Santalum spicatum trial at Northampton, Western Australia 1987 to 1995

Department of Conservation and Land Management, Geraldton

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For: The School of Environmental Science

Industrial Experience Report

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Abstract

A *Santalum spicatum* trial was carried out at Northampton, Western Australia. It was the aim of this trial to determine percentage survival of the sandalwood planted, to approximate the annual growth rate and to comment on provincial differences within the species with regard to survival and rate of growth. With the exception of two rows, survival exceeded 50%. There was an average increase in volume of the seedlings of 43.5% from 1994 to 1995. Seed collected from the Hazelby property (15km east of Northampton) performed markedly better than the other seed collected.

Introduction

Export of Western Australian *Santalum spicatum* began in 1844 (Statham, 1990). Initially, sandalwood was a means of offsetting a trade imbalance against the Western Australian colony; today sandalwood exists in patches of remnant vegetation - still a viable industry. There are adequate supplies in the pastoral region for the foreseeable future [+/- 50 years] (Kealley, 1991) however, regeneration is slow and grazing is heavy (Loneragan, 1990). A time will come when supplies will not be available from pastoral lands.

The Department of Conservation and Land Management recognises that in order to sustain this industry, areas within the agricultural zone of Western Australia have to be replanted with sandalwood. CALM has begun to invest in Indian sandalwood (*Santalum album*) production on the Ord River, but there are still no stands of planted sandalwood that would demonstrate that the timber could be grown commercially on land that formerly grew this species e.g. within the agricultural zone of the South West Land Division.

At this point, little work has been done on identifying a superior oil producer within the local species, *Santalum spicatum*. There is the possibility that an equivalent to the oil bearing *Santalum album* could be identified in *S. spicatum*. Preliminary testing of Shark Bay sandalwood indicates that there may well be high oil yielding provenances or individuals (Haffner, 1994).

It would be beneficial to develop techniques for growing sandalwood in the wheat belt. From the Department of Conservation and Land Management's perspective, successful plantations of perennial vegetation would help to stem the problem of rising groundwater in land that was previously heavily cropped. From the point of view of the farmer, sandalwood

may prove to be a more financially viable method of farming than the more traditional wheat and sheep industry.

A *Santalum spicatum* trial was carried out on private property (Appendix 1), situated 11km SSW of Northampton and 38km north of Geraldton, by the Department of CALM in Geraldton. The 0.8 hectare area was in the 450mm rainfall zone and lay on the south side of Woolawar Gully (a winter flowing creek) approximately 100m from the creek line. The soils in the area were stony, red loamy clay with some minor outcropping of quartz and were reasonably well drained. The land had been cleared for many years with a solitary tree remaining on the fence line (*Acacia saligna*). Since being planted with sandalwood, the area has had *A. saligna, A. rostellifera* and A. *acuminata* emerge. It was the aim of this field trial: to determine percentage survival of the *S.spicatum* planted, to approximate the annual growth rate and to comment on provincial differences within the species with regard to survival and rate of growth.

Materials and Methods

The host plant selected was *Acacia acuminata*. In June 1987, the only seedlings available at the time were produced at Hamel nursery. The seedlings were propagated from seed collected in an area south of Perth, and as such, did not adapt particularly well when compared with the local *A. acuminata*. The Hamel nursery seedlings were prone to leaf burn on the south side of the plant, a characteristic not evident in the local species. From observation, the burning may have been caused by the strong sea breeze (strong winds are common to the Geraldton region) that carried significant salt loads.

Lines were scraped with a back blade to provide a weed free environment for the first season. The tree lines were pre-ripped with a single tyned ripper to remove any stone that may have interfered with the growth of the new seedlings. The hosts were planted in June 1987 using a Nufab tree planter for the 100mm pots. These seedlings were fertilised with an 80gm pellet of compressed super copper zinc on the east side of the tree.

In April 1988, an attempt was made to pre-germinate the seed. A few seeds germinated, then there was an invasion of mould. It was concluded that pre-germinated seed was suitable in a sterile environment, but in an open system, the problems would be prohibitive for anyone attempting to farm sandalwood on a large scale. A small number of plants were established in this manner.

Once having abandoned the effort to use pre-germinated seed, it was decided to use fresh seed collected in 1987 from the Hazelby property, near Northampton. The epicarp was removed, if it was deemed necessary, then the seed was buried to a depth of 25mm into soil loosened by a 100mm hand auger. The auger was employed to free earth to a 150mm depth. It was anticipated that the host plant would initially send its roots along the rip lines, so this seemed an appropriate place to plant.

From previous observations it appeared that the newly germinated sandalwood seedling needed to achieve haustorial attachment to its host by early summer (end of December) if it was going to survive. Any assistance given to the germinant to ensure attachment seemed to be beneficial. It appeared that the germinant may have been dependent on the host, for moisture as well as nutrient, over summer. Most seedlings showing severe wilt in January tended to die. No weed control was carried out and the site was well covered with Patterson's Curse, Wild Oats, Rye Grass, Brome Grass, Turnip, Radish and Capeweed.

The planting for 1988 was 1 row of pre-germinated seed (Row 1), and rows 2, 4, 6, 8, 10, 12 and 14. The planting for 1989 was rows 3, 6, 9, 11 and 13 (Table 1 and Appendix 1).

Table 1: Block layout for *Santalum spicatum* trial at Northampton, Western Australia.

Row 1. Sites 1, 2, 3, 4, 5, 10, 11, 13, 14, and 15 were planted with seeds from the corner of the North West Coastal Highway and the Binnu East Road, 1km north of Binnu. The area was characterised by a quartz ridge. All other sites were planted with seeds from Chris Hazelby's property, situated 15km east of Northampton. This location had red loams soil and granite.

Row 2. All sites were planted with seeds from the Hazelby property (refer to Row 1).

Row 3. All sites were planted with seeds collected from the south side of the Kalbarri National Park. The limestone soil had a pH of 9 and supported small trees.

Row 4. All sites were planted with seeds from the Hazelby property (refer to Row 1).

Row 5. Sites were planted with seeds from Roy Routledge's property at Northampton where the trial was carried out. Seeds were collected from a single tree growing in granite soil. Some sites were planted with seed collected from Mingenew.

Row 6. All sites were planted with seed from the Hazelby property (refer to Row 1).

Row 7. All sites were planted with seed collected from an area near Tom Price in the Pilbara region with red stony soils. The seeds were 5 years old when planted.

Row 8. All sites were planted with seed from the Hazelby property (refer to Row 1).

Row 9. All sites were planted with seed collected from Shell Beach, Nanga station, Shark Bay. These natural stands were a stunted phenotype with thick leaves, growing in limey sands.

Row 10. All sites were planted with seed from the Hazelby property (refer to Row 1).

Row 11. All sites were planted with seed collected from a red earth, drainage line area 20km south of Sandstone.

Row 12. All sites were planted with seed from the Hazelby property (refer to Row 1).

Row 13. All sites were planted with seed collected 18km south of the Billabong Roadhouse on the North West Coastal Highway. Seed was taken from scattered trees in red sandy loams over calcrete.

Row 14. All sites were planted with seed from the Hazelby property (refer to Row 1).

Once the seedlings were established, the heights were recorded in October 1988, April 1989, November 1989, April 1990, September 1990, May 1991, January 1994 and January 1995. The bole length and bole diameter (at a height of 150mm from the ground) were recorded in 1994 and again in 1995. The rainfall for the period was obtained directly from the Bureau of Meteorology.

Results

The first measurements recorded from the trial *Santalum spicatum* at Northampton were the details of individual heights (Appendix 2). In 1988 (Table 2), row 3 had the highest (130mm) recorded average height and row 14 (72.31mm) had the lowest. The average seedling height for 1988 was 104.57mm (S.D. 14.51mm). Row 1 was recorded as having the highest (249mm) average height in April, 1989 and row 14 continued its slow growth (144.5mm). The April, 1989 average seedling height was 193.59mm (S.D. 28.69mm). In November of the same year, row 1 continued having the tallest seedlings (Ave. 389.47mm) while row 5 had the shortest average height of 69.12mm. The average seedling height for November, 1989 was 243.63mm (S.D. 104.20mm).

Table 2: Average heights of S.spicatum from 1988 to 1995

Row no.	14.10.88	4.4 89	1.11.89	9.4.90	27.9.90	22.5.91	24.1.94	30.1.95
1	115.45	249	389.47	592.11	757.89	736.11	1457.5	1550
2	105.83	215.71	295	538.89	710.53	847.22	1908.33	2057.22
3	130		131.47	300	246.67	400	1233.33	1331.67
4	103.89	188.18	302.5	640	913.16	960.53	1898.57	2036.67
5			69.12	221.43	267.86	400	1496.25	1640.59
6	102.08	184	309.09	512.37	711.58	1011.76	1952.78	2244.44
7			114.29	200	360	360	971.43	972.22
8	102.63	191	360.53	665.79	936.84	1105.56	1886.36	2111.36
9			109.09	233.33	281.82	375	1070	1028.57
10	98.33	173.53	358.7	569.32	823.68	840	1870.42	2067.39
11			165.28	350	476.67	503.57	1571.43	1740.71
12	110.65	202.78	333.93	671.74	900	1175	2095.83	2206.25
13			212.04	443.48	576	685.71	1685.71	1861.9
14	72.31	144.5	260.34	509.26	669.31	916.67	1805	1991.38
Average	104.574444	193.5875	243.632143	460.551429	616.572143	736.937857	1635.92429	1774.31214
Std. Dev.	14.5054948	28.6884004	104.197273	163.498285	240.817386	275.88946	336.290554	403.156019

In 1990, the *S. spicatum* were measured in April and September. The highest average seedling height in April was recorded in row 12 (671.74mm) and the lowest in row 7 (200mm). The average height of the seedlings continued to increase (Ave. 460.55mm, S.D. 163.50mm). In September, row 8 had the tallest plants (936.84mm) and row 7 had the shortest plants once again (360mm). Once again in 1991, row 12 had an average seedling height of 1175mm while row 7 continued to be slow growing (360mm). In 1991, the average height of all the seedlings was 736.94mm (S.D. 275.89mm). The average height of the plants in 1994 was 1635.92mm (S.D. 336.29mm). Row 12 (2095.83mm) and row 7 (971.43mm) continued the previous year's trends. In the final year of recording, 1995, the average height of all the seedlings was 1774.31mm (S.D. 403.16mm). Row 6 seedlings finished the tallest (Ave. 2244.44mm) and row 7 seedlings increased little in height (972.22mm) causing them to remain the smallest plants on average.

Graphically illustrating the average heights of *Santalum spicatum* from 1988 to 1995 (Appendix 3) revealed that as the seedlings matured,

there was greater diversity in the recorded heights. From this graph it would be difficult to project growth as will be discussed later.

Percentage survival for each row (Figure 1 and Appendix 4) indicated that with the exception of rows 3 and 9, survival exceeded 50%. Row 1 had the greatest percentage of survival (95.24%) and row 3 had the lowest percentage survival (30%).

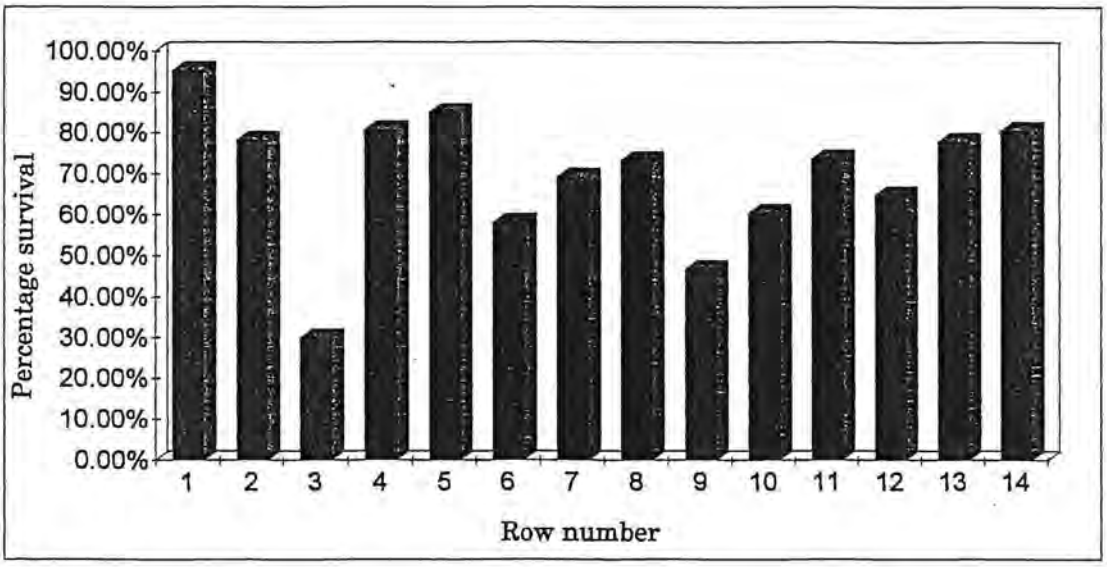

Figure 1: Percentage survival of *Santalum spicatum* in Northampton trial.

In 1994 and 1995, the heights and the bole lengths and bole diameters were recorded. From the bole length and bole diameter measurements, a crude estimate of volume was calculated (Appendix 5). It was noted that Avery (1975) had formulated :

$$V = 0.0785 \times (D \times D) \times L$$

where, V = volume in cubic metres x (10 x 10)
D = mid - diameter in centimetres
L = length in metres.

however, it was decided to use the formula for the volume of a cylinder as an approximate volume of the bole.

The average heights of *Santalum spicatum* in 1994 and 1995 (Figure 2) were mentioned previously (Table 2). Average bole lengths (Figure 3) may be correlated with average height, but with the scope of this trial, were not to be tested. The average bole length in 1994 was 684mm

(S.D. 1369mm and Var. 3591.37mm) and in 1995 it was 705mm (S.D. 1410 and Var. 4802.91). Row 6 had the greatest average bole length in 1994 (861mm) and 1995 (915mm) and row 9 had the shortest average bole length in 1994 (300mm) and 1995 (307mm). The average bole length growth increase (Appendix 5) from 1994 to 1995 was 21mm (S.D. 41 and Var. 87.89).

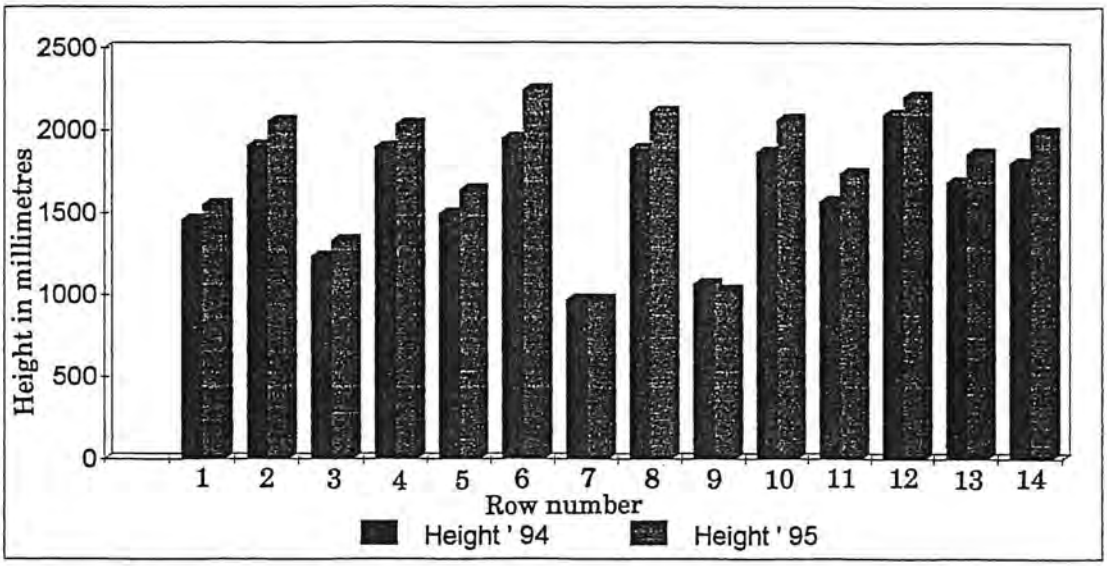

Figure 2: Average heights of *S. spicatum* in 1994 and 1995.

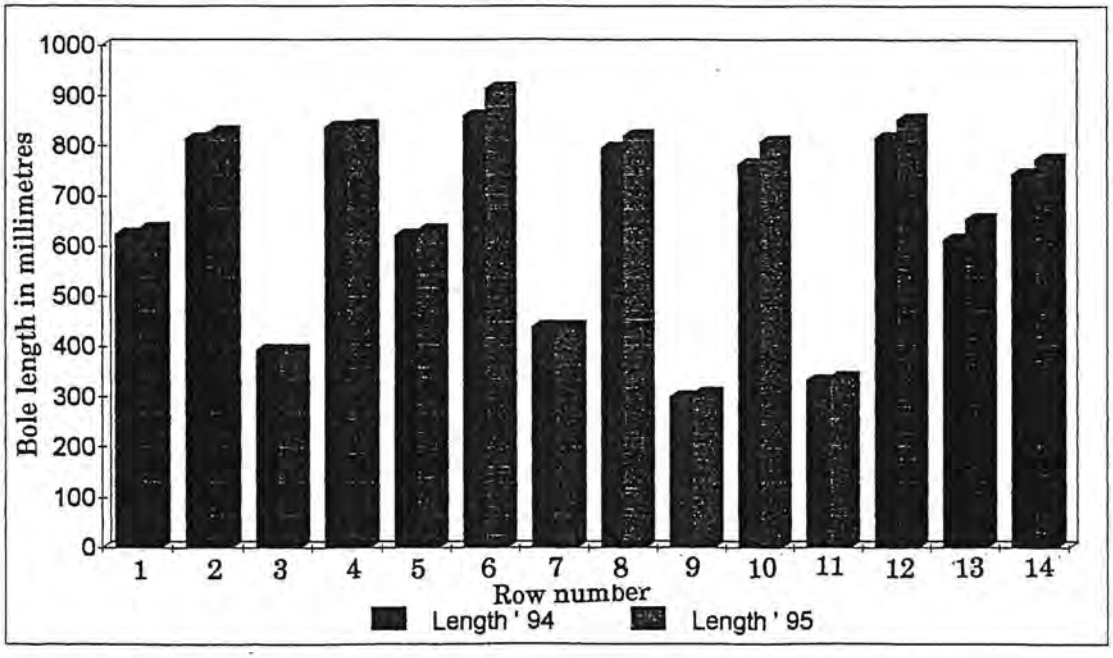

Figure 3: Average bole lengths of *S. spicatum* in 1994 and 1995.

In 1994, the average bole diameter (Appendix 5) was 41mm (S.D. 82mm and Var. 82mm) and in 1995 it was 46mm (S.D. 92mm and Var. 18.19). Row 8 had the largest average bole diameter (Figure 4) in 1994 (50mm) and 1995 (60mm) while row 7 had the smallest average diameter in 1994 (20mm) and 1995 (24mm). The average bole diameter growth increase (Appendix 6) from 1994 to 1995 was 5mm (S.D. 10mm and Var. 2.92).

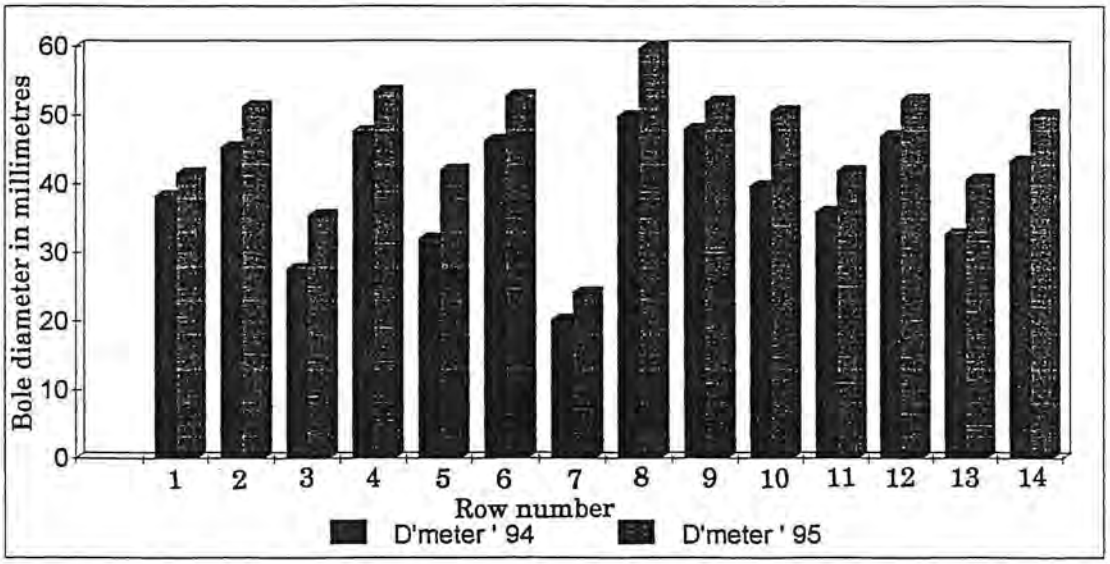

Figure 4: Average bole diameters for *S. spicatum* for 1994 and 1995.

Santalum spicatum seedlings (Figure 5) in row 8 had the greatest average volume in 1994 (1557cm3) and 1995 (2296cm3). The seedlings in row 7 had the lowest average volume in both years (142cm3 and 203cm3 respectively). The greatest average percentage increase in volume (cm3) from 1994 to 1995 (Appendix 7) was in row 5 (75%) and the smallest was in row 9 (20%). This resulted in an overall average percentage increase in volume from 1994 to 1995 of 43.5% (Appendix 5).

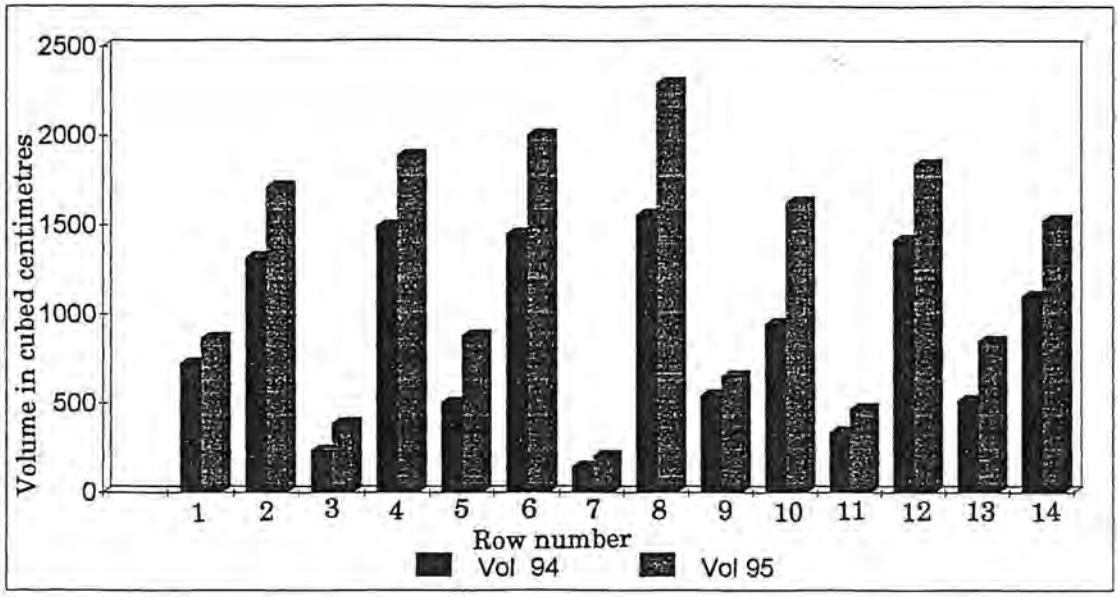

Figure 5: Average volume of *S. spicatum* in 1994 and 1995.
(Volume in cubed centimetres calculated using bole diameter and bole length i.e. 3.14 x squared radius x height.)

Rainfall for the Northampton region between 1987 and 1994 was variable (Appendix 8). In 1991, the highest average yearly rainfall (Figure 6) was recorded (543.2mm, S.D. 45.27mm and Var. 44.83mm). The least amount of average yearly rain fell in 1994 (352.2mm, S.D. 29.35mm and Var. 31.96mm). The months from May through to August tended to have the highest recorded rainfall (Appendix 8). Periods with the least amount of rain were between November and March (Appendix 8).

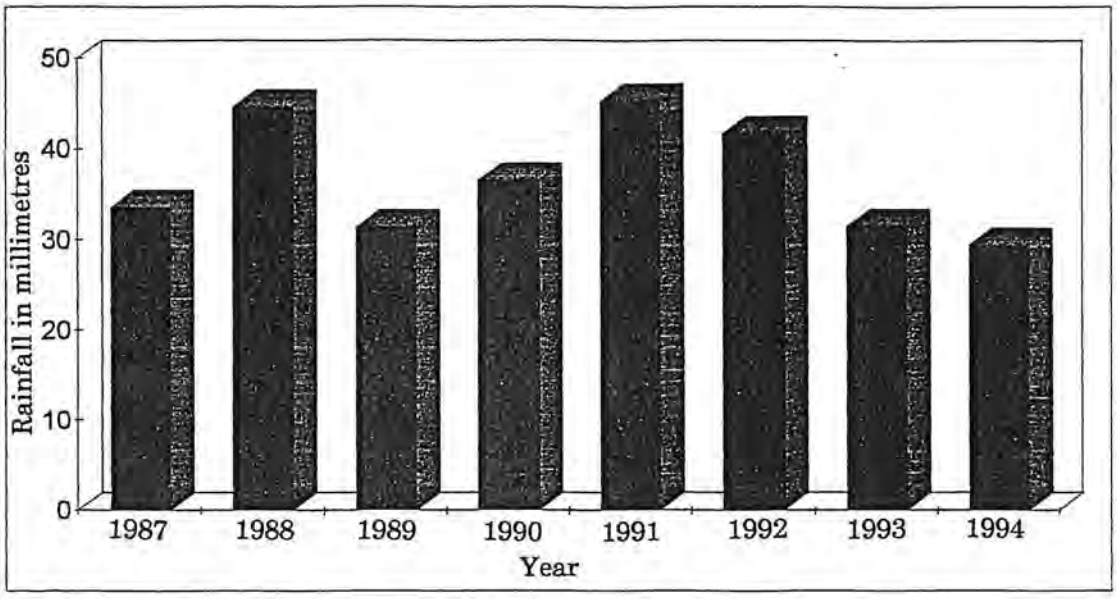

Figure 6 : Average yearly rainfall for Northampton.

Discussion

As was stated in the introduction of this report, the aims of this trial were to determine the percentage survival of the *Santalum spicatum* planted, to approximate the annual growth rate and to comment on provincial differences within the species. All of these factors, due to the obligate root hemi - parasitic nature (Herbert, 1925) of the species, were affected by the physical status of the host. It must be noted that **all** of the hosts in this trial were under stress. The cause of the poor health of the *Acacia acuminata* could only be speculated upon. The reasons may have been related to planting density, differing conditions in the original botanical province or other parasites. Birds were responsible for the introduction of two aerial mistletoes - *Amyema fitzgeraldii* and *Amyema preissii*. These parasites were cut out as they were discovered, to protect the host. The application of fertiliser to the host was considered as it was probable that large numbers of hosts would die in the near future. A small number of sandalwood had died then started to sprout shoots from the base.

Survival

Grazing, cultivation prior to seeding, rainfall, direct seeding, fire, shade, hosts, nutrient requirements and soil types affect the survival of seedlings (Kealley, 1991). Grazing was controlled by fencing off the area from stock, however the mortalities that may have been caused by other

factors, such as rabbits, insects and parasites (unavoidable in an open system) were not regulated. As was mentioned previously, the soil was cultivated to encourage root formation in both the host and the parasite.

From the data collected, it was difficult to determine the effect rainfall had on the sandalwood because there were numerous variables operating besides climatic ones. Some of these variables included date of planting, number of hosts per plant, number of plants per host, the application of fertiliser to the planting sites at various times during the trial, lateral pruning of the sandalwood, replanting of sites where the sandalwood had died, varying degrees of accuracy when recording measurements, time of year when the recording of measurements took place, method of germination, different types of equipment used to take measurements and missing data.

Most of the seedlings were established by the direct seeding method, however there were some pre-germinated. The differences in development cannot be discussed as data was not available on germination rate. With the direct seeding method used, survival exceeded 50% (Appendix 4) in all rows except 3 and 9. Hazelby seed (Table 1) was planted alone in rows 2, 4, 6 , 8, 10, 12 and 14. The percentage survival for these rows was 78.26%, 80.77%, 58.06%, 73.33%, 60.53%, 64.86% and 80.56% respectively. The row planted with Kalbarri seed had a 30% rate of survival, Tom Price seed had 69.23%, Shark Bay had 46.67%, Sandstone had 73.68% and Billabong had 77.78%. The trend was for Hazelby, Tom Price, Sandstone and Billabong seed to have a superior percentage survival in the Northampton trial but no definite conclusions could be drawn regarding the provincial differences. This is for the same reasons that applied to the rainfall data.

No fire was recorded in the area during the trial period or for many years beforehand. The area was completely cleared. Therefore, the only shade that may have been available to the sandalwood would have been provided by the hosts. It was observed that *S. spicatum* planted on the West side of the host grew to a greater height, had a longer bole length, a greater diameter and a better chance of survival.

Acacia acuminata were selected as hosts for the sandalwood because the locally occurring *S. spicatum* parasitised this species. The problems associated with hosts were discussed previously in the beginning of this section. The application of fertilisers and the clearing of the land in this trial site would have had an effect on the nutrient requirements of the seedlings. The exact requirements and the effect that these had on survival were not explored in this trial. Finally, the stony, red loamy clay with minor

outcroppings of quartz was a suitable medium for the seedlings because sandalwood grew naturally in this soil prior to clearing.

Growth Rate

Growth rates are related to factors such as site conditions, climate and soils (Kealley, 1991). It was decided to approximate the rate of growth using volume (calculated from the bole diameter and the bole length using the formula for the volume of a cylinder). Increase in height of the seedling was not a good indicator because the tops of the seedlings tended to die off and then regrow depending on the conditions. The graph in Appendix 3 illustrates the trends in height as the sandalwood matured. The data suggested that the heights may plateau off with age. The increase in the bole length was also unsuitable as a pointer towards growth rate. This was because the lateral branches were regularly pruned to encourage the development of a single, straight bole. Bole diameter was not used for the reason that this measurement tended to plateau off as the seedling matured, but the seedling continued to increase in volume.

From the data obtained it was possible to determine the increase in volume, or the growth rate, over a one year period (from the age of 79 months to 91 months). An average percentage increase in volume of 43.5% for that year was calculated (Appendix 5). Even though this data provided information on the approximate growth of the seedlings between 1994 and 1995, unless the entire pattern of growth for sandalwood is understood it is difficult to extrapolate the results to predict the age where these seedlings would be of the commercially harvestable size.

Provincial Differences

Differences in the *Santalum spicatum* seedlings, from different regions in Western Australia, with regard to survival were discussed in that section. Variations in growth (it must once again be qualified that these may not have been due to differences in province but rather, to other uncontrolled variables) may have involved height, volume, bole length and bole diameter. It was interesting to note that in the final year of observations, when the sandalwood seedlings were 91 months old (Appendix 5), the 7 rows that had the tallest plants, on average, came from seed that was collected from the Hazelby property (2244mm, 2206mm, 2111mm, 2067mm, 2057mm, 2037mm and 1991mm respectively). Seed collected from Billabong, Sandstone, Binnu and Hazelby, Routledge and Mingenew, Kalbarri, Shark Bay and Tom Price were the next tallest on average, in that order (1862mm, 1741mm, 1641mm,

1550mm, 1332mm, 1029mm and 972mm). The average seedling height at 91 months was 1771mm (S.D. 3541mm).

On inspection of the average increase in height from 1994 to 1995, it was discovered that once again, Hazelby seed performed well. The first 4 rows had an average increase in height over the one year period of 292mm, 225mm, 197mm and 186mm. These were all Hazelby seed. The other ten rows had an average increase in height of 176mm, 169mm, 149mm, 144mm, 138mm, 110mm, 98mm, 93mm, 1mm and - 41mm (this negative value was attributed to the upper canopy dying off in poor conditions). These were, in order; Billabong, Sandstone, Hazelby, Routledge and Mingenew, Hazelby, Hazelby, Kalbarri, Binnu and Hazelby, Tom Price and Shark Bay. The average increase in height from 79 months to 91 months was 139mm (S.D. 279mm).

In 1995, the average volume (cm3) of all the sandalwood was 1165cm3 (S.D. 9322cm3) with an average increase from the previous year of 43.5% (Appendix 5). All the sandalwood originating from the Hazelby property had a greater volume than all the other seedlings (2296cm3 [increase of 47.4%], 2003cm3 [increase of 38.3%], 1886cm3 [increase of 26.4%], 1837cm3 [increase of 29.8%], 1713cm3 [increase of 30.3%], 1626cm3 [increase of 71.5%] and 1529cm3 [increase of 38.3%]). The remaining rows had volumes decreasing in this order: Routledge and Mingenew (879cm3 [increase of 75%]), Binnu and Hazelby (865cm3 [increase of 20.2%]), Billabong (850cm3 [increase of 65%]), Shark Bay (651cm3 [increase of 20%]), Sandstone (468cm3 [increase of 38.8%]), Kalbarri (389cm3 [increase of 64.6%]) and Tom Price (203cm3 [increase of 43.4%]).

At 91 months of age the average bole length of the seedlings was 705mm (S.D. 1410mm) with an increase in the length of the bole from last year of 21mm (S.D. 41mm). Hazelby sandalwood had the longest bole lengths on average (Appendix 5). They were: 915mm [increase of 54mm], 854mm [increase of 38mm], 841mm [increase of 4mm], 828mm [increase of 13mm], 821mm [increase of 24mm], 809mm [increase of 45mm] and 774mm [increase of 30mm]. Billabong, Binnu and Hazelby, Routledge and Mingenew, Tom Price, Kalbarri, Sandstone and Shark Bay had the next longest bole lengths in that order (654mm [increase of 40mm], 636mm [increase of 11mm], 633mm [increase of 11mm], 440mm [no increase], 393mm [no increase], 339mm [increase of 6mm] and 307mm [increase of 7mm]).

The final measurement that was taken that might indicate a provincial difference was bole diameter (Appendix 5). At the age of 91 months, the average sandalwood seedling had a bole diameter of 46mm (S.D. 92mm) with an increase from the previous year of 5mm (S.D. 10mm). The 4 largest bole diameters, on average, were Hazelby sandalwood (60mm [increase of 10mm], 53mm [increase of 7mm], 53mm [increase of 6mm] and 52mm [increase of 5mm]. The next largest average bole diameter was from the Shark Bay region (52mm [increase of 4mm]). Hazelby sandalwood had the next largest bole diameters, on average, (51mm [increase of 6mm], 50mm [increase of 7mm] and 50mm [increase of 7mm]). The remaining rows had decreasing bole diameters in this order: Routledge and Mingenew (42mm [increase of 10mm]), Sandstone (42mm [increase of 6mm]), Binnu and Hazelby (42mm [increase of 3mm]), Billabong (41mm [increase of 8mm]), Kalbarri (36mm [increase of 8mm]) and Tom Price (24mm [increase of 4mm]).

Conclusion

Taking into consideration that all the hosts were under stress and the large number of uncontrolled variables in this Northampton trial, statements regarding the outcome of this trial could be made. These points were related to survival, growth rates and provincial variations.

With the exception of two rows, survival in the *Santalum spicatum* seedlings exceeded 50%. The greatest percentage survival for any row was 95.24% and the lowest was 30%. Seed collected from the Hazelby property (15km east of Northampton), Tom Price, Sandstone (an area 20km south of Sandstone) and the Billabong (18km south of the Billabong Roadhouse on the North West Coastal Highway) had a superior percentage survival.

From observation, trees planted on the west side of the host had greater heights, longer boles and larger bole diameters. An increase in volume was used to indicate the growth rates. From 1994 to 1995, there was an average increase in volume of 43.5%.

The variations in the rate of growth between the different provinces was relatively marked. Seed collected from the Hazelby property produced trees that were taller with a greater increase in height over the 12 month period from 1994 to 1995. Hazelby plants had greater volumes, also with larger increases in this parameter from the previous year. Additionally, bole lengths and bole diameters were, on average, longer and larger in the Hazelby sandalwood than in any of the remaining sandalwood types.

Acknowledgments

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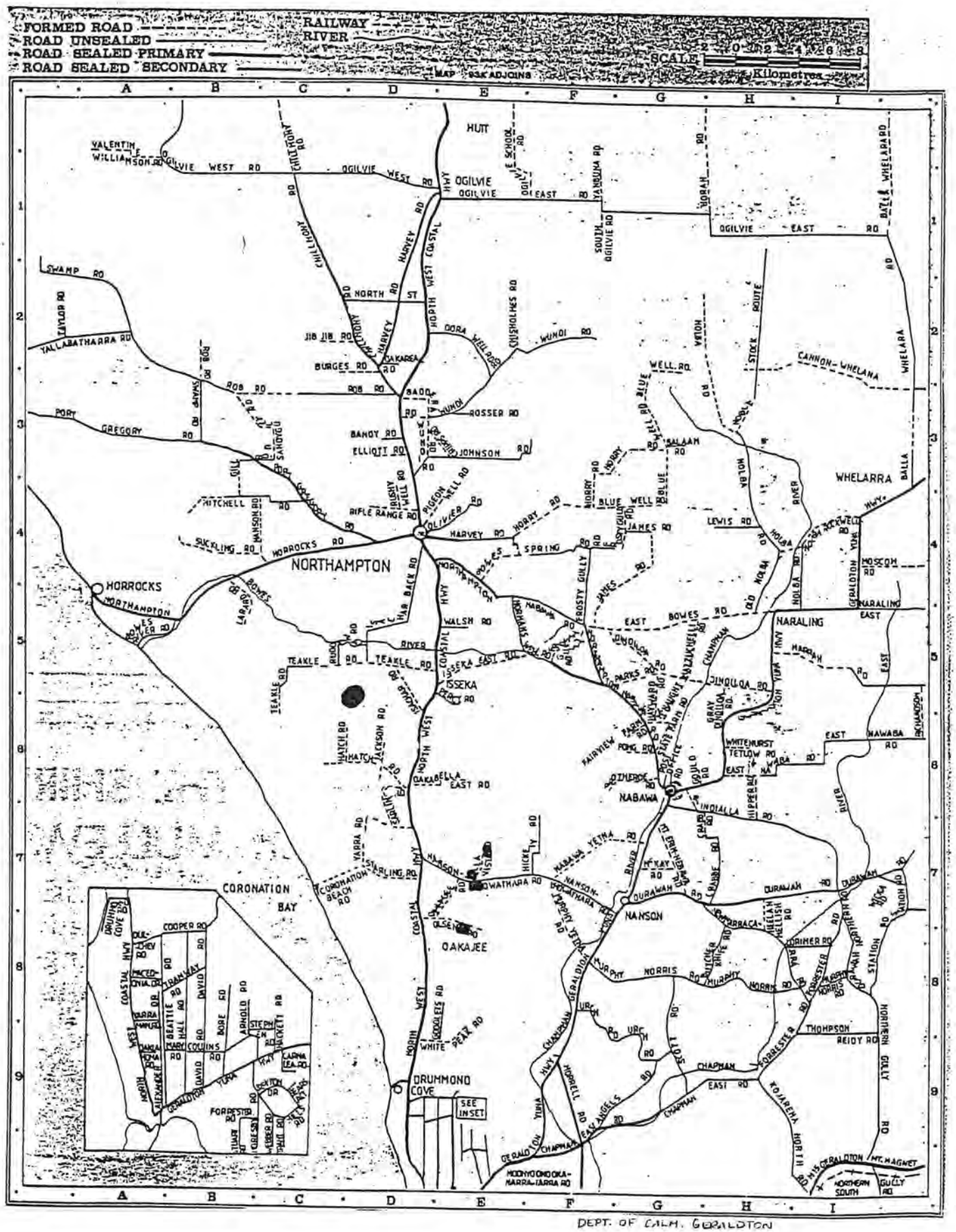
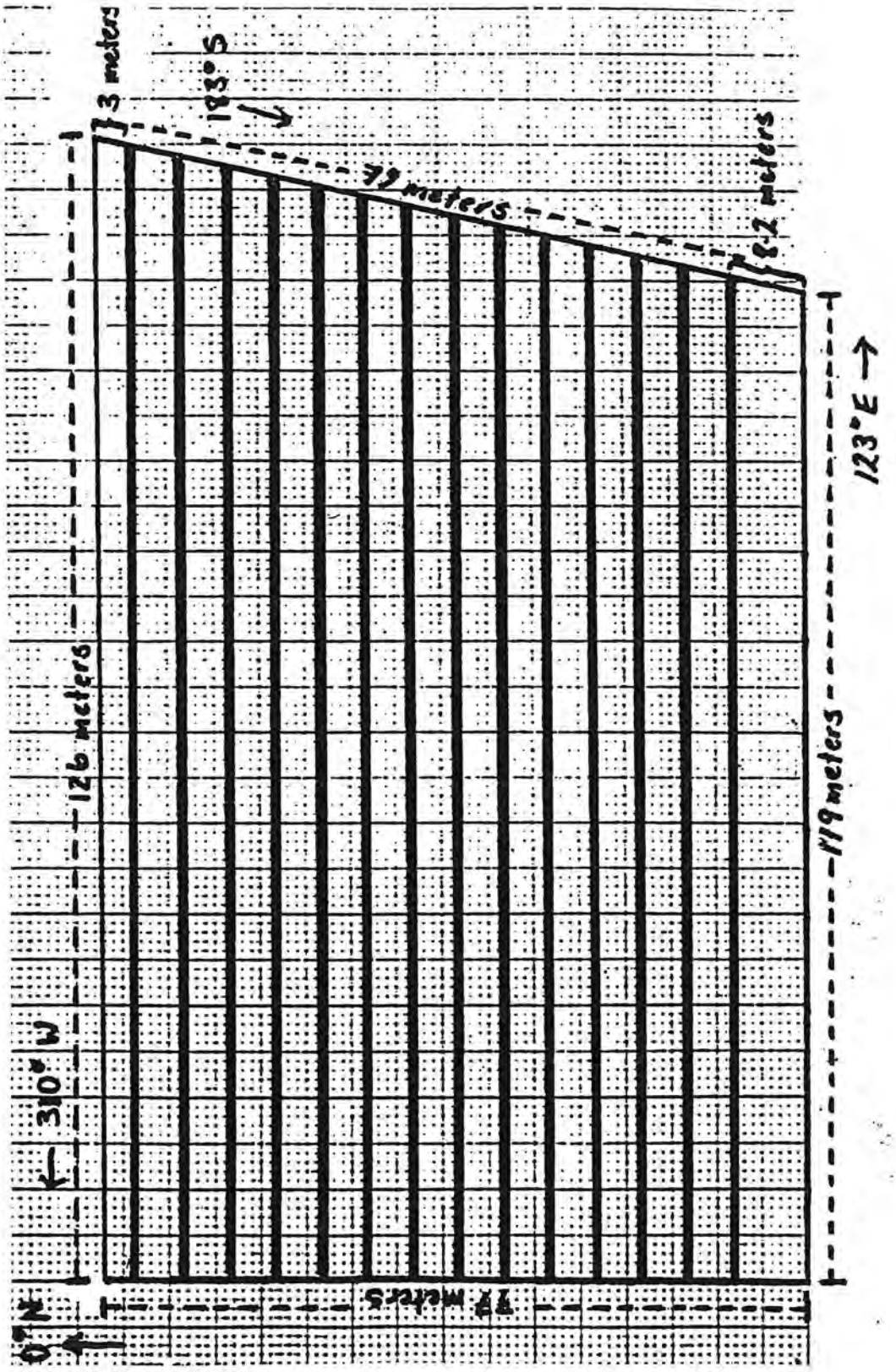
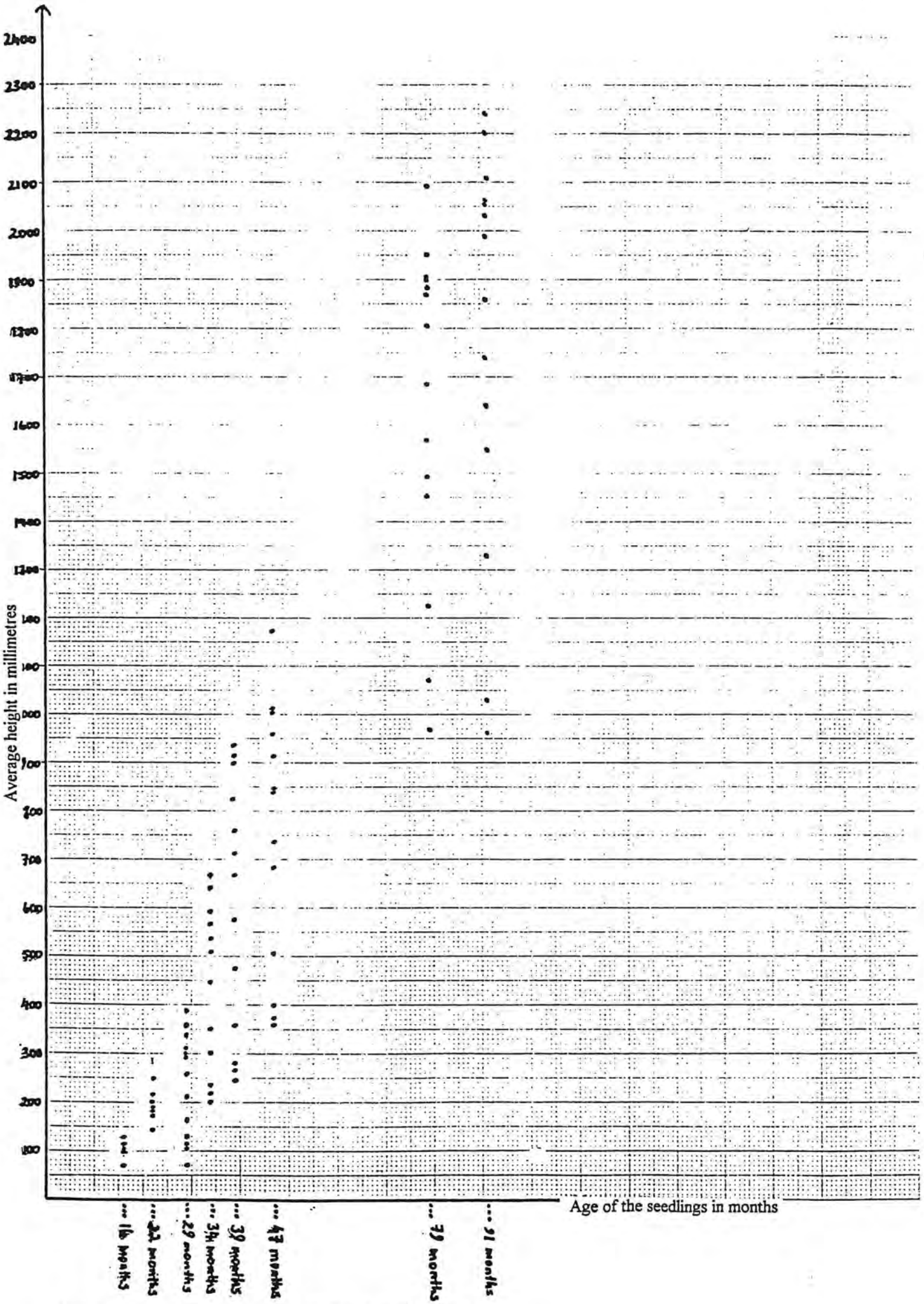
ppendix 1: Location of the *Santalum spicatum* trial.



Appendix 1 continued: Block layout including position and dimensions. The heavy lines indicate the rows that were planted (approximately 4.5 meters apart).



All heights in Appendix 2 are in millimetres



Appendix 3: Average heights of *S.spicatum* from 1988 to 1995

Appendix 4: Percentage survival of S.spicatum for each row

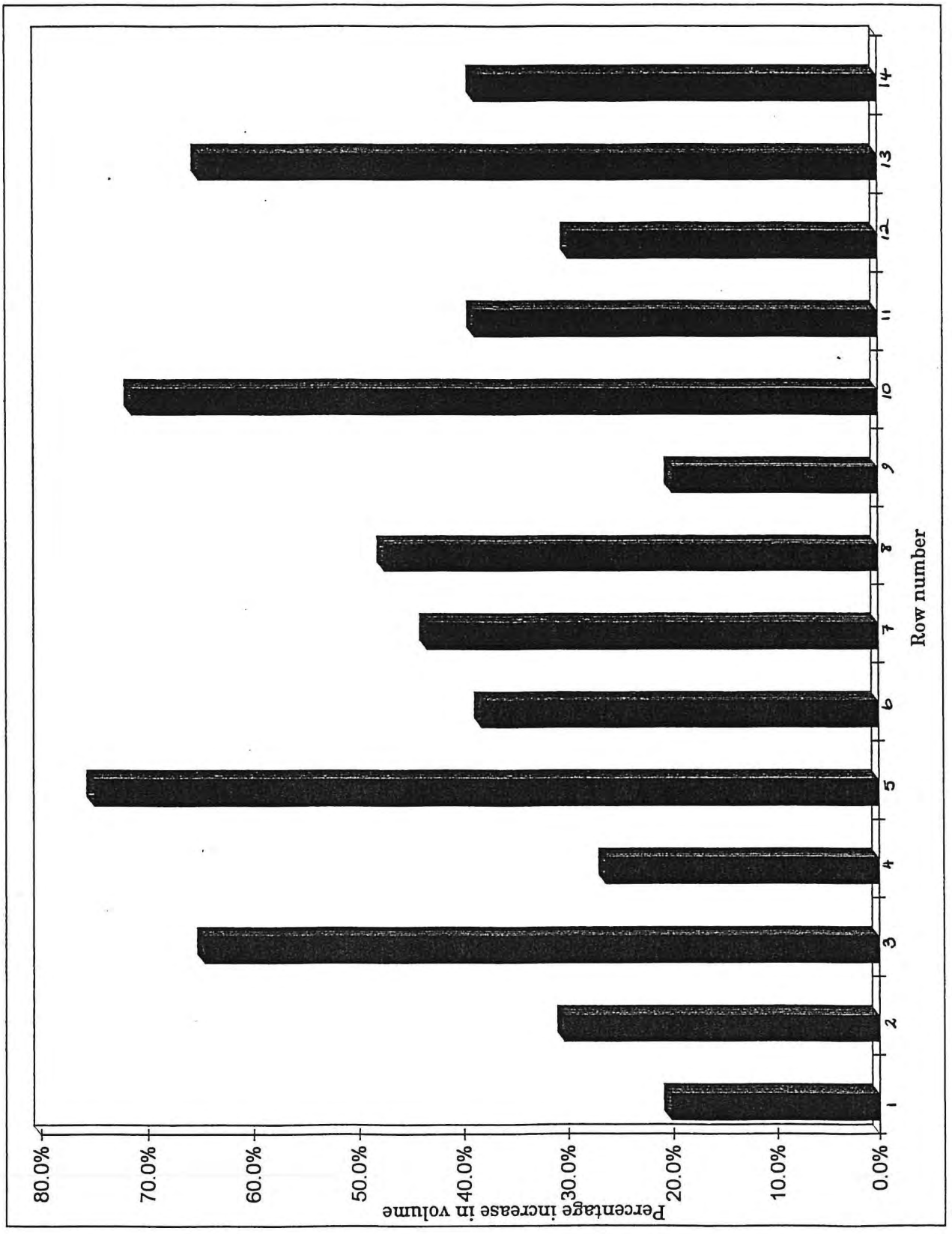
1	20/21	95.24%
2	18/23	78.26%
3	6/20	30%
4	21/26	80.77%
5	17/20	85%
6	18/31	58.06%
7	9/13	69.23%
8	22/30	73.33%
9	7/15	46.67%
10	23/38	60.53%
11	14/19	73.68%
12	24/37	64.86%
13	21/27	77.78%
14	29/36	80.56%

*With the exception of two rows, survival exceeded 50%

Appendix 5: Average height(mm), bole length(mm), bole diameter(mm) and volume(cm3) in 1994 and 1995.

	Height '94	Height '95	Growth	Length '94	Length '95	Growth	D'meter '94	D'meter '95	Growth	Vol 94	Vol 95	Increase	% Increase
Row 1	1458	1550	93	624	636	11	38	42	3	719	865	145	20.2%
Row 2	1908	2057	149	815	828	13	45	51	6	1315	1713	399	30.3%
Row 3	1233	1332	98	393	393	0	28	36	8	236	389	153	64.6%
Row 4	1899	2037	138	838	841	4	48	53	6	1493	1886	393	26.4%
Row 5	1496	1641	144	622	633	11	32	42	10	502	879	377	75.0%
Row 6	1953	2244	292	861	915	54	46	53	7	1449	2003	554	38.3%
Row 7	971	972	1	440	440	0	20	24	4	142	203	61	43.4%
Row 8	1886	2111	225	797	821	24	50	60	10	1557	2296	739	47.4%
Row 9	1070	1029	-41	300	307	7	48	52	4	543	651	108	20.0%
Row 10	1870	2067	197	765	809	45	40	51	11	948	1626	678	71.5%
Row 11	1571	1741	169	333	339	6	36	42	6	337	468	131	38.8%
Row 12	2096	2206	110	816	854	38	47	52	5	1415	1837	422	29.8%
Row 13	1686	1862	176	614	654	40	33	41	8	515	850	335	65.0%
Row 14	1805	1991	186	744	774	30	43	50	7	1102	1529	427	38.8%
Average	1631	1771	139	684	705	21	41	46	5	897	1165		43.5%
Std. Dev.	3263	3541	279	1369	1410	41	82	92	10	7178	9322		
Variance	30189.0625	48703.85541	2203.31666	3591.365184	4802.905809	87.890625	6.528025	18.18596025	2.92239025				

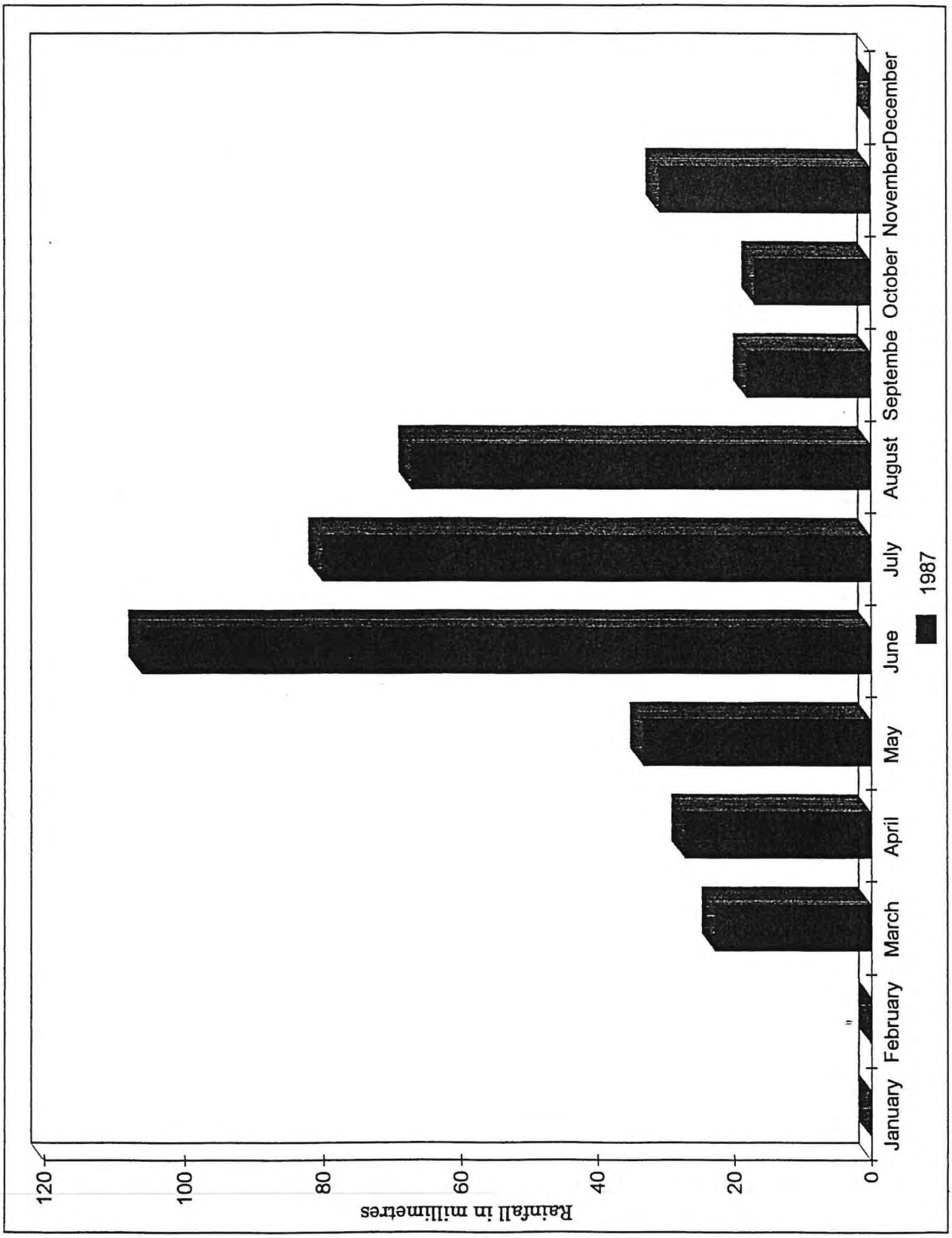
Appendix 7: Average percentage increase in volume(cm3) from 1994 to 1995 in *S.spicatum*.



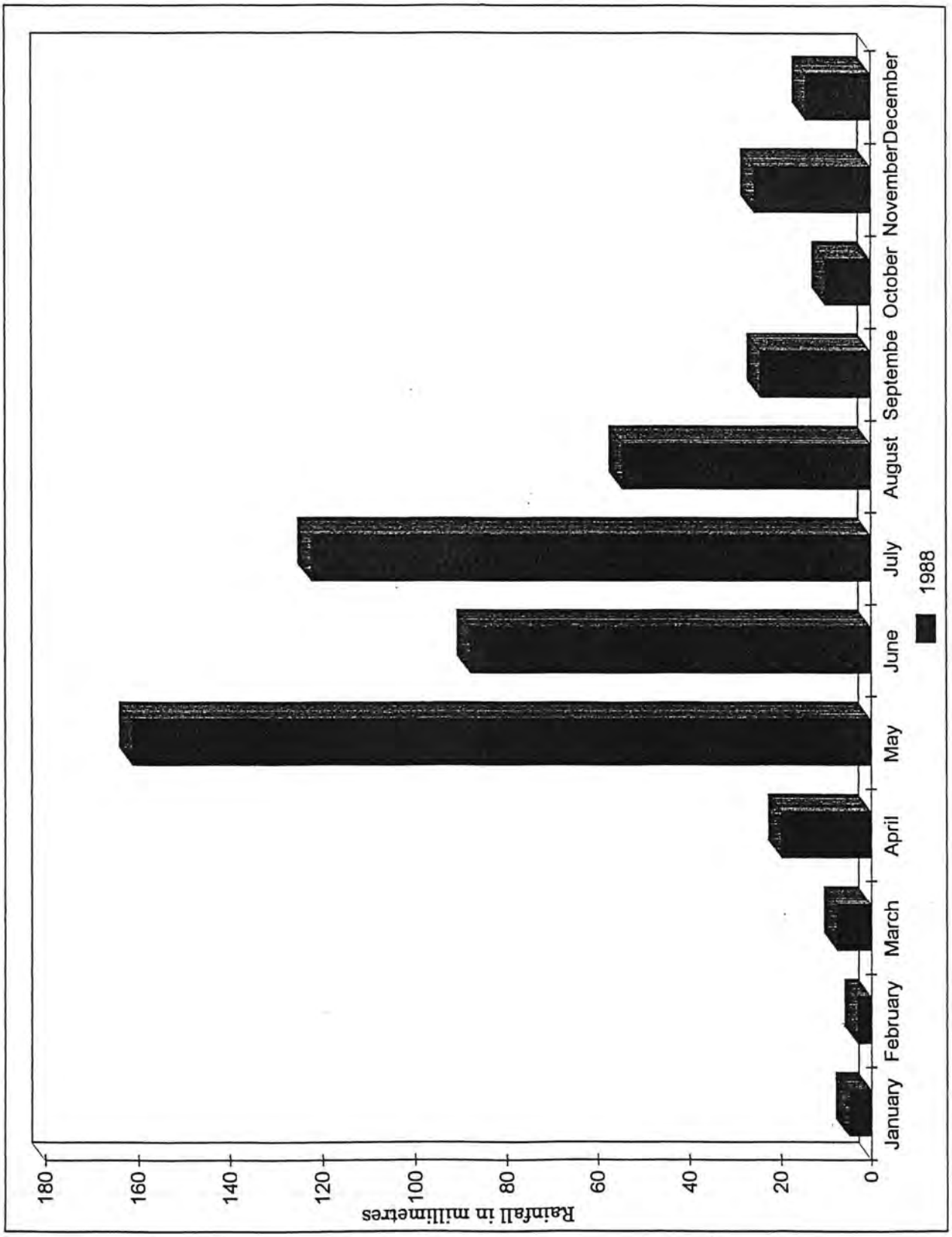
Appendix 8: Rainfall for Northampton 1987 - 1994.

	1987	1988	1989	1990	1991	1992	1993	1994
January	0	5	2.8	50.6	0	15.2	0	0
February	0	3.1	28	1.8	15	0.2	16.4	24
March	22.8	7.6	0	3.2	21.4	30.2	7	3.6
April	27.2	19.8	12.2	48	45.6	19.8	4.2	0
May	33.2	161.2	130.5	71.8	32.8	21	75.2	82.6
June	106.1	87.8	74	82	120	92.5	37.8	73.6
July	80	122.2	57	65.8	158.4	32.8	79.4	64.4
August	67	54.4	33.2	61	41.8	197.2	80.8	70.8
September	18	24.2	16.5	26.4	33	56.9	44.8	21.8
October	16.8	10	21.6	18	23.6	17.6	8.4	11.4
November	30.7	25.5	0	1.6	43.8	15.2	22.2	0
December	0	14.2	0	7.6	7.8	1.6	0.6	0
Total	401.8	535	375.8	437.8	543.2	500.2	376.8	352.2
Average	33.4833333	44.5833333	31.3166667	36.4833333	45.2666667	41.6833333	31.4	29.35
Std. Dev.	32.4078908	49.7965332	37.381119	28.7468791	44.8259102	52.7786705	30.2651615	31.9593622

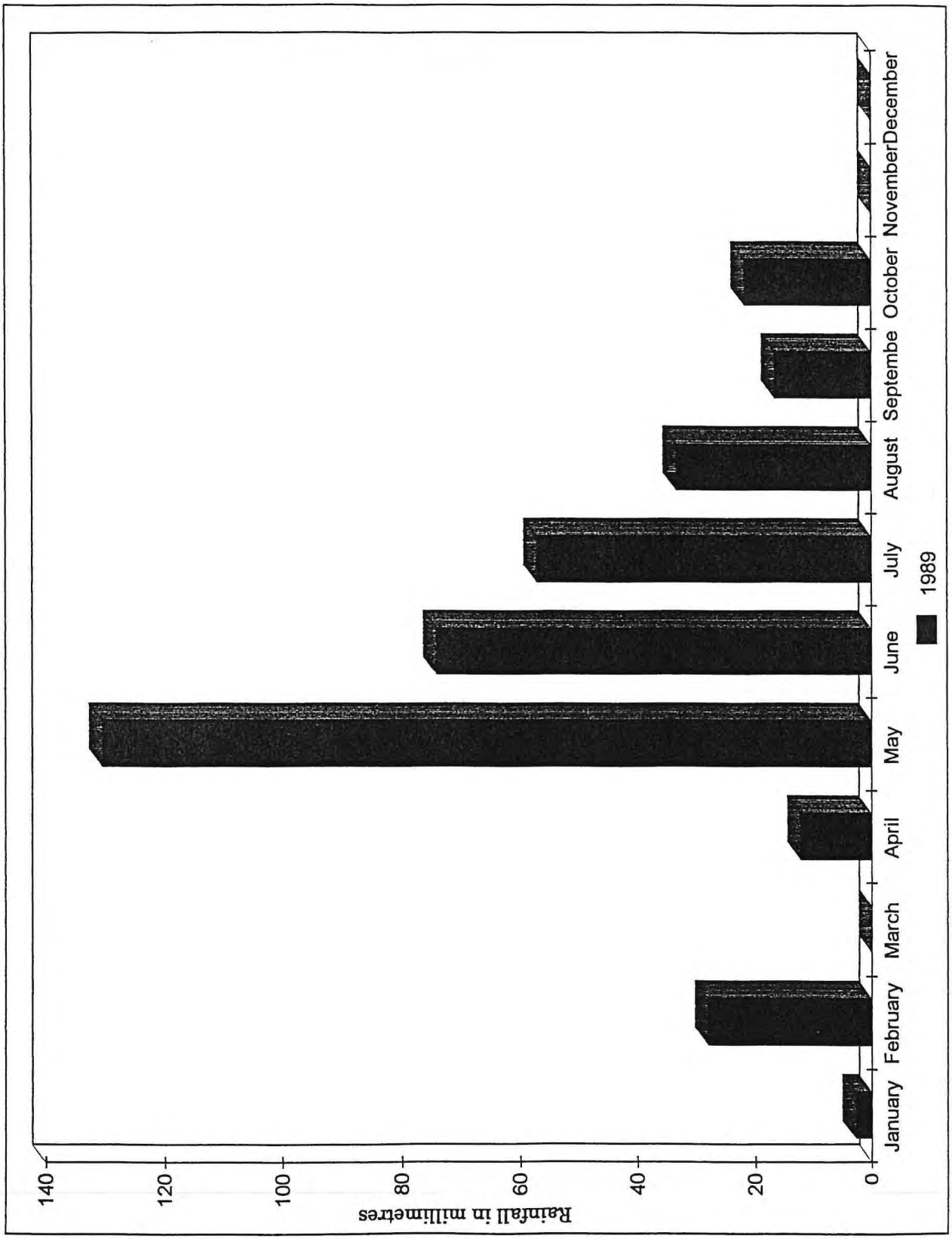
ppendix 8: 1987 rainfall for Northampton.



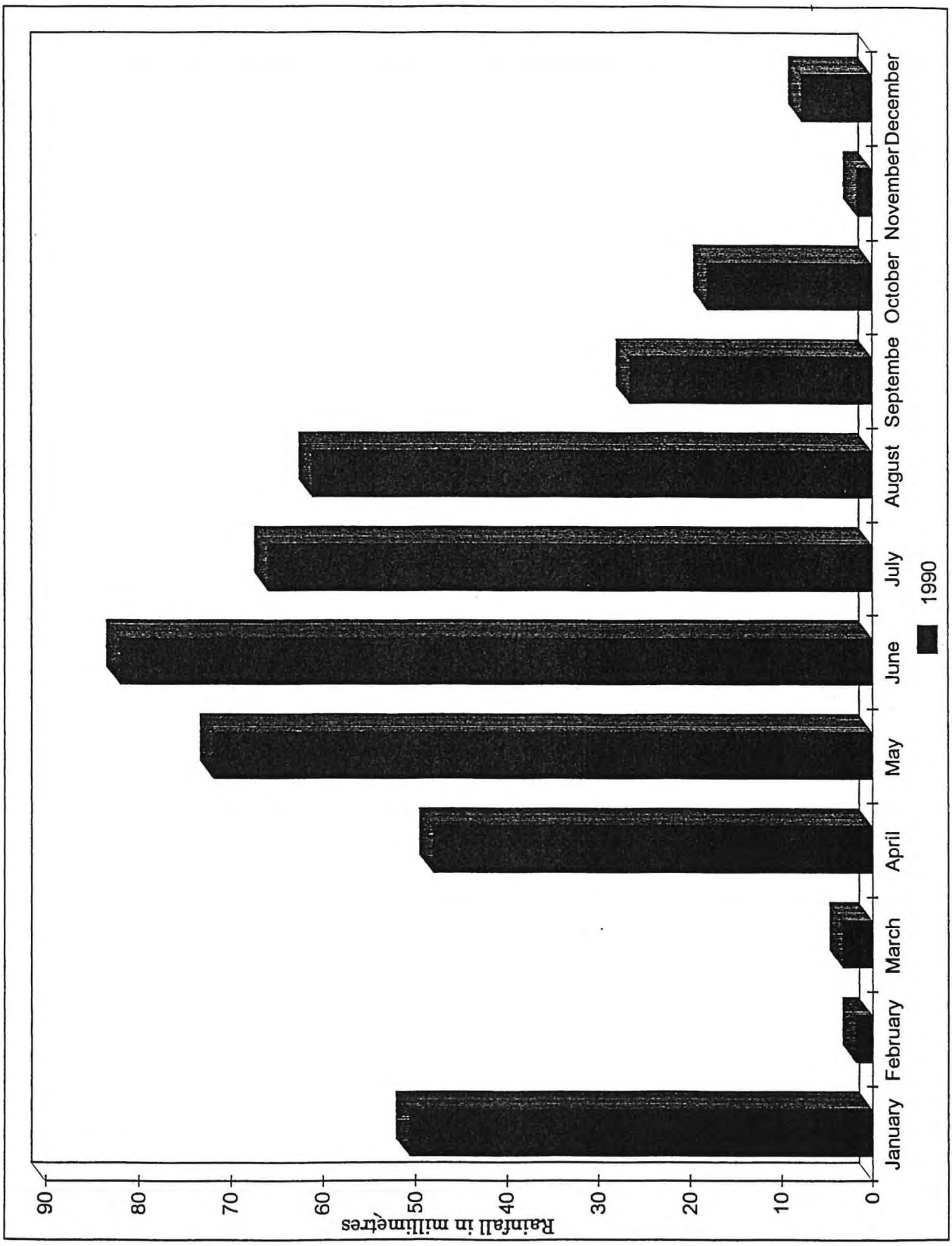
ppendix 8 continued: 1988 rainfall for Northampton.



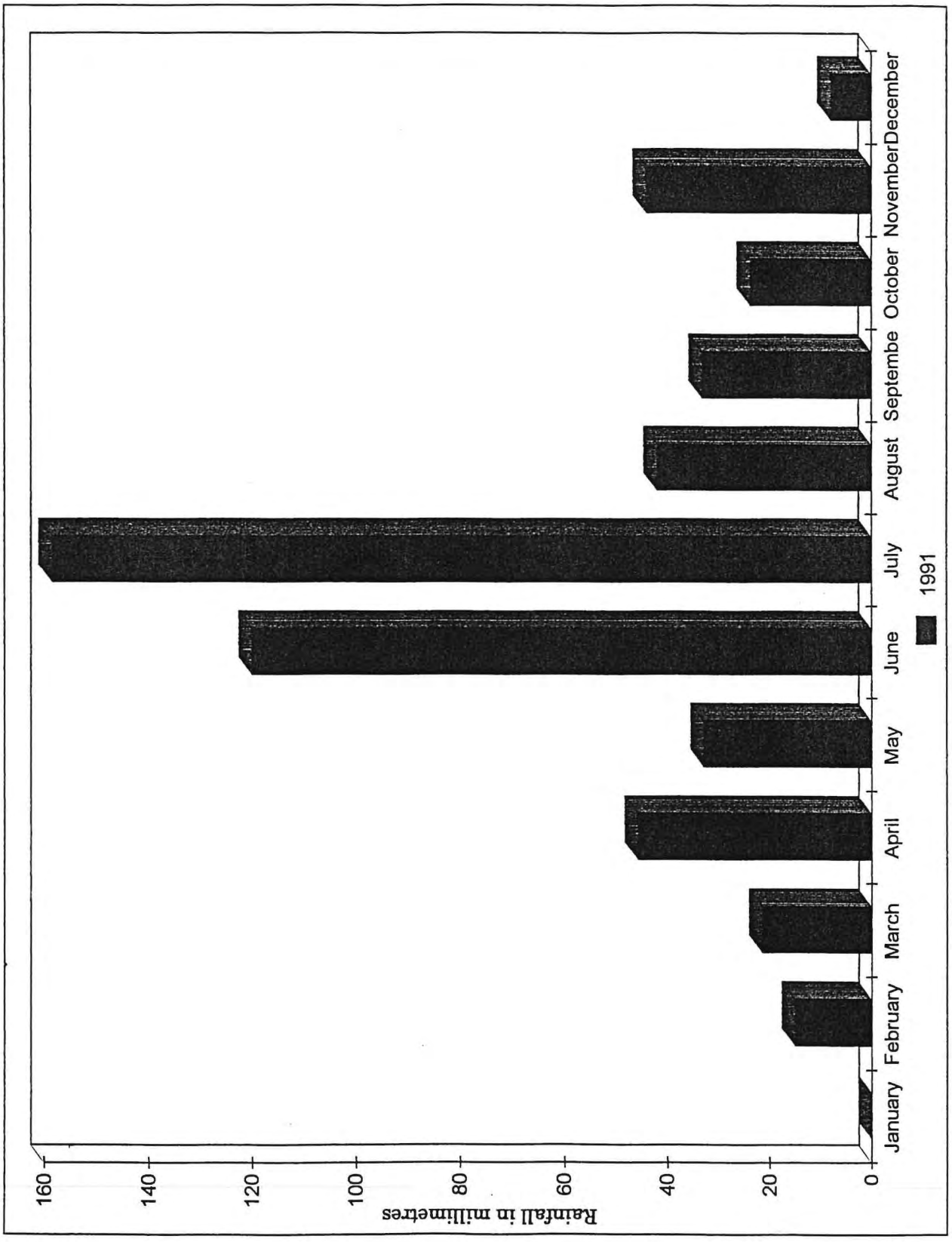
Appendix 8 continued: 1989 rainfall for Northampton.



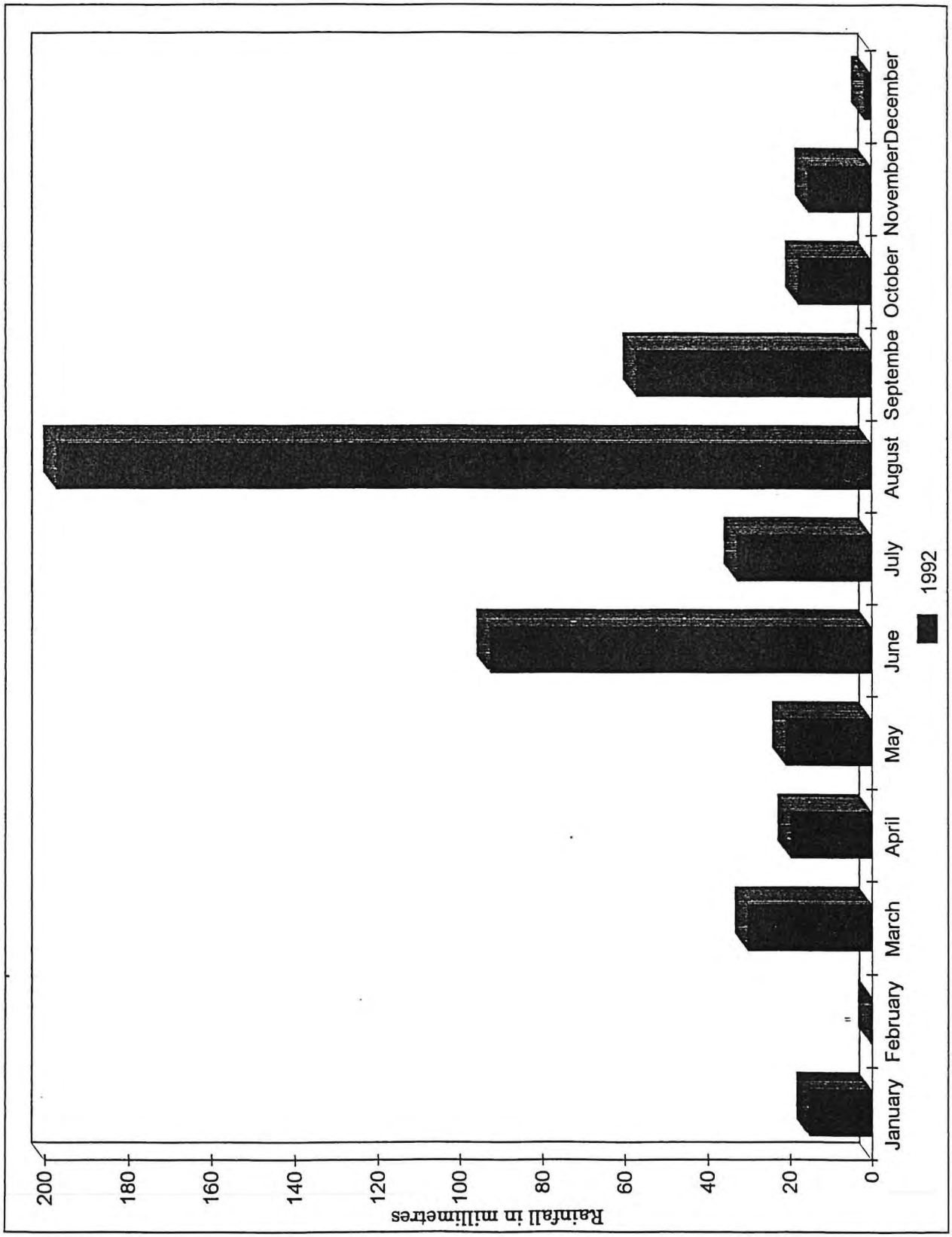
ppendix 8 continued: 1990 rainfall for Northampton.



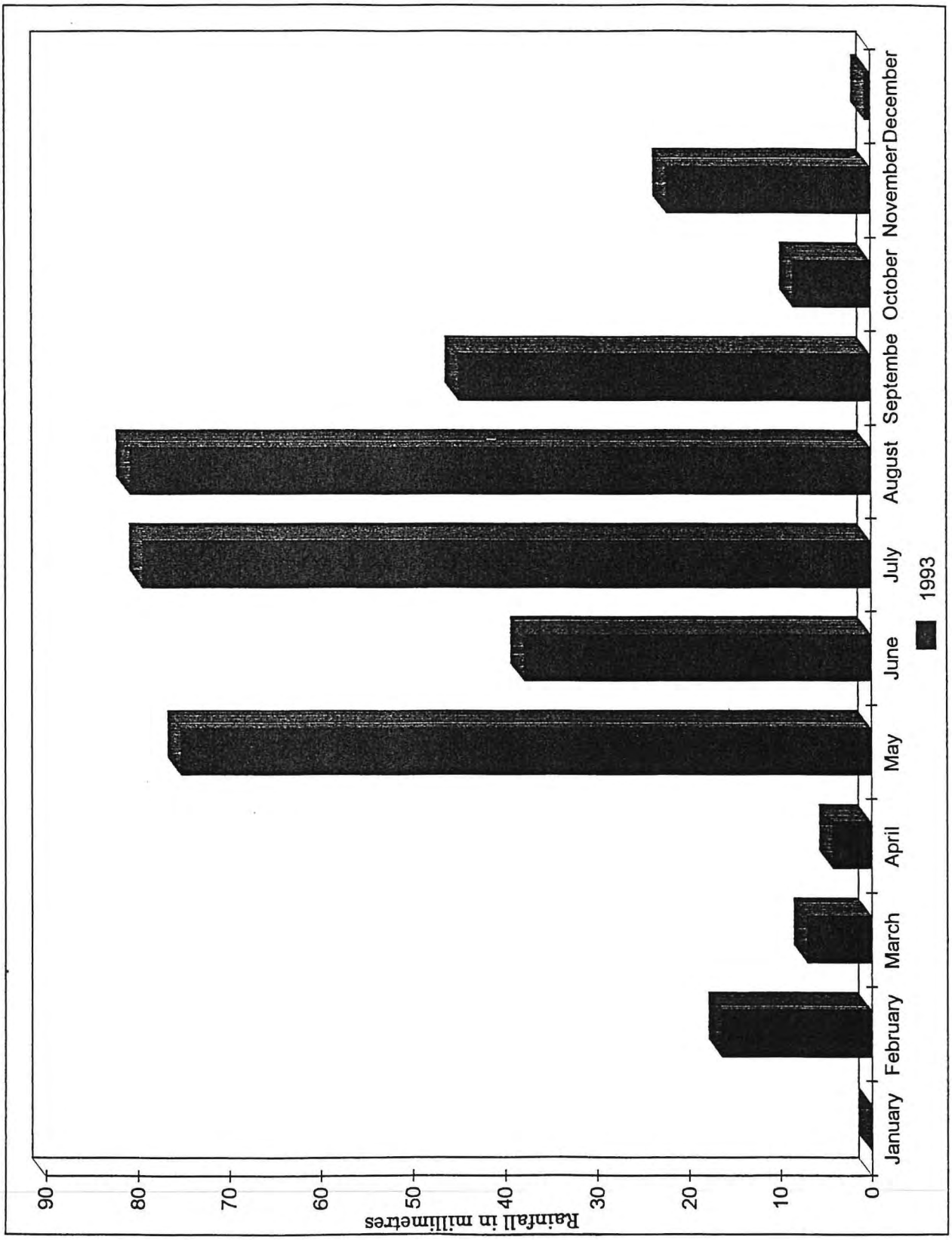
Appendix 8 continued: 1991 rainfall for Northampton.



ppendix 8 continued: 1992 rainfall for Northampton.



ppendix 8 continued: 1993 rainfall for Northampton.



Appendix 8 continued: 1994 rainfall for Northampton.

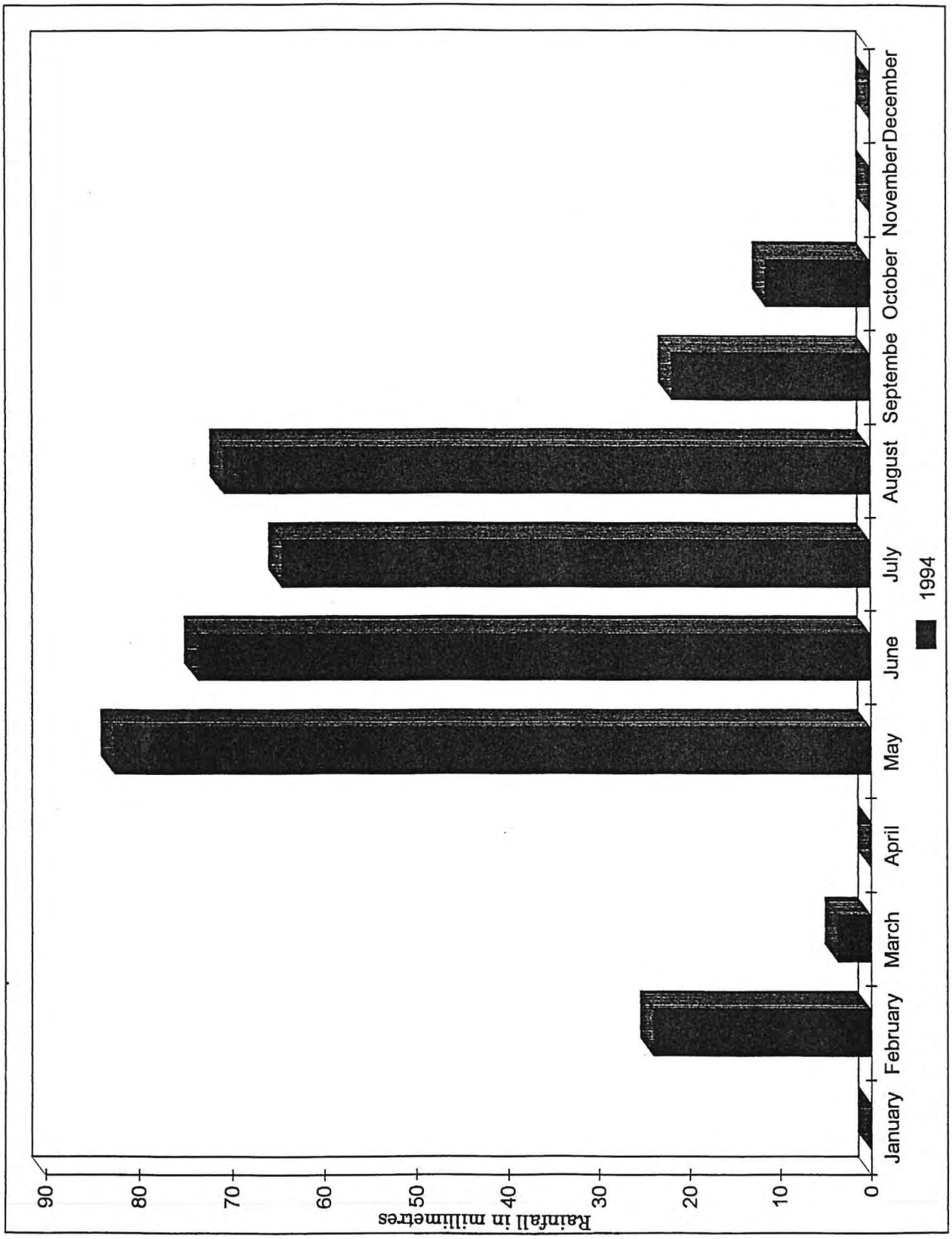


Table : Average height(mm), bole length(mm) and bole diameter(mm) of S.spicatum at the Northampton trial in 1994 and 1995.

	Height ' 94	Height ' 95	Length ' 94	Length ' 95	D'meter ' 94	D'meter ' 95
Row 1	1457.5	1550	624.375	635.625	38.313	41.625
Row 2	1908.33	2057.22	815	828.333	45.333	51.333
Row 3	1233.33	1331.66	393.333	393.333	27.667	35.5
Row 4	1898.571	2036.667	837.5	841	47.65	53.45
Row 5	1496.25	1640.588	622	632.667	32.067	42.067
Row 6	1952.778	2244.444	860.625	915	46.313	52.813
Row 7	971.429	972.222	440	440	20.25	24.25
Row 8	1886.364	2111.364	796.5	820.5	49.9	59.7
Row 9	1070	1028.571	300	306.667	48	52
Row 10	1870.417	2067.391	764.5	809	39.75	50.6
Row 11	1571.429	1740.7142	332.857	339.286	35.929	41.929
Row 12	2095.833	2206.25	816.087	853.913	47	52.348
Row 13	1685.714	1861.905	613.5	653.5	32.7	40.7
Row 14	1805	1991.379	744.231	774.231	43.423	50.154

Appendix 2: Heights of S.spicatum from 1988 to 1995

ROW 1

site no.	14.10.88	4.4.89	1.11.89	9.4.90	27.9.90	22.5.91	24.1.94	30.1.95
1	100	350	750	900	900	800	1000	1000
2	70	80	400	700	850	800	1200	1200
3	100	350	750	1050	1200	1200	1550	1500
4	150	400	800	950	1250	1200	1550	1600
5	110	220	500	750	800	700	1000	1100
6			200	400	600	750	1700	1730
7			200	200	250	200	1150	1430
8							850	1140
9							1400	1450
10	210	280	500	800	900	800	1650	1550
11	100	200	400	700	850	900	1200	1200
12			200	700	950	1000	2300	2700
13	200	270	600	800	1000	800	1300	1400
14	100	240	350	700	1000	800	1400	1450
15	70	100	300	500	600	500	1350	1450
16			250	500	900	800	2100	2250
17			250	400	300	500	2100	2200
18			350	400	700	400	1600	1700
19			200	200	450	400	1300	1450
20	60		300	500	800	700	1450	1500
21			100	100	100			

Appendix 2 continued: Heights of S.spicatum from 1988 to 1995
ROW 2

site no. & pos E/W	14.10.88	4.4.89	1.11.89	9.4.90	27.9.90	22.5.91	24.1.94	30.1.95
1w	80	220	850	1100	1200	1200	1450	1600
1e								
2w								
2e			150	500	700	1200	2100	2100
3w								
3e			150	600	800	900	1800	2200
4w	90							
4e			150	200	500	600	2500	2800
5w								
5e			150	150	250	400	1800	2000
6w								
6e			300	500	700	800	2100	2200
7w								
7e			275	400	600	750	1750	2000
8w								
8e								
9w								
9e			250	400	800	800	1900	2200
10w								
10e			250	700	1100	1100	2500	2800
11w	120	450	800	1300	1750	1900	2450	2500
11e								
12w								
12e			100	200	500	500	1900	1900
13w								
13e	120	100	100		100			
14w								
14e								
15w	90	130	400	750	800	750	1550	1650
15e	120							
16w	100	120	200	400	500	700	1950	2200
16e	120		80	100	200	100	1400	1400
17w								
17e			150	500	600	750	1850	2000
18w			150	200	300	400	1700	1800
18e	110							
19w	140	200	350	600	600	650	1400	1480
19e	60							
20w	120	290	750	1100	1500	1750	2250	2200

Appendix 2 continued: Heights of S.spicatum from 1988 to 1995

ROW 3

site no.	14.10.88	4.4.89	1.11.89	9.4.90	27.9.90	22.5.91	24.1.94	30.1.95
1	150		150					
2	110		150		100			
3					100			
4			150		100			
5			150					
6			150		100			
7			40		100			
8			100		100			
9					100			
10					150			
11			150		100			
12			75					
13			150					
14			100	300	350	400	1100	1250
15			150	200	400	300	1150	1400
16			150	400	500	400	1450	1500
17			150	250	400	300	1200	1340
18			170	350	600	500	1050	1000
19			200	300	500	500	1450	1500
20			50					

Appendix 2 continued: Heights of S.spicatum from 1988 to 1995

ROW 4

site no. & pos E/W	14.10.88	4.4.89	1.11.89	9.4.90	27.9.90	22.5.91	24.1.94	30.1.95
1w	100	170	350	600	700	700	1650	1800
1e	80							
2w	40		200	400	700	700	2150	2350
2e								
3w	120	180	500	900	1100	1200	2500	2500
3e	80							
4w	100	90	200	500	600	700	1800	1800
4e								
5w							1150	1300
5e								
6w	90	100	400	750	1000	1200	2000	2250
6e	110							
7w								
7e	180	240	500	800	1400	1600	2600	3000
8w	110	110	350	900	1300	1300	2200	2400
8e	60							
9w			150	500	800	750	1270	1350
9e	100	240	600	1000	1300	1200	1800	1750
10w								
10e	140	190	500	800	1100	1000	2300	2400
11w			100	300	500	750	2200	2200
11e								
12w			150	400	700	750	1400	1500
12e								
13w			100	550	800	700	1900	2000
13e	60							
14w			150	400	500	600	1400	1450
14e								
15w			50	100			1500	1670
15e								
16w	150	270	600	1100	1100	1100	2300	2600
16e	90	160	400	1000	1100	1200	2300	2600
17w			100	200	450	400	1900	2150
17e								
18w								
18e								
19w								
19e	180	320	400	950	1200	1400	1900	2000
20w	80		250	650	1000	1000	1650	1700

Appendix 2 continued: Heights of S.spicatum from 1988 to 1995

ROW 5

site no.	14.10.88	4.4.89	1.11.89	9.4.90	27.9.90	22.5.91	24.1.94	30.1.95
1			50				1600	2000
2			50	200	400	500	1800	1900
3			75	200	500	500		490
4			50				1400	1800
5			50		100			
6					100	200	1470	1600
7			75					
8			75		100		1300	1600
9					100		1900	2400
10			100	300	600	600	1800	2100
11			75		100	100	1600	1550
12			75		100		1270	1650
13			70					
14							1500	1700
15			50	100	350	500	1600	1800
16			75		100		1170	1350
17			100	250	400	400	2000	2200
18			75	200	400	400	1500	1500
19			80	300	400	400	730	700
20			50				1300	1550

Appendix 2 continued: Heights of S.spicatum from 1988 to 1995

ROW 6

site no. & pos E/W	14.10.88	4.4.89	1.11.89	9.4.90	27.9.90	22.5.91	24.1.94	30.1.95
1w								
1e			200	500	1000	1100	2200	2200
2w								
2e	90	100	300	600	700	900	2250	2400
3w	120							
3e	50		175	200	400	400	2000	2600
4w	140	140	250	550	800	1100	2300	2650
4e			150					
5w	110							
5e			225	600	800	1100	2100	2700
6w								
6e								
7w	90							
7e			200	200	200			
8w	110						710	800
8e	70		50					
9w	150	150	350	900	1000	1300	2500	2800
9e			150	350	200	500	2300	2500
10w	90							
10e	120	110	150	300	300			2300
11w	110	100	500	750	900	1500	2000	2500
11e			200					
12w								
12e	20		200	450	800	800	2300	2500
13w	120	260	750	135	1500	2000	2400	2800
13e								
14w								
14e	160	620	1200	1500	1800	2100	2600	2650
15w								
15e			200	200	500	600	1750	2000
16w	70	140	400	850	120	1300	2350	2500
16e	150							
17w	60	140	500	750	1000	1100	1950	2000
17e	120							
18w	60							
18e	170		150	100	200	200	850	
19w	50	80	350	600	800	800	1400	1300
19e	60							
20w								
20e	160		150	200	500	400	1190	1200

Appendix 2 continued: Heights of S.spicatum from 1988 to 1995

ROW 7

site no.	14.10.88	4.4.89	1.11.89	9.4.90	27.9.90	22.5.91	24.1.94	30.1.95
1			100	100	200		1000	1200
2			100	300	400	400	950	1200
3			75	100		200	800	
4			200	400	500	500	1400	1500
5								
6								
7								
8								
9			125					
10								500
11			50					
12								500
13				100	300	400	1250	1500
14							300	650
15			150					
16								
17				200	400	300	1100	1350
18								
19								350

Appendix 2 continued: Heights of S.spicatum from 1988 to 1995

ROW 8

site no. & pos E/W	14.10.88	4.4.89	1.11.89	9.4.90	27.9.90	22.5.91	24.1.94	30.1.95
1w			150	250	400	600	2150	2050
1e								
2w			225	400	700	600	1850	1900
2e	90							
3w								
3e	100			500	800	1100	2150	2300
4w	130	150	550	1000	1300	1200	2200	2350
4e	40							
5w	80	180	400	850	1200	1300	2450	2600
5e								
6w	60	70	350	600	900	1100	2500	2600
6e							200	350
7w			225	500	600	800	1600	2000
7e								
8w			200	500	700	700	1400	1750
8e	60							
9w			200				1350	1750
9e								
10w	100	260	800	1300	1500	1900	2700	3400
10e	180	200	800	1200	1600	2000	2700	2900
11w	60		200	200	500	500	2200	2400
11e							500	800
12w	130							
12e	190	230	350	800	1400	1400	2600	2950
13w	70	110	250	750	900	1400	1800	2200
13e	60							
14w	100	270	800	1100	1500	1400	1900	1950
14e	60							
15w	110	110	300	400	700	700	1600	1850
15e								
16w							1500	1850
16e								
17w								
17e	180	330	600	1100	1400	1300	2150	2100
18w			175	600	800	1200	2000	2100
18e	150							
19w			125	100	200			
19e								
20w			150	500	700	700	2000	2300

Appendix 2 continued: Heights of S.spicatum from 1988 to 1995
ROW 9

site no.	14.10.88	4.4.89	1.11.89	9.4.90	27.9.90	22.5.91	24.1.94	30.1.95
1			75					
2			125	200	400	500	1250	1200
3			200	550	700	700	1700	1750
4								
5								
6			50		100			
7								350
8			25		200			
9			150	250	400			
10			150	200	200			
11			100	100	200			550
12							300	600
13								
14								
15					200	100	400	650
16			125		200			
17								
18			100	100	300	200	1700	2100
19					200			
20			100					

Appendix 2 continued: Heights of S.spicatum from 1988 to 1995

ROW 10

site no. & pos E/W	14.10.88	4.4.89	1.11.89	9.4.90	27.9.90	22.5.91	24.1.94	30.1.95
1w	70	170	400	750	800	1000	1700	1650
1e								
2w	90			550				1850
2e	130		100		500	500	1700	
3w	70	260	800	1100	1300	1600	2700	2850
3e				100				
4w	90	300	800	250	1400	1500	2000	1950
4e					800			
5w				250	400			2500
5e	50		200					
6w	50	90	200		1000	1000	2600	2300
6e	80							
7w				300		500	2100	2500
7e	50		250	300				
8w					1200			1850
8e	140		200	150	800	1300	2400	1500
9w	80	190	600	500	1200		1900	2300
9e	100	130	300			200	1200	2100
10w	100	240	600	1000	1300	1100	2050	2450
10e	150					700	1800	
11w	120	230	600	900	600	1200	2300	2800
11e	70							
12w	130	150	300	900	200	1900	2700	2800
12e				600				
13w					450	700	2250	1600
13e	100		125	200			1250	
14w	130	140	350				1550	1850
14e	170	200	300	600		200		
15w				300	400	400	1500	1700
15e	90		100			200	1500	1850
16w	100	110	200		400		1600	1550
16e	20			600				
17w	120	120	175	1200	1200	400	1500	1500
17e	140							
18w	100	180	700	1100	700	500	2300	2400
18e	120	170	100				740	
19w	120	140	350		1000	1100	2200	2450
19e	90			125				
20w	80	130	500	750		800	1350	1250

Appendix 2 continued: Heights of S.spicatum from 1988 to 1995

ROW 11

site no.	14.10.88	4.4.89	1.11.89	9.4.90	27.9.90	22.5.91	24.1.94	30.1.95
1			200					
2			175	300	500	400	1600	1700
3			175	500	600	600	1500	1550
4			125	400	500	500	1650	1900
5			125	600	700	750	1900	1850
6			250	550	700	700	1700	1700
7			250	300	500	500	1300	1500
8			175	500	600	800	1700	1700
9			200	200	400	400	1150	1250
10					150	200	1900	2500
11								
12			200	500	600	600	2000	2200
13			150					
14			150	400	500	600	1700	1850
15			200					
16			200	200	300			
17			75	150	400	300	1250	1420
18			100					
19			100	150	300	300	1300	1500
20			125	150	400	400	1350	1750

Appendix 2 continued: Heights of S.spicatum from 1988 to 1995

ROW 12

site no. & pos E/W	14.10.88	4.4.89	1.11.89	9.4.90	27.9.90	22.5.91	24.1.94	30.1.95
1w	50		150					
1e	160							
2w			300	500	900	1000	2000	2250
2e								
3w			100	150	200	200	1300	1350
3e								
4w	70		200	400	800	1000	1850	2300
4e	120							
5w	110	160	350	800	1100	1900	2650	2700
5e								
6w	70	70	150	600	800	1200	2550	2450
6e								
7w	140	560	800	1100	1300	1900	2100	2000
7e								
8w	60	70	100	200	500	400	1900	2300
8e								
9w	70	140	400	800	1000	1000	2550	2550
9e								
10w								
10e	130	200	400	1000	1300	1800	2550	2650
11w	70	150	250	750	1000	1500	1800	1900
11e	150	150	150		300			
12w	140	560	800	1200	1400	1900	1950	1800
12e	150							
13w								
13e								
14w	100	100	100	150	300	300	1400	300
14e								
15w	100	200	700	1100	1400	1900	2200	2400
15e								
16w			200	650	800	1000	2100	2100
16e	180							
17w	100	140	350	550	700	1100	2800	3150
17e	180							
18w	110	150	500	1100	1300	1800	2100	2250
18e	160	310	700	1200	1300	1800	2300	2550
19w	120		150			800	2000	2400
19e	80							
20w	130	360	1000	1450	1600	2000	2550	2700
20e	50							
21w			200	250	500	800	1500	1600
21e								
22w	70	70	150	350	600	500	1600	1850
22e								
23w			150	150		400	2250	2450
23e								
24w	110	110	300	500	800	800	2100	2400
24e	70							
25w			100					
25e	130							
26w	140	150	300	500	800	1200	2200	2550
26e								
27w	110		300					

Appendix 2 continued: Heights of S.spicatum from 1988 to 1995

ROW 13

site no.	14.10.88	4.4.89	1.11.89	9.4.90	27.9.90	22.5.91	24.1.94	30.1.95
1			225	250	400	300	1250	1350
2			300	700	700	700	1850	2000
3			250	650	700	800	1750	2000
4			250	700	900	1000	1900	2000
5			250	550	800	900	1900	1850
6			200	300	400	500	1600	1900
7			250	450	500	800	1500	1600
8			200	600	600	800	1600	1800
9			150	500	700	900	1600	1500
10			200	500	700	1000	2300	2500
11			225	550	700	800	1850	2000
12			200	650	800	800	1650	1900
13			200	250	500	500	1400	1750
14			225	500	600	600	1900	2150
15			250	300	500	500	1900	2200
16			250	650	900	800	1800	2000
17			200					
18			200	550	900	800	1800	1900
19			150	250	500			
20			200	400	600	600	1400	1700
21			200	250	500			
22			175	250	500	500	1650	1650
23			175	150	300	400	1600	1800
24			150		100			1550
25			200	250	500	400	1200	
26			200					
27			250		100			

Appendix 2 continued: Heights of S.spicatum from 1988 to 1995

ROW 14

site no. & pos E/W	14.10.88	4.4.89	1.11.89	9.4.90	27.9.90	22.5.91	24.1.94	30.1.95
1w			150	500	800	800	1900	1900
1e								
2w	50	60	75	100	300	200	450	
2e	60	100	250	400	600	800	1600	1450
3w	40	350	800	1300	1400	1900	2000	1950
3e	50							
4w								
4e			200	250	500	1100	1800	2000
5w								
5e			150	750	1000	1100	2300	2500
6w	90	290	600	800	1100	1300	2000	2050
6e	40	90	200	500	900	1200	1600	1550
7w	140	180	350	300	400	500	1300	1450
7e	80	110	350	500	600	900	1800	2300
8w	110	120	150	450	700	1000	2100	2300
8e								
9w	70	180	350	650	600	700	1850	2150
9e								
10w								
10e	60	150	400	750	1200	1900	2700	2950
11w								
11e	40		125	400	600	800	1800	1850
12w	70	70	100	250	400	700	2100	2300
12e								
13w	60	120	250	300	500	600	1600	1600
13e								
14w	60	160	500	750	1000	1000	1900	1950
14e	60	230	400	700	800	1000	1500	1450
15w	160	180	300	500	600	600	2400	2600
15e								
16w	60	100	300	700	1000	1300	2600	2600
16e								
17w	70							
17e	100	110	300	450	500	600	1800	2150
18w	70	90	125		100			
18e								
19w								
19e	40		150	450	700	750	2350	2700
20w	60							
20e			125	250	400	400	2000	2300
21w	80	100	200	250	500	600	1600	1800
21e	90	100	150	200	500	600	2000	2200
22w							1000	1100
22e								
23w								
23e			100	550	900	1100	2400	2600
24w								
24e			250	750	800	1100	2100	2150
25w							500	550
25e			150					
26w					10		1100	1300
26e	70							