28.8	996

Figure 26. Mean volume and basal area increment of mopane leading shoots in T2 and T4 subplots



Furthermore, the mean volume and basal area increment of the leading shoots in T2 and T4 subplots is illustrated in Figure 26. Obviously in this figure, the average yearly increment for the indicated variables in T2 remained higher in comparison with T4 subplots, although in some years, specifically the year 1997 and 2002, the increment was approximately similar.

It is worth mentioning that even though such differences occur between T2 and T4 subplots, the shape of their graphs nearly looks identical for all depicted variables all the way through. It can be seen in all figures that where the mean values of variables in T2 subplots is lower or higher, this same trend also applies to all variables in T4 subplots. This means that there is some factors that affect the growth of the leading shoots in both T2 and T4 subplots equivalently; presumably the amount of rainfall received and the way measurement was taken each year.

5.5 Results for harvested shoots in T3 and T4 measurement subplots

Table 12. Mean volume and basal area of the harvested shoots in T3 and T4 measurement subplots in the year 2000-2002

	Treatment 3				Treatment 4			
Year	Mean volume (m^3)	Mean basal area (m^2)	Mean weight (kg)	Number of subplots	Mean volume (m^3)	Mean basal area (m^2)	Mean weight (kg)	Number of subplots
1996	0.11922	0.06944	**	9	*	*	*	*
2000	0.35726	0.36931	573.0	15	*	*	*	*
2001	0.13609	0.14309	116.4	7	0.07419	0.07608	95.0	3
2002	0.19300	0.20513	392.3	15	0.07275	0.07680	159.3	7

* No thinning was done
** Figures cannot be verified

The principal objective of the 'Mopane Shrubland Management Trial' is to assess the growth and yield of mopane shrubs when protected and managed along lines, which give products that are desirable to local subsistence farmers. Table 12 have just demonstrated that well protected and well-managed mopane shrubs can provide local farmers with such required materials within a reasonable short period of time. To elaborate more on this, it can be stated that some of the shoots in T4 subplots that coppiced from the stumps thinned in the year 1995, first reached their required harvestable size (the minimum height of 2 m and diameter of 2 cm) just after six years of their growth as illustrated in Table 12.

Close examination of the data recorded earlier than the year 2001 from T4 subplots revealed that some coppice shoots even reached their harvestable size earlier, just after two growing season, but these were not harvested due to some unexplained reason until the year 2001. In addition, shoots in T3 subplots, which are believed in the past to have been over exploited by the local community, and over grazed by livestock also managed to grow well.

5.6 Results for the regeneration shoots in the year 2002

Table 13. The regeneration of mopane shoots in the four measurement subplots in the year 2002 (Figures are per hectares)

Variable	Descriptive statistics	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Shoot Number	Mean	242	90	200	79
Volume (m^3)	Mean	0.0210	0.0072	0.0140	0.0061
Basal area (m^2)	Mean	0.0480	0.0141	0.0350	0.0125
Subplot Number	-	6	5	5	12

Unlike in other years of mopane shoots measurements, efforts were made in the year 2002 to observe, count and record new measurable shoots in each treatment subplot, which seemed to appear and reached their measurable size after the establishment of the trial. The mean numbers of new shoots for each treatment plot are illustrated in Table 13 and other descriptive statistics are illustrated in **Appendix 14**. Even though there was no specific mentioning of new shrubs before the year 2002, close investigations of the data recorded earlier indicated that there had been some new shrubs and shoots that regenerate prior to the year 2002. For example it is obvious in Figure 9 and 10 that the number of shrubs and shoots had been on increase since the year 1997.

It was potential to know whether these new shrubs had stemmed from seeds or from the subterranean stem. However, this was not possible to know in this study as it was far beyond the scope of this study. Nevertheless, with more financial aid, efforts will be made in the future in trial like this to examine whether the new shrubs are from the seeds or are from the underground stems.

6. Analysis

6.1 Analysis for all four treatments subplots

After thinning in 1995, the mean number of shoots per hectare in T2 and T4 measurement subplots were dramatically reduced by 84.8% and 87.4% respectively in order to leave just one leading shoot at each shrub. In addition to that, the mean value of volume and basal area per hectare in T2 subplots was reduced by 74.6% and 76.9% respectively. In T4 subplots, 75.9% of mean volume and 78.9.0% of mean basal area were removed during thinning. Even though this huge reduction has affected the total biomass of these two respective treatment subplots, this was a bonus for the remaining shoots, which reacted positively to thinning by increasing their mean volume and basal area in the year following the heavy thinning. The growth of shoots in T2 and T4 subplots in 1996 following the thinning in 1995 was remarkable high compared to T1 and T3. For example mean volume increment in T2 subplot was higher by approximately 50% and 60% compared to volume increment in T1 and T3 respectively while in T4 subplots it was more by about 40% and 50% compared to that in T1 and T3 respectively. From the year 1996 to 1997, the mean the number of shrubs and number of shoots in the whole trial plot decreased by about 13% and 28% respectively while the mean volume fell down by 1%.

Results in previous sections and subsections demonstrated that different treatments applied to mopane thicket stands affect the growth of mopane shoots differently. Effort was then made to see whether this differences in the growth of mopane shoots was statistical significant or not. Thus ANOVA from Minitab 13 software (using 95% confidence interval) was used for this analysis. If significant difference was detected, further analysis was carried out to see which means differed, by using multiple comparison of means method. Fisher's least significant difference method with an individual error of 5% was used for this comparison of means. Multiple comparisons of means allow someone to examine which means are different and to estimate by how much they are different. Minitab presents the results from multiple comparisons of means in confidence interval form to allow someone to assess the practical significance of differences among means in addition to statistical significance. The null hypothesis of no differences among the means is rejected if and only if zero is not contained in the confidence interval. In addition, a p-value of less than 0.05 indicates that there is significance difference among the means of the sample.

The outcomes of the analysis are indicated in Table 13 and 14. These tables summarised data of the confidence intervals of differences among pair of means of increase in volume and basal area and the p-value, a test of statistical significance from analysis of variances table. Tables containing full figures for the analysis of the mean value of increase in volume and basal area are found in **Appendix 15.**

The p-value in Table 13 and 14 shows that in all years, except the year 2001, a significance difference for the mean values of increase in volume and basal area exists between treatment subplots. However, this significance difference occurs only between some pair of treatment subplots as it is illustrated in the same tables by the confidence intervals for the difference between the pair of treatment subplots. For example during the period of 1995-1996 a significant difference in the mean values of increase in volume and basal areas only occurs between 3 pair of treatment subplots that contain a treated and untreated subplot (except an insignificant difference in mean value of increase in basal area between T1 and T2). In the same period insignificance differences take place between a pair of treatment that contains either both treated or untreated subplots. Strangely in the year 1997, significance differences in mean values of increase in volume and basal areas occur between all pairs of treatment subplots.

In 2002, significant differences for mean values of increase in basal area occurred between all pairs except one pair of T3 and T2 while insignificance difference for the mean values of increase in volume occurred between all pair, except two pair, T4 and T2 and T4 and T3. Almost in all years, a significant difference in the mean values of increase in volume and basal area takes place between a pair of T1 and T2, T1 and T4 and T3 and T4 subplots whereas an insignificant difference in the same time nearly occurs between a pair of T2 and T4. The difference for the mean value of increase in volume and basal area between T2 and T3 was approximately significant only in the first three growing seasons but not in the rest.

Table 14. Multiple comparisons and analysis of variance for mean values of increase in volume for 4 groups of treatments subplots in the year 1996 up to 2002

	Confidence intervals for differences between pair of treatment						Analysis of variance
Year ↓	**2 & 1**	**3 & 1**	**3 & 2**	**4 & 1**	**4 & 2**	**4 & 3**	**P-value**
1996	-41.81 -8.52	-7.59 25.70	17.58 50.87	-43.73 -10.44	-18.57 14.72	-52.79 -19.50	0.000
Sig. dif	Yes	No	Yes	Yes	No	Yes	Yes
1997	-40.96 -22.69	-22.03 -3.76	9.79 28.06	-52.72 -34.45	-20.90 -2.63	-39.83 -21.56	0.000
Sig. dif	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1998	-42.59 -17.36	-22.89 2.33	7.08 32.31	-39.81 -14.59	-9.84 15.39	-29.53 -4.31	0.000
Sig. dif	Yes	No	Yes	Yes	No	Yes	Yes
2000	-58.77 -21.38	-33.66 3.73	6.42 43.81	-51.52 -14.13	-11.45 25.94	-36.56 0.83	0.000
Sig. dif	Yes	No	Yes	Yes	No	No	Yes
2001	1.27 43.62	3.19 45.54	-19.25 23.10	0.73 43.09	-21.71 20.64	-23.63 18.72	0.081
Sig. dif	Yes	Yes	No	Yes	No	No	No
2002	-0.44 23.04	-1.73 21.74	-13.03 10.45	-20.28 3.20	-31.58 -8.10	-30.29 -6.81	0.004
Sig. dif	No	No	No	No	Yes	Yes	Yes

1 Treatment 1   3 Treatment 3
2 Treatment 2   4 Treatment 4
Sig. dif Significance difference

Table 15. Multiple comparisons and analysis of variance for mean values of increase in basal area for 4 groups of treatments subplot in the year 1996 up to 2002

	Confidence intervals for differences between pair of treatment						Analysis of variance
Year ↓	**2 & 1**	**3 & 1**	**3 & 2**	**4 & 1**	**4 & 2**	**4 & 3**	**P-value**
1996	-28.31 5.44	-9.72 24.04	1.71 35.47	-41.57 0. 7.81	-30.13 3.62	-48.73 -14.97	0.002
Sig. dif	No	No	Yes	Yes	No	Yes	Yes
1997	-44.58 -27.14	-18.64 -1.21	17.22 34.65	-62.90 -45.46	-27.04 -9.60	-52.97 -35.54	0.000
Sig. dif	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1998	-39.33 -11.57	-22.19 5.57	3.92 31.02	-45.37 -17.61	-19.92 7.84	-37.06 -9.30	0.000
Sig. dif	Yes	No	Yes	Yes	No	Yes	Yes
2000	-38.33 -4.48	-29.28 4.48	-7.82 25.93	-48.73 -14.97	-27.27 6.48	-36.33 -2.57	0.003
Sig. dif	Yes	No	No	Yes	No	Yes	Yes
2001	2.19 49.68	2.91 50.39	-23.03 24.45	-4.65 42.83	-30.58 16.90	-31.30 16.18	0.099
Sig. dif	Yes	Yes	No	No	No	No	No
2002	4.11 27.73	0.95 24.57	-14.97 8.65	-25.00 -1.38	-40.92 -17.30	-37.76 -14.14	0.000
Sig. dif	Yes	Yes	No	Yes	Yes	Yes	Yes

1 Treatment 1 **3** Treatment 3
2 Treatment 2 **4** Treatment 4
Sig. dif Significance difference

6.2 Analysis of T2 and T4 measurement subplots

Table 16. Comparison of the standing biomass and growth rate of the leading shoots in T2 and T4 measurement subplots in the year 1995-2002

	Mean volume	Mean volume increment	Mean basal area	Mean basal area increment
Year	P-value	P-value	P-value	P-value
1995	0.432	-	0.706	-
Sig. dif	No	-	No	-
1996	0.930	0.068	0.593	0.014
Sig. dif	No	No	No	Yes
1997	0.938	0.597	0.621	0.715
Sig. dif	No	No	No	No
1998	0.212	0.007	0.137	0.018
Sig. dif	No	Yes	No	Yes
1999	0.031	0.383	0.035	0.641
Sig. dif	Yes	No	Yes	No
2000	0.003	0.133	0.004	0.134
Sig. dif	Yes	No	Yes	No
2001	0.000	0.043	0.001	0.081
Sig. dif	Yes	Yes	Yes	No
2002	0.000	0.274	0.000	0.647
Sig. dif	Yes	No	Yes	No

KEY
Sig. dif Significant difference

In this section, attempt was made to compare the growth of a group of the leading shoots in T2 and T4 measurement subplots. Most of the leading shoots in these subplots were marked at the beginning of the trial and this makes it easier to track down their average growth rate all the way through. This attempt was made in order to see whether, coppice shoots in T4 subplots, which were left to grow together with the leading shoots until they reached a decided harvestable size, will slow down the growth of these leading shoots and if they do, how significantly this will be in comparison with the growth of the leading shoots in T2 measurement subplots. ANOVA was again used for this analysis. The results of this analysis are tabulated in Table 16.

Despite differences in the number of leading shoots (Table 11) in T2 and T4 subplots right at the beginning of the trial, the mean volume and basal area per hectare in these treatments subplots was roughly the same in the first three years of the trial establishment (1995-1997). Since the year 1998 however, clear differences in the mean values of volume and basal area between T2 and T4 subplots start to emerge and this differences begin to be statistical significant in the year 1999 as demonstrated in Table 16. Regardless of significant differences for the mean volume and basal area between T2 and T4 subplots, differences in their mean annual increment is insignificant in all years. However the mean volume and basal area increment in T2 subplots had been a little bit higher compared to T4 subplots as evidenced in Figure 26.

6.3 The relationship between height and diameter

Figure 27. The relationship between height and diameter (Linear Regression Model)

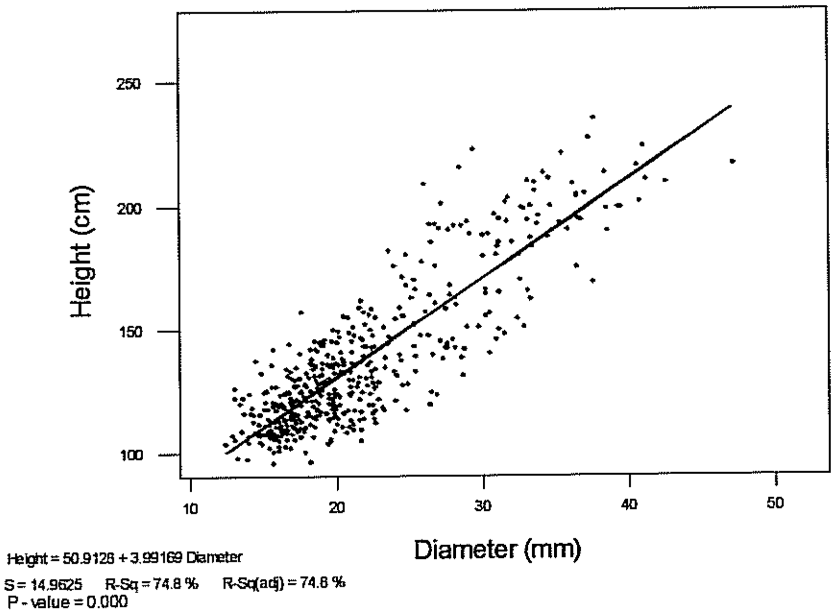
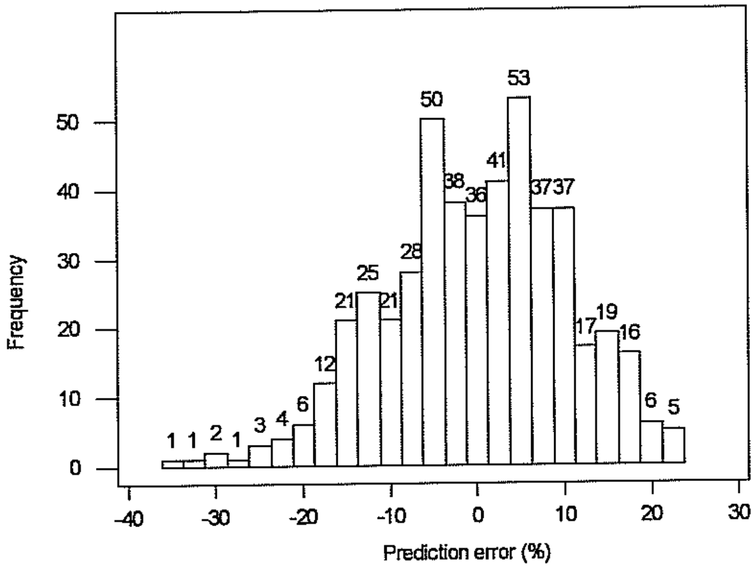


Figure 28. Distribution of the prediction error of height by diameter



Regression analysis was performed to see whether there is any relationship between the mean height and the mean diameter (pooling together the mean height and diameter in all measurement subplots together) of the mopane shoots. In this analysis, height was the response while diameter was a predictor. General linear model using a procedure called *Fitted Line Plot* was used for this regression analysis. Using this model, a graph in Figure 27 was generated and the equation of the fitted model was developed. It can be seen in this figure that there is a positive relationship between the mean height and mean diameter of mopane shoots. That means that the mean height tend to increase with one unit increase in the mean diameter. The equation of the fitted model is as follows:

Height = 50.9128 + 3.99169 Diameter
R-squared (goodness of fit) is 74.8%.

This developed equation was then used to predict the mean height in each measurement subplots using the diameter readings taken during the field measurements. The aim to do this is to see with how much the predicted and the observed mean height differ. The predicted mean height and observed mean height are given in Table 17. In this table, p-value (at $\alpha = 0.05$), which indicates whether the difference between the predicted and observed mean height is significant or not, is also given. In Table 17, only 34.4% of the predicted mean height is not significant different from the observed mean height while the rest of the difference is highly significant.

Further investigation was also made to see with how much percentage the predicted mean height differed from the observed mean height by dividing the observed-predicted mean height difference by observed mean height and multiply the answer by 100. The product from this calculation is referred to as prediction error. The distribution of prediction error of height by diameter is indicated in Figure 28. In this figure, it can be noticed that the majority of the shoots fall in the prediction error of –10% to 10%. The shoots fell in this region represent 71.0% of the total number of shoots. The shoots that have their heights overestimated by more than 10% represent 13.0% of the total number of shoots, while those that have their heights underestimated by more than 10% represent 15.8% of the total number of shoots. It is also interesting to detect that the distribution of prediction error of the mean height by diameter is normal distributed, as the shape of the graph is almost bell-shaped. That means the majority of the prediction error are around the mean prediction error, which appear to be approximately zero in the graph.

Table 17. The comparison of observed and predicted mean height in treatment subplots and analysis of variances of their means

		Observed Height			Predicted height			
Year	Treatment	Mean Height	Standard Deviation	Standard error of mean	Mean Height	Standard Deviation	Standard error of mean	P-value
1995	1	107.294	4.5155	1.16590	116.677	3.4408	0.88841	0.000
1995	2	109.548	4.3663	1.12737	115.853	4.0494	1.04554	0.000
1995	3	108.104	5.8732	1.51646	112.447	4.1590	1.07386	0.027
1995	4	112.979	5.3093	1.37085	117.687	3.3022	0.85262	0.007
1996	1	115.403	8.0037	2.06655	120.587	8.2658	2.13422	0.096
1996	2	153.766	8.9026	2.29864	147.933	8.6190	2.22543	0.079
1996	3	117.111	6.7544	1.74399	118.404	6.3986	1.65212	0.595
1996	4	120.767	10.3973	2.68458	115.686	9.6345	2.48761	0.176
1997	1	115.738	8.0491	2.07826	136.467	8.0464	2.07757	0.000
1997	2	145.327	13.0918	3.38028	165.06	9.2432	2.38659	0.000
1997	3	119.304	6.5778	1.69839	134.198	6.7024	1.73054	0.000
1997	4	114.44	9.3010	2.40151	123.251	10.6871	2.75939	0.023
1998	1	118.457	8.9495	2.31076	140.795	7.4728	1.92947	0.000
1998	2	152.718	10.9614	2.83022	174.819	11.3124	2.92085	0.000
1998	3	124.397	8.4733	2.18781	137.42	5.5351	1.42915	0.000
1998	4	114.904	11.1833	2.88752	123.622	8.0232	2.07158	0.021
1999	1	154.872	8.7331	2.25488	145.772	9.3491	2.41392	0.010
1999	2	190.186	9.9474	2.56842	166.717	11.9975	3.09773	0.000
1999	3	147.784	7.6571	1.97706	127.42	7.8243	2.02023	0.000
1999	4	191.318	16.9584	4.37864	159.937	10.7890	2.78572	0.000

Table 17 continue from previous page

Year	Treatment	Mean Height	Standard Deviation	Standard error of mean	Mean Height	Standard Deviation	Standard error of mean	P-value
2000	1	130.459	10.4024	2.6859	131.355	7.1947	1.85766	0.786
2000	2	190.411	11.4609	2.9592	187.989	12.3539	3.18977	0.582
2000	3	135.674	6.5284	1.68562	126.673	5.5266	1.42695	0.000
2000	4	123.013	10.9199	2.8195	116.31	5.8018	1.49801	0.045
2001	1	131.697	9.3995	2.42694	138.174	8.7601	2.26185	0.061
2001	2	197.808	12.219	3.15492	203.295	15.1871	3.92128	0.285
2001	3	133.536	6.2434	1.61203	131.011	6.1513	1.58826	0.274
2001	4	128.124	10.8051	2.78988	120.409	7.6262	1.96909	0.032
2002	1	127.673	7.5934	1.96061	124.171	5.3609	1.38418	0.156
2002	2	208.797	14. 3587	3.70739	189.398	11.9275	3.07967	0.000
2002	3	134.614	10. 0405	2.59244	121.302	6.7368	1.73944	0.000
2002	4	121.993	7.0567	1.82204	107.381	3.1622	0.81647	0.000

6.4 The correlation between weight and basal area

As in the previous section, an attempt was again made to see whether there is correlation between weight and basal area and volume. The fresh weight of the shoots harvested in the year 1995, 2000 and 2002 and linear regression model was used for the study of this relationship. Two models, one for the relationship between fresh weight and basal area and the other for the relationship between fresh weight and volume were produced. In order to improve the linear regression model and to achieve its acceptable accuracy, some of the extreme outliers in the data were excluded in the model.

The fitted model (Figure 29) for the fresh weight-basal area relationship produces r-squared (goodness of the fit) equals to 97.8%, while the one for the fresh weight-volume relationship (graph not shown) produces r-squared equals to 90.4%. Because the model produced from the relationship between fresh weight-basal area fit the data well, it was instead used to predict the biomass of the mopane shrub stand. The best fitted equation for the relationship between fresh weight and basal area is as follows:

Weight = 166.936 + 1188.93 Basal area

Figure 29. Relationship between weight and basal area (Linear Regression model)

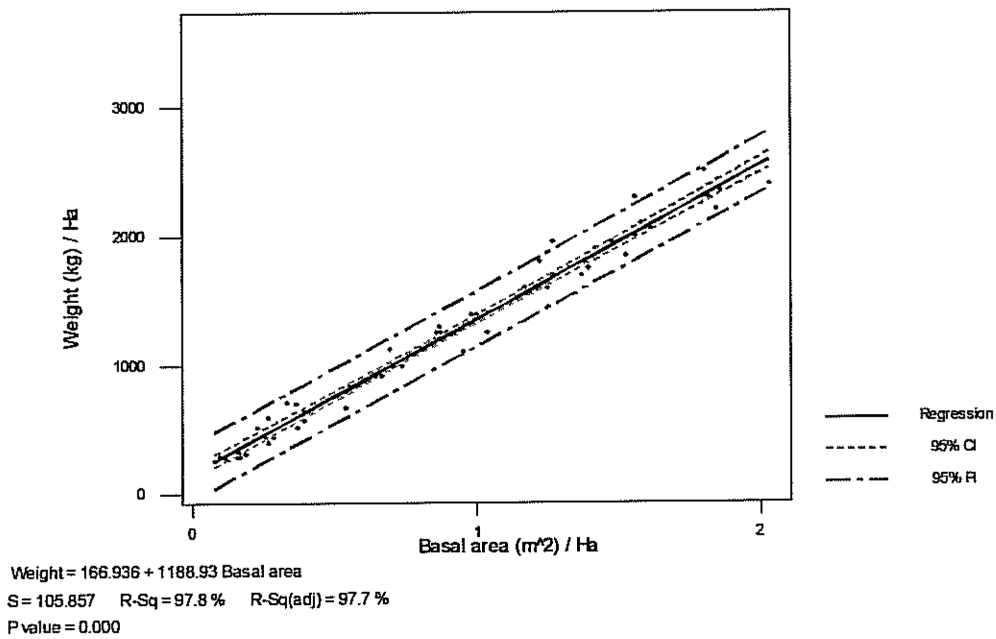
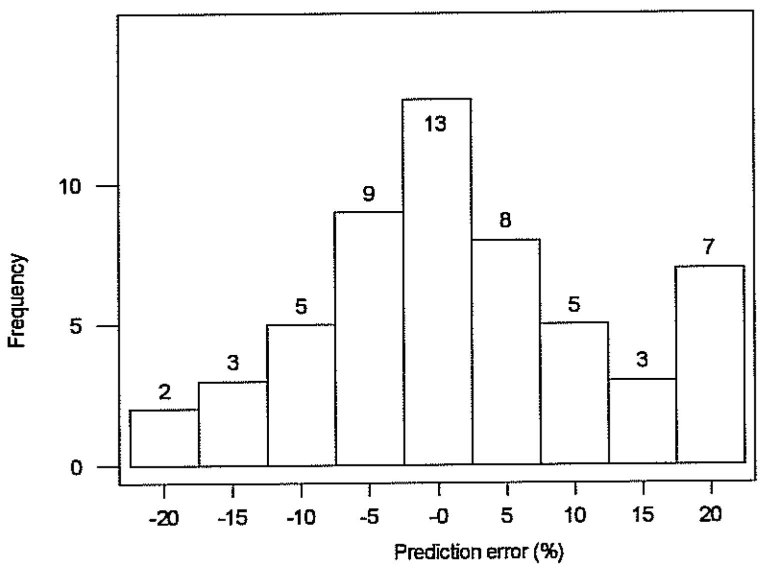


Figure 30. Distribution of prediction error of weight by basal area

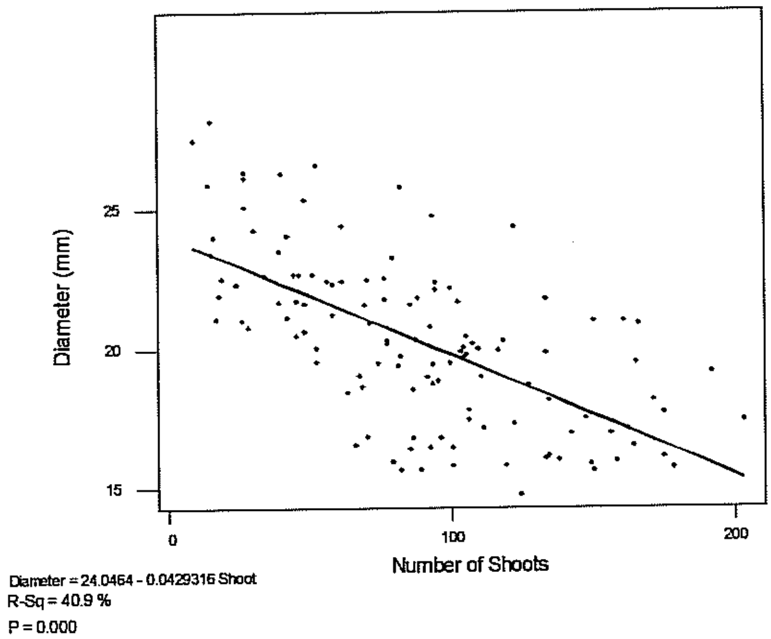


This equation was used to predict the weight of the harvested shoots. The mean value of observed and predicted weight per hectare was then statistically compared to see whether any significance differences occurred between them. This comparison is indicated in

6.5 The relationship between diameter and the number of shoots

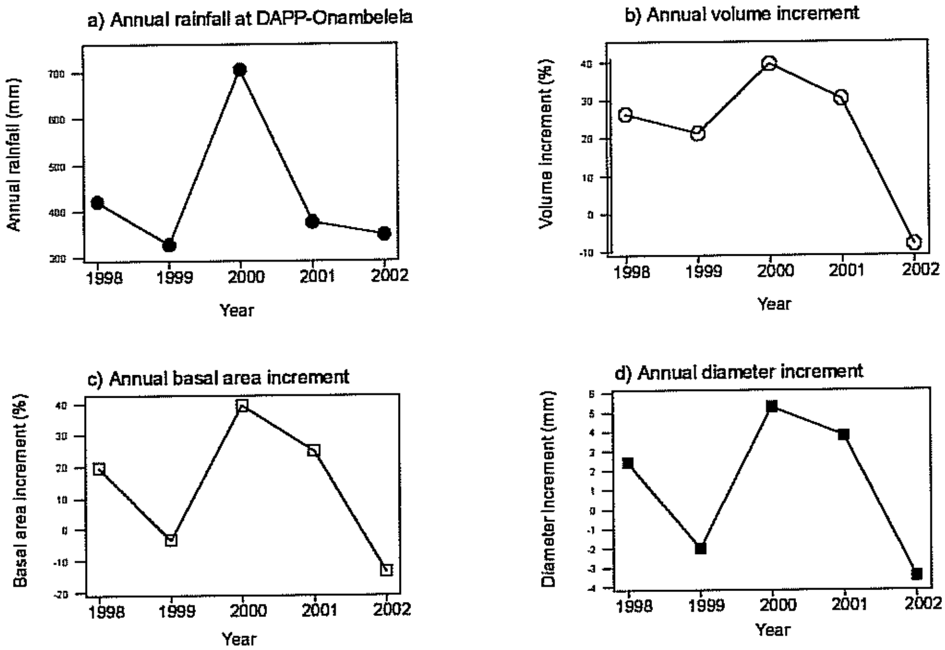
The study was done to see whether there is any correlation between the mean diameter and the number of shoots of mopane. The data collected in all years from all the control plots or subplots was pooled together and used in this analysis. Control plots (T1 plots) are thought to be good for this analysis as there were no treatments done in these plots and that they symbolise the way shrubs grow naturally. The result of this analysis is demonstrated in Figure 32. It is illustrated in the graph that there is a negative relationship between the mean diameter of the shoots and the number of shoots of mopane. In other words this means that the mean diameter of the shoots tends to decrease as the number of shoots in the subplots increases.

Figure 32. The correlation between the mean diameter and the number of shoots of mopane



6.6 The relationship between rainfall and the growth of the mopane shoots

Figure 33. The relationship between the rainfall and the growth of mopane in T2 subplots



Often, many researchers are of the opinion that the growth of many tree and shrub species is influenced by many factors on which climate is included. To prove the validity of this statement, effort was made on this trial to see whether the growth of mopane can also be affected by rainfall. The rainfall data used was collected at DAPP-Onambelela, the site at which Mopane Shrubland Management Trial is located. The rainfall data was collected since the year 1997 up to the year 2002. As the there is no rainfall data available for the year 1995-1996, only the growth of mopane obtained in the year 1997 up to 2002 was compared with the rainfall data recorded in the same period.

The monthly rainfall data was brought together in such a way that the monthly rainfall data recorded from August to July was added together to form an annual (12 months period) figure. For example the annual rainfall data represented by the year 1998 is made up of the monthly rainfall data from August 1997 to July 1998. Only the growth of the leading shoots in T2 subplots was compared with the rainfall data because the marking of these shoots make it easier to follow their development.

Figure 33 displays the changes in the annual rainfall, annual volume increment, annual basal area and annual diameter increment. It appears in Figure 33 that the growth of mopane and the rainfall interrelate because if you closely look at the figure, the outline of all graphs is roughly similar. Where the rainfall is high, the mean growth of the shoots is also high and where it falls, the growth also declines. The highest rainfall recorded in the year 2000 also coincides with the highest growth recorded in a similar year for all variables.

7. Discussion

It is clear from the above-presented results that different treatments of mopane affect the growth of mopane differently. The results indicate that thinning of mopane shrubs can dramatically increase the growth of this species beyond any reasonable doubt. There is no hesitation in believing that thinning can reduce the total biomass of the thinned plot compared to unthinned plots, however it was also demonstrated in the results that it can only takes few years for the biomass in the thinned plots to equate the biomass that the plots have initially. For example after the first thinning in 1995, the biomass in T2 and T4 plots takes only about 5 years to reach the biomass that the plots have before thinning. The biomass in T1 and T3 plots has not been changing that much as no thinning was done in T1 and in case of T3 major thinning occurred only in 2000 upwards. Hence, thinning could be the way to go to manage mopane if the purpose of the management is to produce some required size classes of poles in a shortened period of time.

This study has also confirmed what has been concluded in other studies that the growth of the shoots in a plot can slow down if the density of the shoots is high. The study carried out in South Africa on mopane found the significant negative relationship between equivalent basal diameters of sprouts and sum of nearest neighbour diameters to distance (Rathogwa et al, 2002). Similarly in this study it was discovered that the growth of the leading shoots in T4 plots was actually slowing down when many stumps thinned in 1995 started coppicing and when the plot reached the mean density of 2767 shoots per hectare. This was also revealed in Figure 33, that the mean diameter of the shoots with time could actually be reduced if the density of the shoots increased. However the growths of the leading shoots in T2 subplots did not slow down but remained increasing because the coppicing shoots in these plots were continuously removed every year. The reason why the growth of the leading shoots in T4 plots was slowing down could be due to the reason that at high density the competition for natural resources such as water, nutrient and lights could start and this could eventual lead to the slow growth rate of the shoots in the subplots. In thinned subplots the spacing between the shoots was increased thus the availability of the natural resources for the remaining shoots was enhanced. This therefore boosted the growth of the individual shoots and finally the growth of the whole plot.

Moreover, the study of the mean height and diameter increment per year of the leading shoots in T2 and T4 plots was conducted to further assess the effect of high density on the growth of mopane shoots over the period of 7 years (1996-2002). This assessment showed that, the mean height and diameter increment in T2 plots during this period was 11.4 cm and 2 mm per year respectively. In the same period, the mean height increment in T4 subplots was 7.6 cm per year whilst the mean diameter increment was 0.9 mm per year. The mean number of the measurable shoots per hectare in T2 and T4 subplots within such period was roughly 1218 and 5068 in that order. Therefore roughly speaking, shoots growing at an average density of 1218 shoots per hectare can reach their minimum required diameter of 2 cm in about 10 years while at an average density of 5068 shoots per hectare, the shoots can reach this minimum required diameter in approximately 20 years.

If the purpose of mopane management is to get products such as poles for roofing, fencing, palisade and hut construction, the harvesting time can further be prolonged if the shoots are growing at the above-mentioned growth rate. According to Erkkilä and Siiskonen (1992), the diameter of the poles required for roofing, palisade, fencing and hut walls construction of an average house is 4 cm, 7.5 cm, 12 cm and 9-10 cm respectively. Hence shoots growing at an average density of 1218 shoots per hectare will reach the diameter required for roofing, palisade and hut's walls after about 20, 38 and 48 years respectively. Shoots growing at an average density of 5068 per hectare will reach the same diameter requirement in about 48, 83 and 105 years respectively.

Furthermore, studies carried out in Namibia at Onankali and Ogongo Agricultural College in early 1970s on the effects of thinning on mopane growth concluded that with careful management, mopane could produce good dropper-size poles in about 3-4 years (Kreike, 1995). This was a fast growing rate compared to what was found in this study. The reason why the growth rate of trees in those years was high could be due to the reason that the rainfall during that time was also high and that the trees were growing at lower density compared to trees or shoots at Onambelela trial. However, these estimated figures are just primarily and in future, more studies aiming to assess the effect of thinning and high density on individual mopane trees instead of a group of trees needs to be carried out if growth rate estimation of the mopane shoots is to be improved.

Also this study made it possible to produce elementary models like linear regression models that can be used to predict useful valuables such as fresh weight of the standing shoots without first destroying the trees as well as to predict the height of the shoots in the stand by just measuring the diameter in the field. It should be born in mind however that these are preliminary models for these specific species and if they are to be used in any way to predict the above-mentioned variables, this must be done attentively. It must be understood that if these formula are to be used by anyone in anyway for stand height or weight prediction, it must also be expected that some of the predicted results may fall far away from the expected mean value as it was seen in Figure 28 and 30. In addition, users must make sure that they use comparable or similar method as the one used in this study when measuring essential and functional variables such as diameter, for example in this case the diameter was measured at 10 cm from the ground; that climatic and edaphic conditions are corresponding and that the species assessed is identical. It is wise to follow these recommendations in order to avoid over or under predicting the required or estimated variables.

Furthermore, these regression equations though basic, will make it possible for people wish to engage themselves in sustainable management and production of mopane to be able to estimate the total biomass production in mopane stand. These models will be useful for the users as they can alleviate difficulties normally associated with decision making on when and how much of mopane products should be harvested and in the process, the incidence of over harvesting and depleting the stand of its natural resources is reduced. In addition to that, environmental problems such as soil erosion, which causes land degradation, will also be controlled. To improve the importance, the accuracy and precision of these models, more repetitive studies on the same species growing in the same or different areas with corresponding or non-equivalent climatic and edaphic condition needs to be carried out. Also care must always be taken when carrying out measurement in the field to make sure that measuring instruments are used correctly and that data are recorded accordingly.

Observation of the growth of coppiced shoots especially in T4 subplots or plots has indicated that most of the coppiced shoots grow more faster than the shoots which were left as the leading shoots at the beginning of the trial establishment. This gives an impression that mopane shrub land that show sign of slow growing can grow better if clear cut to stimulate the growth of new shoots which can grow vigorously faster. In addition, regeneration of mopane as a result of clear-cut demonstrates to be the easiest way to go than raising seedling from the nurseries. Huge costs incurred in raising seedling in the nursery and when planting seedlings in the field cause the method of regenerating mopane from coppicing to be more preferably than raising seedlings from nurseries specifically in Namibia climatic conditions. Also one reason to avoid nursery seedling is due to the fact that mopane seedling in the nursery are prone to damping off (Flower, et al. (1999); that mopane is slow growing and has difficult in establishing itself in the face of competition from grass (Timberlake, 1999); and that the survival rate of nursery-raised seedlings in the field is not yet known and not yet well studied (Mushove, 1992).

Even though it was not the principal objective of this trial, visual investigation of the grass in treatment plots was conducted. The investigation reveals that T2 subplots, where only one leading shoot was left at each shrub, have more grass than other treatment plots, which have high number of shoots. Thinning has opened up more space in T2 plots and this has created optimum conditions such as more light and nutrients, which are required for the growth and survival of the grass. The importance of having grass in these well-managed plots is that the grass can be utilised to feed livestock as well as to thatch traditional huts. The grass cover can also reduce the soil erosion usually caused by running water and wind, and this eventually can increase the productivity and sustainability of the thinned plots. However if thinning is conducted in the area where no protection of the trees is not well planned (for example fencing off the area), regenerating grass can attract a lot of animals, which will not only feed on the grass but can also browse on the green leaves of the managed mopane shoots, therefore destroying the retained shoots in the practice. As a consequence, the growth of the shoots can be significantly disturbed and slowed down.

8. Implication for the management of 'Mopane Shrubland Management Trial'

Although this trial seems to be a success, its management right the way through has been faced with a lot of problems such as reassignment and resigning of the forestry staffs responsible for the collection of the data and report writing; missing of the trial marking poles and labelling metal pegs; unauthorised cutting of the high-quality shoots in the trial and deteriorating of the fence surrounding the trial. Unauthorised access into the trial and interfering with the treatments has been happening despite the efforts made by Directorate of Forestry (DoF) and DAPP staffs to explain the importance of the trial to local community and regardless of the appeal to the local people to refrain from using the trial site as the source of their wood products.

One of the additional objectives of the trial was to involve the community people in the management of the trial right at the beginning of the trial, however the involvement of the local people at first was a bit slow. The community realised that no cash was offered to them for their work in addition to the products they got from treatment operations. However in subsequent years, many local people start to come around after the introduction of small payment to them.

Moreover, there has been a system of coming and going of the people responsible for the annual measurement of the trial and therefore those responsible for the data processing and compiling of the report about the trial. This led to the accumulation of the collected data without any processing for the period of 8 years. There were only two reports (the 1995-1996 technical reports) written by Martinus Gelens, the initiator and establisher of the trial. No other reports have been written since then after Gelens left, which the composer of this reporter is aware of.

It happens then that entering this accumulated data of 8 years into the computer and processing it was a very big challenge because this has been a responsibility of one person only even though it could have been the responsibility of more than one person. It comes therefore that it costs a person responsible a lot of time just to enter and process the data and then compile this report afterwards.

It should be understood and stressed that complicated research and compiling of research works like this one should normally be handled and headed by more experienced research people with masters and doctorate qualifications. The reality is now that some of these people are lacking in Forestry Research Division and the qualified officers who are available or present in the division are engaged on other responsibilities and duties that are more or less related to management rather than research obligations.

It comes therefore that the responsibility for writing this scientific report was left to people with Bachelor of Science qualifications and those with very limited background or experience in research field and who were not in the past exposed to such tasks. Hence the knowledge used for data entrance and processing and for compiling this scientific report was merely the one gained from the University. As the result of above-mentioned problems, the content of this report especially the interpretation of the results, the discussion and the conclusion, might not be up to the standard of the scientific way of reporting. However with time, and through useful criticisms and recommendations received from the viewers and readers of this report, a room for improvement will always be there.

9. Conclusion

It can be concluded from this study, that high stocking density of mopane can dramatically reduces the growth rate of the individual trees and stand as a whole in comparison with the low stocking density. Also results from this study indicate that it is possible to rehabilitate formally degraded mopane shrub land by cutting down all shrubs which show signs of slow growing and which are crooked and stunted in nature in order to stimulate the growth of vigorous and new fast growing shoots that can produce required products in a short period of time.

This study also produces the hope that if local people properly manage their mopane shrub land, which is either growing in a communal or private land, this can eventually alleviate poverty amongst themselves as products produced from the well managed mopane shrub land can be sold and generate money. Also if the local people can manage their own mopane stands accordingly they can save money, which they normally use to buy essential commodities like fuel wood. Energy, which is normally used by many women and men in walking long distances for fuel wood and other wood products collection can be saved for other local work which can additionally generate more money. For example women can engage on other household works such as making baskets and clay pots, which they can also sell. In addition appropriate management of mopane shrub land and sustainable use of mopane products means that pressure of harvesting wood from protected areas such as nature reserves and forest reservation can be alleviated.

It is therefore up to the extension officers in the Directorate of Forestry during their extension work to see to it that they distribute and made well known some of these presented information, which they find useful, to all stakeholders who are interested in the proper management of mopane.

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