PRELIMINARY INVESTIGATION INTO THE REFLECTANCE OF *Banksia grandis*

DEFINITIONS:-

REFLECTANCE FACTOR:-

This factor is calculated as the ratio between the amount of energy reflected by the specimen and the reflectance standard expressed as a percentage.

REFLECTANCE STANDARD:-

This is a perfectly reflecting surface exhibiting Lambertion characteristics such that the incident radiation is reflected equally in all directions. The standard used in this instance is a sheet of metal coated with Eastman White Reflectance coating with a 100 % reflectivity over the 400-700 nm waveband.

Banksia grandis:-

This species was chosen as the experimental specimen because it is an indicator species for Jarrah Dieback. Since it is used for detecting centres of dieback from aerial photography it is important to know and understand its spectral signature as observed by various remote sensing imaging systems.

OBJECTIVES:-

Determining the spectral signature of any object such that it is recognizable from other objects adjacent is a prime objective in a remote sensing situation, but one which is thwart with complications due to the many interacting factors which contribute to producing the spectral signature.

Initially this investigation will determine the factors of most importance in the interaction of radiation with the canopy of a *B. grandis* tree, thus enabling the determination of the spectral signature of this species.

Once the spectral signature is recognizable various conditions can be imposed upon the plant and the effect on reflectance then noted. Thus analysing the reflectance pattern of the species concerned should enable the determination of the conditions producing the observed effect.

INTRODUCTION:-

This investigation comes about as a consequence of the requirement to be able to detect Jarrah Dieback when only incipient symptoms are being expressed by the affected vegetation.

The presence, expression and status of dieback disease in the Jarrah Forest of Western Australia has been reported in detail by many workers and shall not be expounded upon here.

At present the detection of dieback disease is achieved either by discovering a patch of diseased forest on the ground or by detecting the deaths of indicator species using low level aerial photography. The latter is being employed at present by the W.A. Forests Department in a detailed study to locate all centres of dieback so that management plans can be implemented to prohibit the rapid spread of the disease due to man's activities.

The aerial photography employs only colour photography. The disease is detected by a visible change in colour of the *Banksia grandis* trees or other indicator species. Following detection on the photograph the area is examined and specimens of the affected plants taken for analysis to prove the existence or otherwise of the disease since the indicator species may die from alternative causes.

This method employs only a limited range of the radiation spectrum available for remote sensing purposes. Colour photography employs the range of wavelengths from 390 to 780 nm which is the visible part of the electromagnetic spectrum.

Various instruments are available for the detection of radiation in other parts of the electromagnetic spectrum. The Infrared section of the spectrum from 780 nm to 2500 nm has received much attention from scientists concerned with the spectral signatures of plants and the status of a plant system.

It has been found by many workers that a plant foliage has a reasonably specific interaction with infrared radiation, and this interaction can be used to determine the status of the vegetation's health and vigour.

Of course, the effect of vegetation on the visible part of the spectrum is also well documented as are the expected changes due to health and vigour of the plants.

The point of interest is the stage at which a change in vegetation status produces a change in the Reflectance pattern and in what part of the spectrum a significant change occurs first.

Changes occurring in the I.R. are referred to as <u>extra-visual changes</u>.

If these changes occur prior to any significant changes in the visible then they are referred to as <u>pre-visual changes</u>. Naturally these pre-visual changes are of major importance in determining vegetation status as they would allow fairly immediate action to be taken to correct a detrimental change possibly before irreversible damage had occurred.

A photographic imaging system was established during W.W.II for the detection of infrared light. Infrared photography captures light in the green, red and near infrared parts of the spectrum from 350 nm to 900 nm. It produces an image which is an integration of all wavelengths detected.

Sensing systems called spectroradiometers are available which sort the spectrum into its component parts and thus allow the observer to only consider those of most interest i.e. where the greatest changes are occurring.

The present study looks at the reflectance pattern of mature *B. grandis* and ascribes some of the known effects on reflectance patterns to the observed changes.

MATERIALS AND METHOD:-

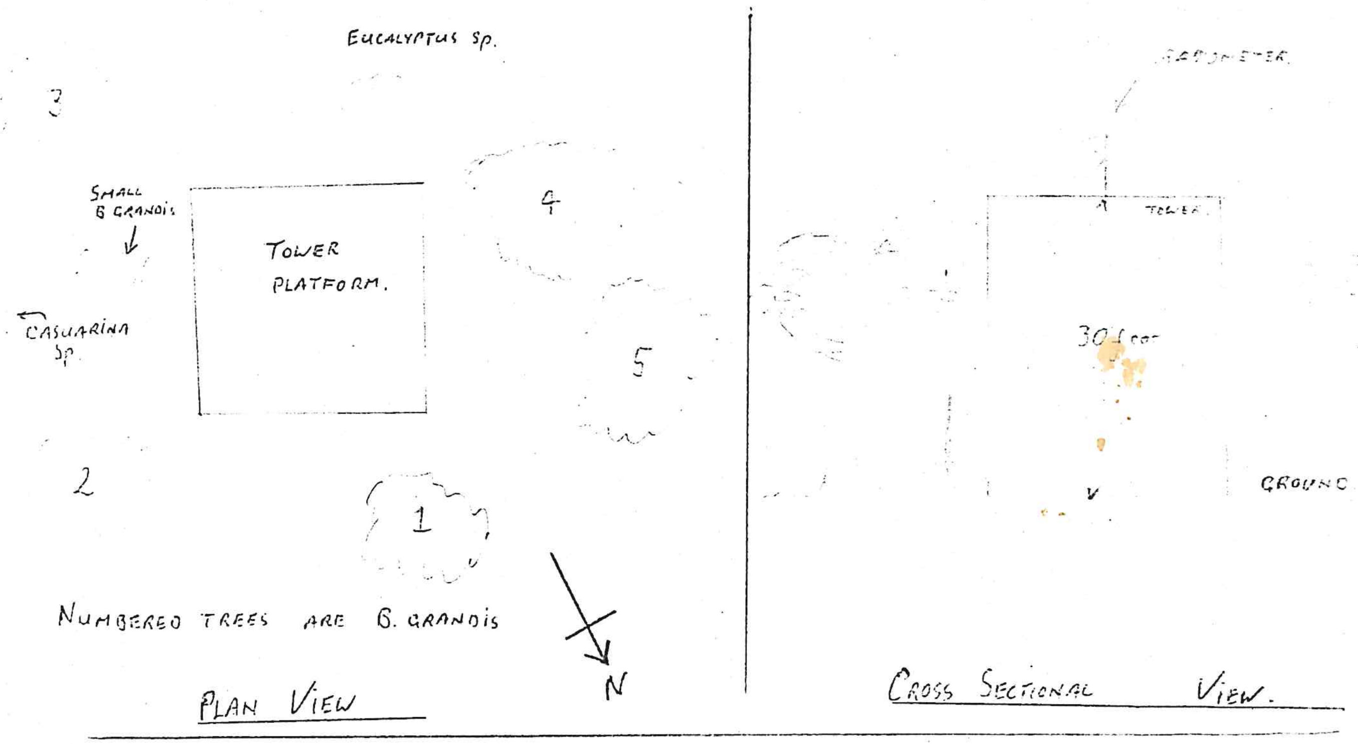
The spectroradiometer system used for observations is an instrument produced by Gamma Scientific Inc. of America. It has the capabilities of scanning the spectrum from 300 - 1100 nm with the use of two photomultiplier detectors. The data is recorded as micro watts per square centimetre per steradian ($\mu w/cm^2.Sr.$).

Another instrument used is the Exotech Radiometer which employs diodes to collect the radiation within known wavelength bands corresponding to the wavelengths used in the ERTS satellite system.

The third instrument used is a pair of cameras set up to photograph the same area simultaneously with colour and colour infrared film.

To observe the *B. grandis* trees a tower had to be erected. A site was chosen such that a number of *B. grandis* specimens could be observed from the platform at different angles. (See photographs* and Diagram 1)

DIAGRAM 1



* PHOTOGRAPHS AVAILABLE IN SLIDE FORM.

Ideally the observation angle would be vertically above the specimens.

In this instance the angle of observation is fairly low due to the height of the tower. This angle however may have good correlation with the angle at which oblique aerial photographs would be taken and from this point of view is considered appropriate as it is the ultimate intention of this study to correlate the radiometric readings with oblique photographs.

All three instruments were used in making observations from the tower.

The specimens are located round the tower as depicted in Diagram 1. Thus the look angle can be varied in relation to the sun to possibly obtain some insight into the best direction of observation.

To simulate stress on some branches of the specimen, a few branches were ring barked and severed fairly deeply but not so much that they fell from the tree. In fact these branches were able to get enough moisture through the uncut part of the stem and so did not die readily.

This treatment was used on specimens 1 and 2 initially. When it was found that they would not die the branches had to be severed from the tree completely.

Specimen 3 had a branch severed from it completely. This branch was located, so that a good view of its foliage could be seen, under the tree from which it came. This branch was observed for five days.

It was found that scanning with the spectroradiometer should only be done under full sunlight or under diffuse cloud. This is because of the extended length of time required when broken cloud disrupts reading and thus errors are introduced. Caution must be taken even under diffuse cloud because of the variations in light intensity coming through which could cause errors between specimen reading and standard reading.

Each scan takes approximately ten minutes. Four sets of scans are done for each specimen observed, viz, one of the specimen followed by one of the standard for both of the photomultiplier tubes. Readings are taken at 25 nm intervals.

RESULTS

OBSERVATIONS on *B. grandis* specimens 1 and 2 at Jandakot:

These observations were taken from the 11/8/80 - 15/8/80.

GENERAL:-

REFLECTANCE PATTERN:-

The Reflectance Factor is a very low percentage in the visible region up to 700 being below 10%. This may be a real effect or is partly due to the fact that the specimen is 10 - 15 m from the observation point whereas the standard is only a few metres from the observing instrument.

Seedlings which were only a few metres from the instrument and at the same distance as the standard had reflectances greater than 10% for the green to red section of the spectrum for two of the four specimens.

The start of the rise in the near infrared occurs at 700 nm. This is the case for all scans taken.

At 750 nm a distinct bulge occurs in the rising part of the curve. This is not as expected from typical curves and may be a distinctive feature of this species. See graphs 1 and 2.

REFLECTANCE VALUES:-

Significant changes can be seen in the values of reflectance in the green, red and infrared sections of the graphs. Much less variation occurs in the blue section.

The change indicated by Specimen 2 LIVE suggests that reflectance particularly in the near infrared increases with increasing time throughout the day. Specimen 2 CUT was cut as described earlier. On the first day after cutting the reflectance patterns for the LIVE and the CUT were similar. See graph 2.

On the following day however, the above trend did not occur. Earlier in the day the reflectance at 800 nm was much higher than later in the day. At shorter wavelengths the reflectance values were lower earlier in the day complying with the LIVE results. At 2.15 and 3.15 pm the CUT curves are very similar.

On the 15/8/80, the previously cut branch on Specimen 2 was severed from the tree and placed in an observation position on the ground. Its observed reflectance at midday was very much lower in the near infrared but fairly similar in the visible as compared to the previous observation.

It is suspected that this reduced reflectance was due to

a) change in orientation
b) change in distance
c) change in background

- all of which have significant effects upon the reflectance of specimens.

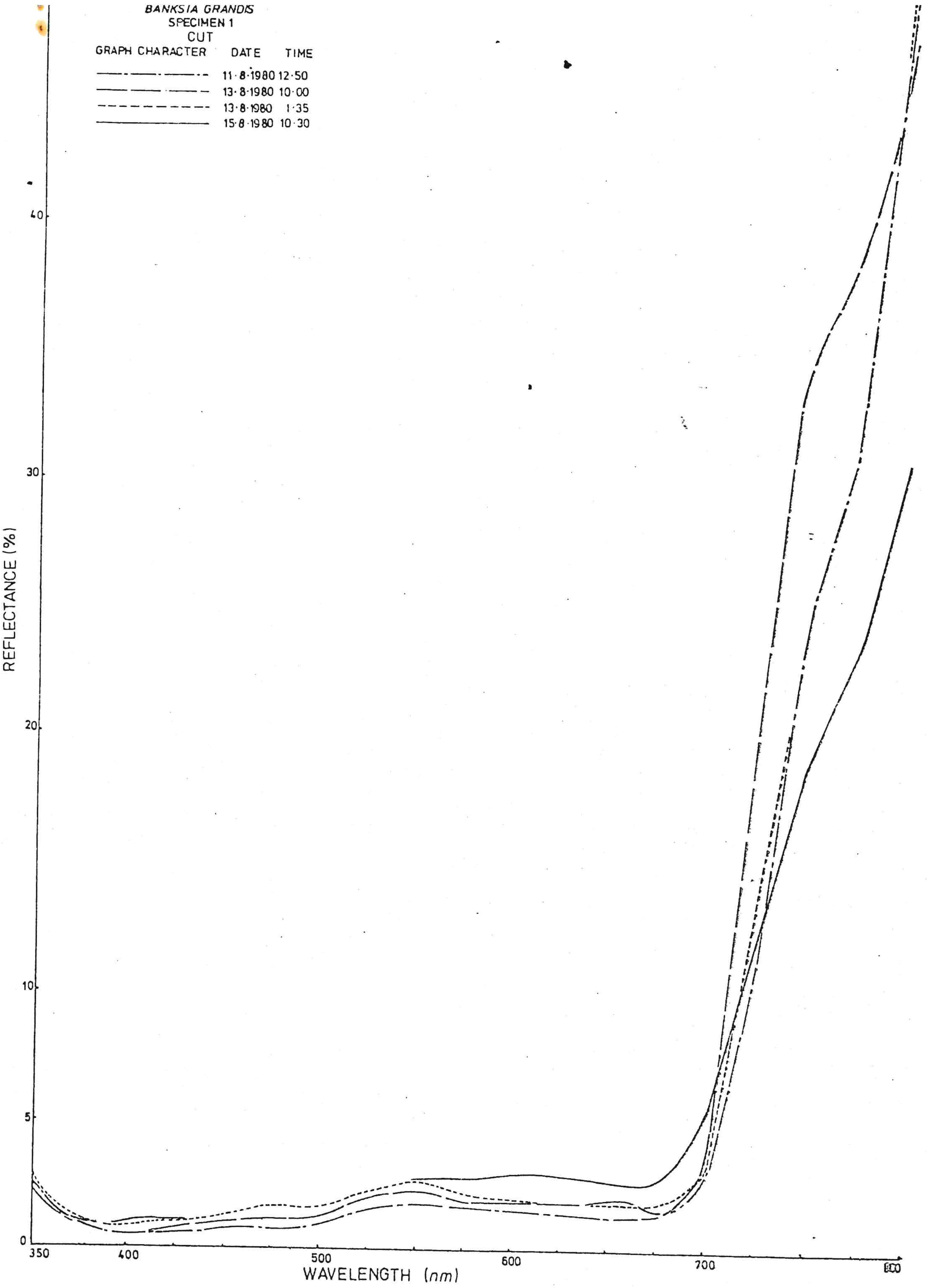
The control side (RHS) of Specimen 2 had very high reflectance at 800 nm on this day, and lower reflectance at 775 nm and 750 nm on the 15/8 than on the 13/8.

Specimen 1 showed little trend in its reflectance patterns.

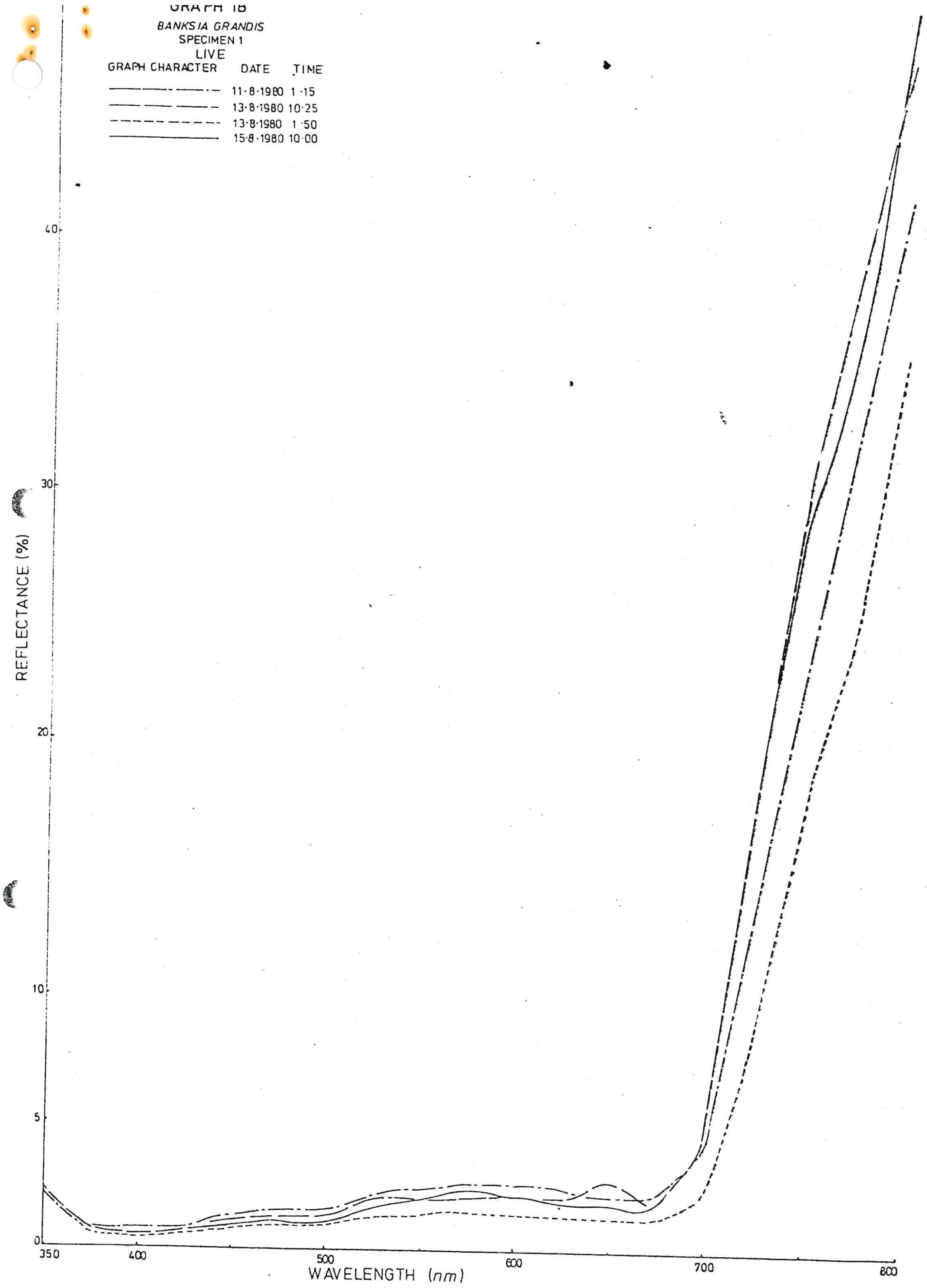
There was less variation in the visible part of the spectrum.

The near infrared did not show the same trend as it did in Specimen 2. See graph 1.

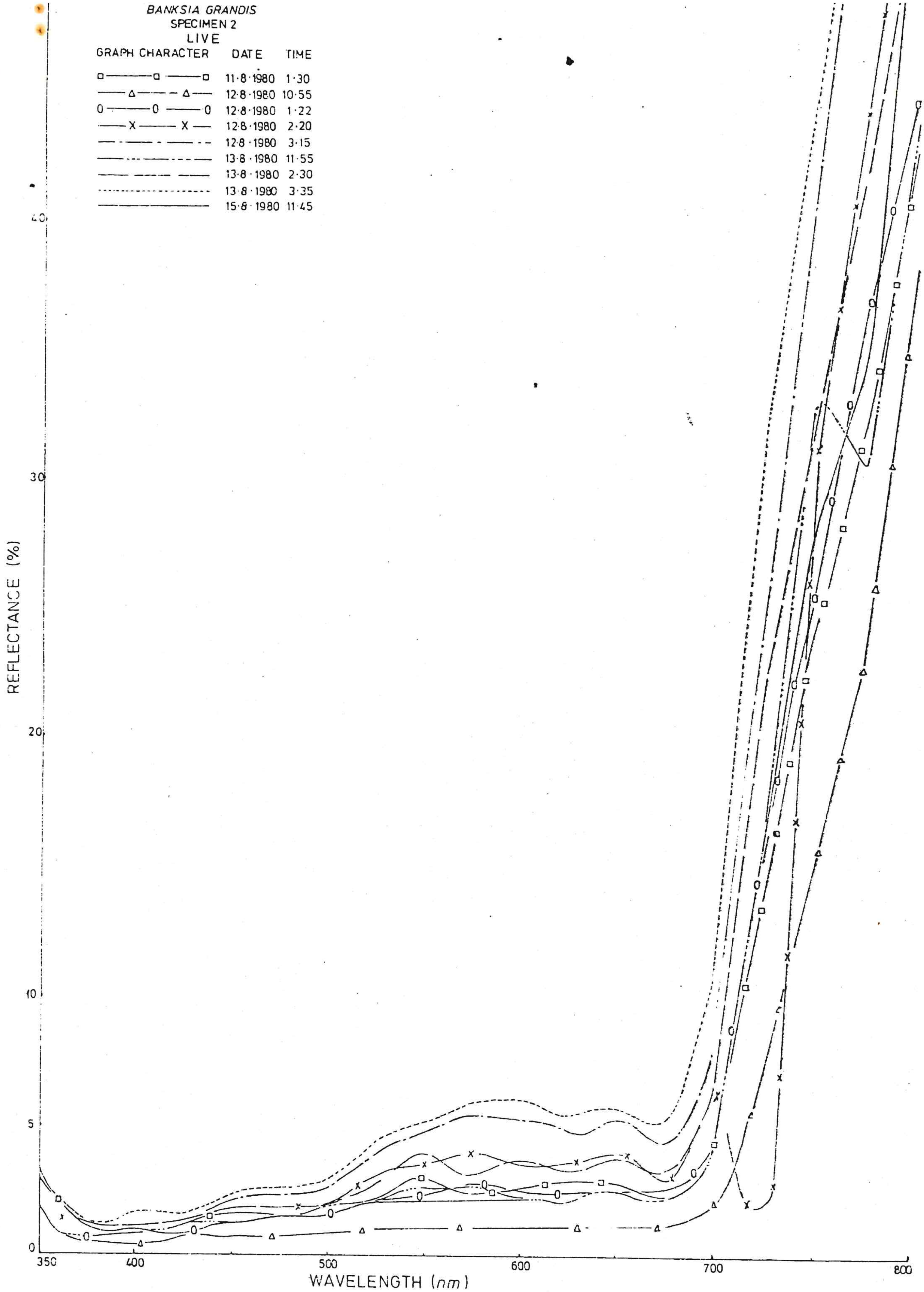
The cut branch which fell from this specimen when observed on the ground had a lower reflectance in the near infrared, probably due also to the changes in direction, distance, orientation and background.

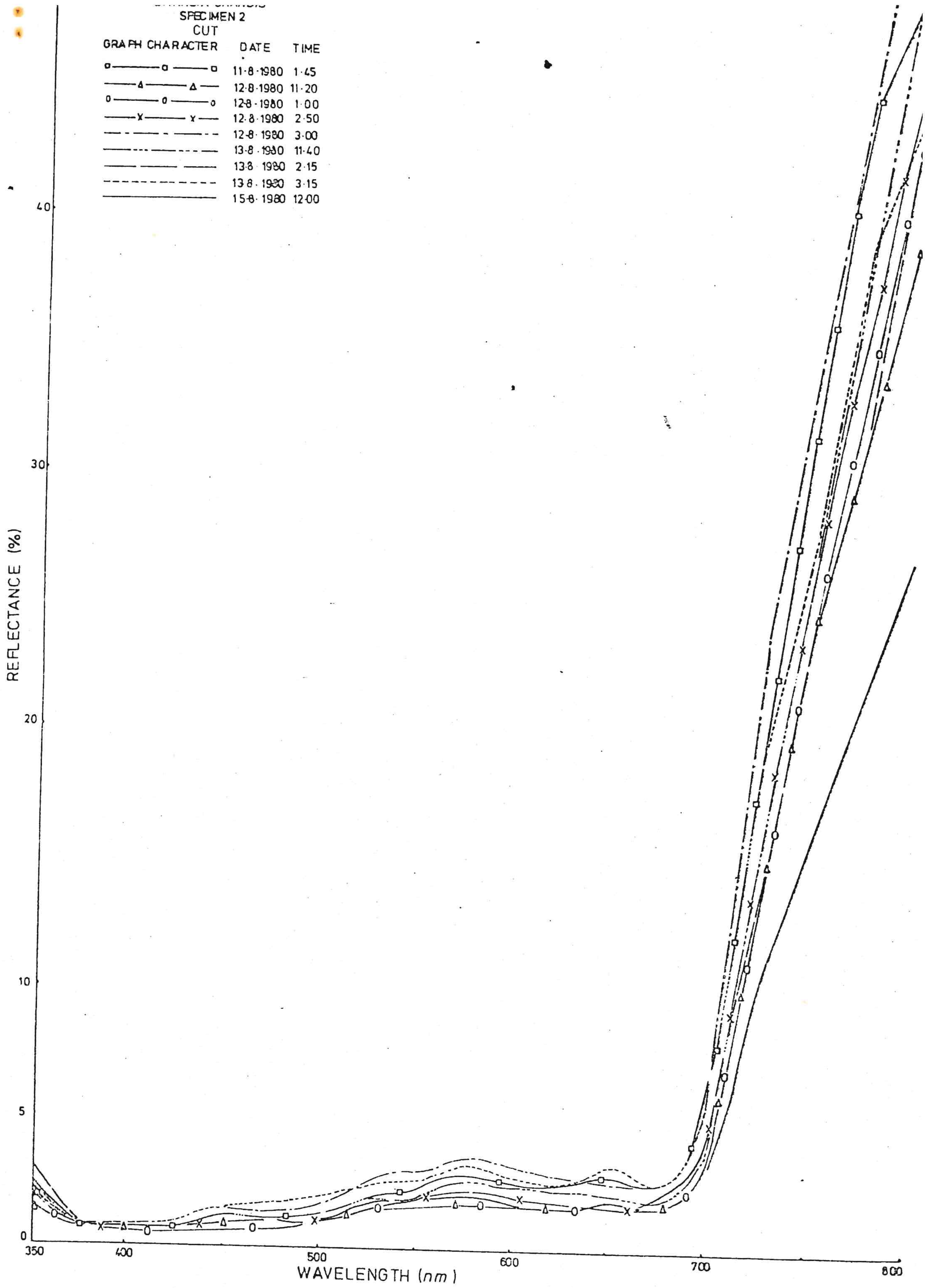


BANKSIA GRANDIS
SPECIMEN 1
CUT
GRAPH CHARACTER DATE TIME
11·8·1980 12·50
13·8·1980 10·00
13·8·1980 1·35
15·8·1980 10·30
REFLECTANCE (%)
40
30
20
10
5
0
350
400
500
600
700
800
WAVELENGTH (nm)



GRAPH 1B
BANKSIA GRANDIS
SPECIMEN 1
LIVE
GRAPH CHARACTER DATE TIME
11·8·1980 1·15
13·8·1980 10·25
13·8·1980 1·50
15·8·1980 10·00
REFLECTANCE (%)
40
30
20
10
5
0
350
400
500
600
700
800
WAVELENGTH (nm)


BANKSIA GRANDIS
SPECIMEN 2
LIVE
GRAPH CHARACTER DATE TIME
11·8·1980 1·30
12·8·1980 10·55
12·8·1980 1·22
12·8·1980 2·20
12·8·1980 3·15
13·8·1980 11·55
13·8·1980 2·30
13·8·1980 3·35
15·8·1980 11·45
REFLECTANCE (%)
40
30
20
10
5
0
350
400
500
600
700
800
WAVELENGTH (nm)


SPECIMEN 2
CUT
GRAPH CHARACTER DATE TIME
11·8·1980 1·45
12·8·1980 11·20
12·8·1980 1·00
12·8·1980 2·50
12·8·1980 3·00
13·8·1980 11·40
13·8·1980 2·15
13·8·1980 3·15
15·8·1980 12·00
REFLECTANCE (%)
WAVELENGTH (nm)
0
5
10
20
30
40
350
400
500
600
700
800

OBSERVATIONS on Specimen 3

In future readings, to be more sure of the conditions affecting the specimen and to hold as many factors as possible constant it was decided to sever a large branch completely from the tree. This branch was located under the control specimen from which it was cut.

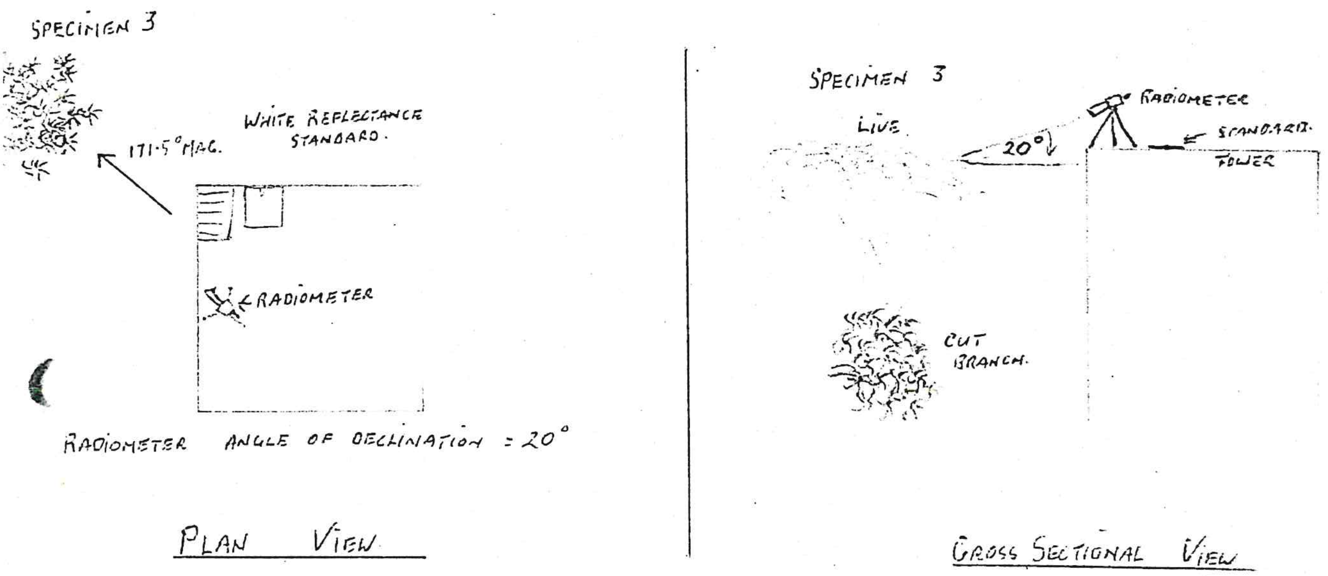
These observations were tkane between 8/9/80 - 20/9/80.

At 11.00 a.m. on 8/9/80 a branch was severed from Specimen 3. This branch was located under the tree where it would receive sunlight for part of the day and where it could be observed from the tower. The branch was orientated so that the observation angle was almost perpendicular to the plane of the foliage. This is in contrast to the control whose foliage was at more of an angle to the observation direction.

The orientation of these two parts of Specimen 3 produced a visible difference. The cut branch looked a darker green than the control section which probably accounts for the higher values of visible reflectance of the cut branch compared to the live specimen.

Diagram 2 depicts the set up for this specimen.

DIAGRAM 2



Due to the limited time in which the cut branch of Specimen 3 was actually illuminated only two readings per day were taken.

Readings were also taken of adjacent trees and grass specimens to see how these compared with the *B. grandis*.

Leaf specimens were collected once a day of both the live and cut branches to see what changes were taking place in the leaf morphology due to the cutting.

With regard to visible effects of the cutting, within an hour of cutting a young flower spike on the cut branch had wilted. There were no other visible signs of wilting or change in leaf arrangement or colour on the cut branch within the first five days.

THE CUT BRANCH:-

The overall trend from the beginning to the end of the experiment was for the reflectance in the 750 - 850 nm band to decrease. From 850 - 1100 nm the pattern is more confused making interpretation difficult.

The trend on each day was for the reflectance around noon to be lower than the reflectance later in the afternoon. This demonstrates earlier suggestions that the reflectance throughout the day increases even beyond noon.

THE CONTROL BRANCH:-

Noon time readings show an indefinite trend. That is to say that on consectuve days they are sometimes above and below the readings of the previous day.

The afternoon readings on the other hand show the same trend as for the cut branch and decrease overall throughout the five days in the 750 - 950 nm region.

On two of the days the afternoon reading was higher than the noon time readings on the same day.

On the fifth day which was cloudy the noon reading between 725 to 925 nm was higher than the afternoon reading and from 925 to 1100 nm the two readings were fairly similar.

In most cases for both branches, by 1100 nm the reflectance levels were up to 100% or more.

In the visible, the control branch was mostly lower than the cut branch. The exceptions were on the first day and day four.

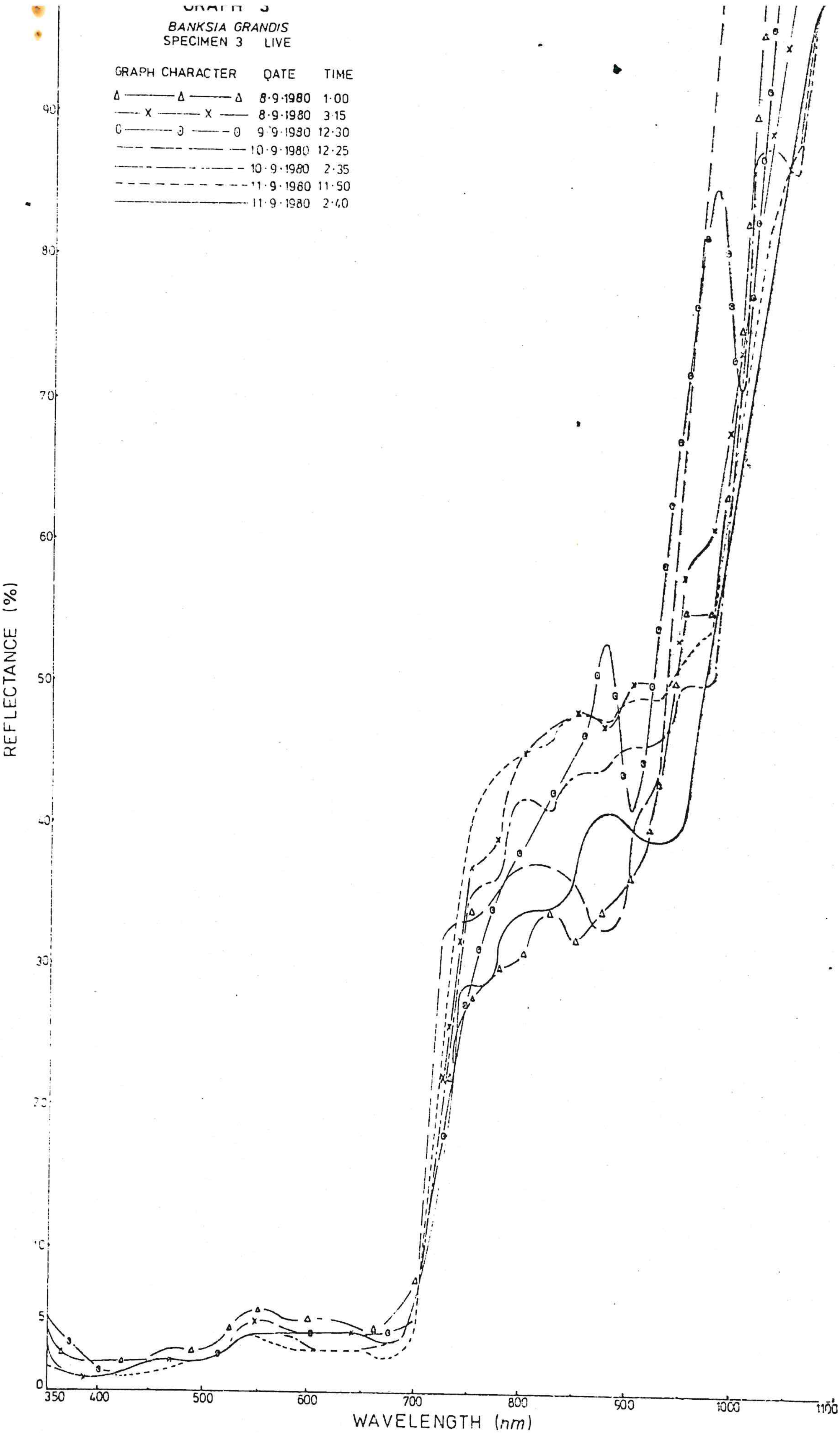
The results in the visible region as taken on the 20/9/80 show much higher reflectance at all wavelengths for the cut branch than for the live branch. But a rapid and steep increase still occurs in the near infrared.

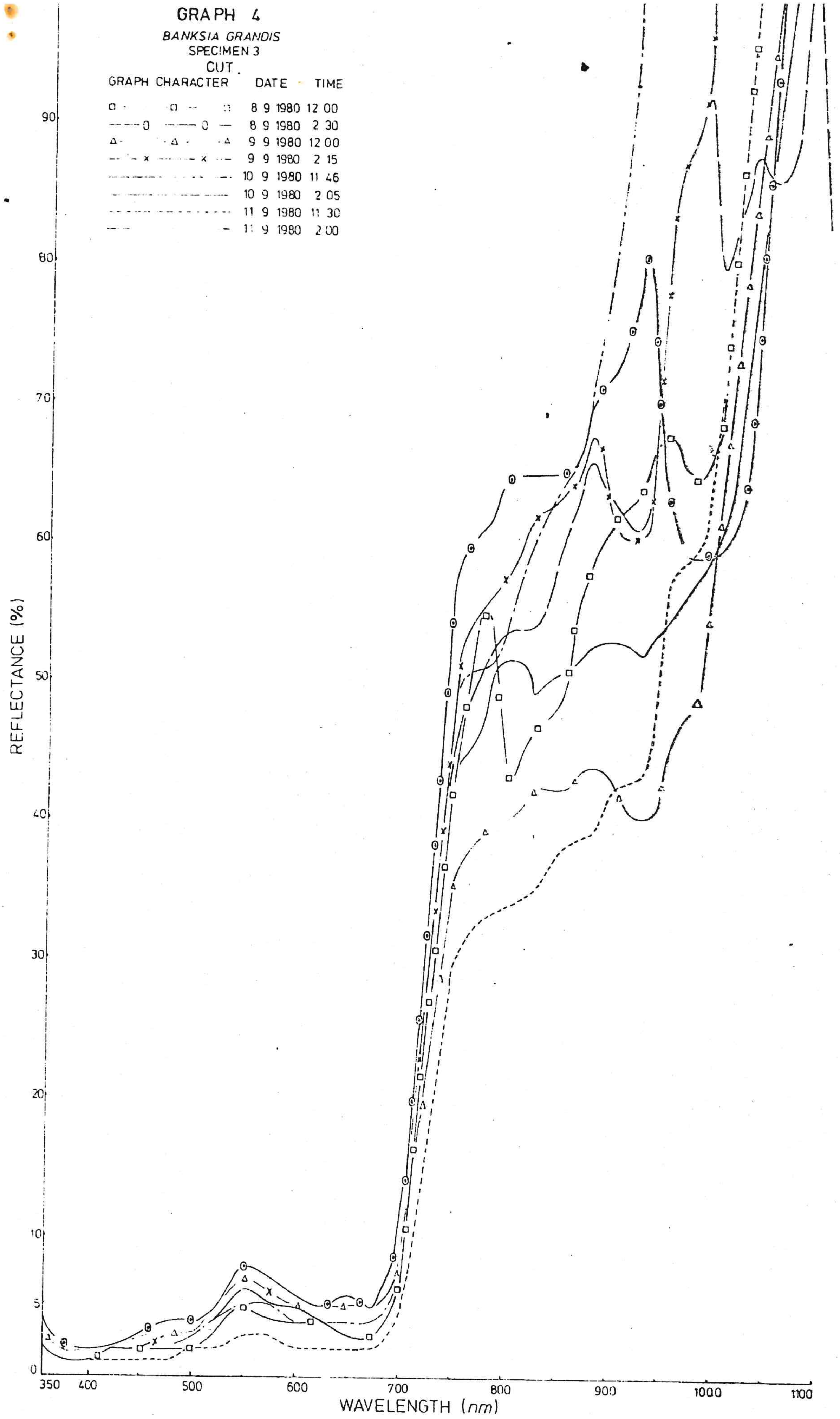
On this day, the afternoon reading for the live branch in the near I.R. between 750 and 925 nm is higher than the noon time reading, but for the cut branch the afternoon readings in the near I.R. are lower at all wavelengths from 975 nm up.

The reflectance pattern of Specimen 3 is depicted in graph 3 and 4 and subsequent graphs. The subsequent graphs show the differences between the live and the cut specimens.

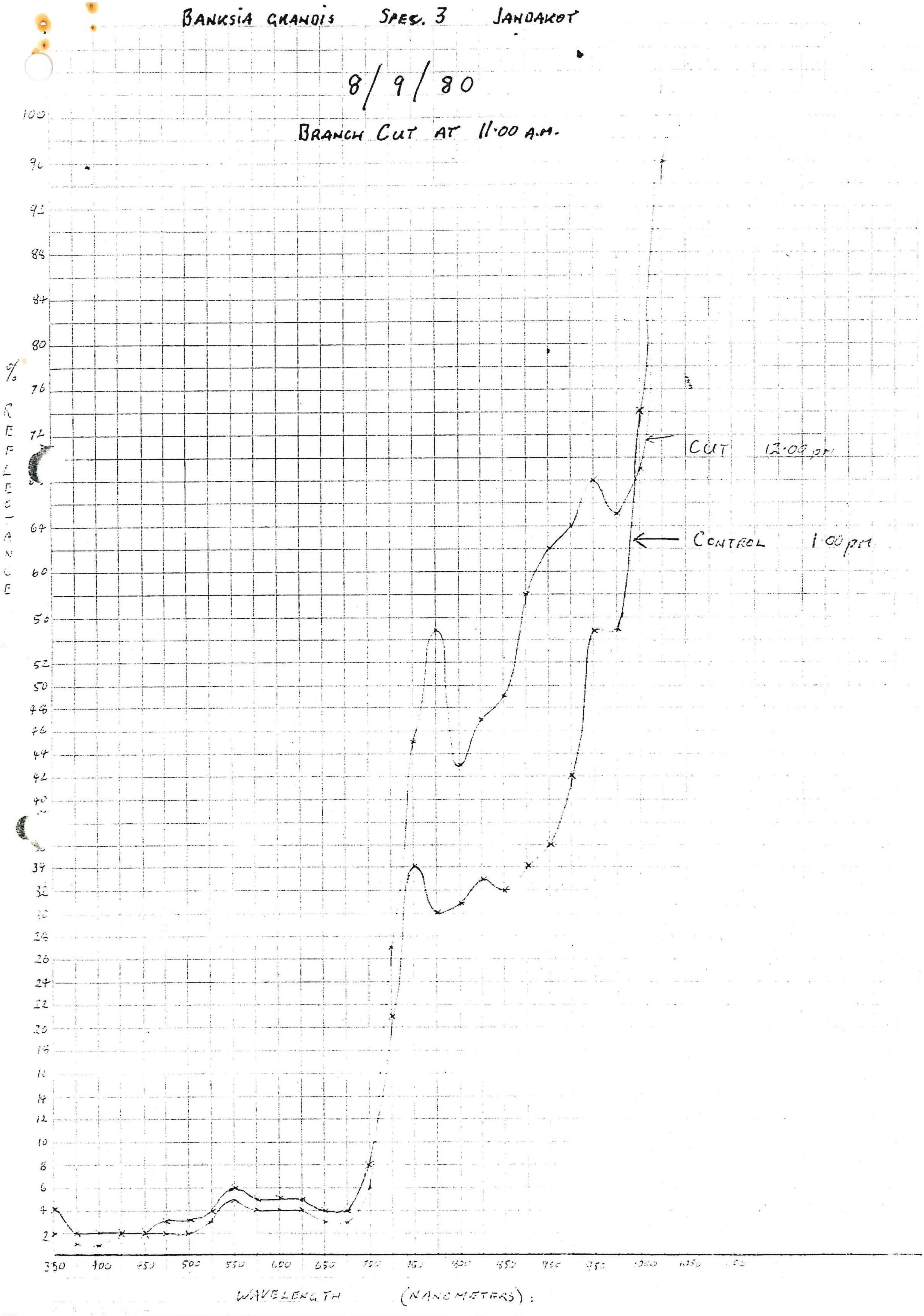
Graph 15 shows the reflectance pattern for other specimens around the tower as detailed on the graph.

Note the variation in the pattern for the Eucalypt specimen.


GRAPH 3
BANKSIA GRANDIS
SPECIMEN 3 LIVE
GRAPH CHARACTER DATE TIME
8·9·1980 1·00
8·9·1980 3·15
9·9·1980 12·30
10·9·1980 12·25
10·9·1980 2·35
11·9·1980 11·50
11·9·1980 2·40
REFLECTANCE (%)
WAVELENGTH (nm)
350
400
500
600
700
800
900
1000
1100



GRAPH 4
BANKSIA GRANDIS
SPECIMEN 3
CUT
GRAPH CHARACTER
DATE
TIME
8 9 1980 12 00
8 9 1980 2 30
9 9 1980 12 00
9 9 1980 2 15
10 9 1980 11 46
10 9 1980 2 05
11 9 1980 11 30
11 9 1980 2 00
REFLECTANCE (%)
WAVELENGTH (nm)
0
5
10
20
30
40
50
60
70
80
90
350
400
500
600
700
800
900
1000
1100

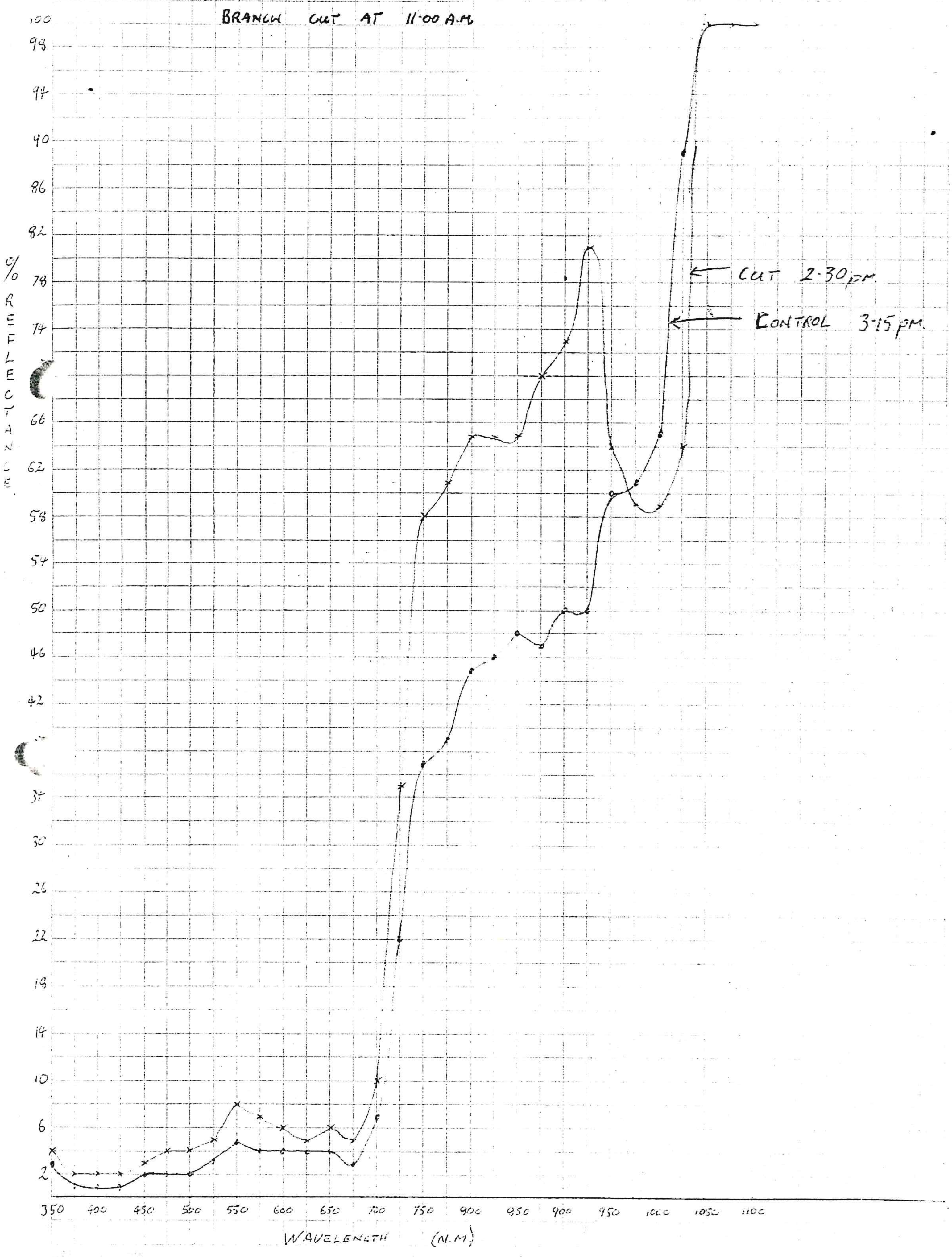


BANKSIA GRANDIS SPEC. 3 JANDAKOT
8/9/80
BRANCH CUT AT 11·00 A.M.
CUT 12·00 pm
CONTROL 1·00 pm
% REFLECTANCE
WAVELENGTH (NANOMETERS).

BANKSIA GRANDIS SPEC. 3. JANDAKOT

8/9/80

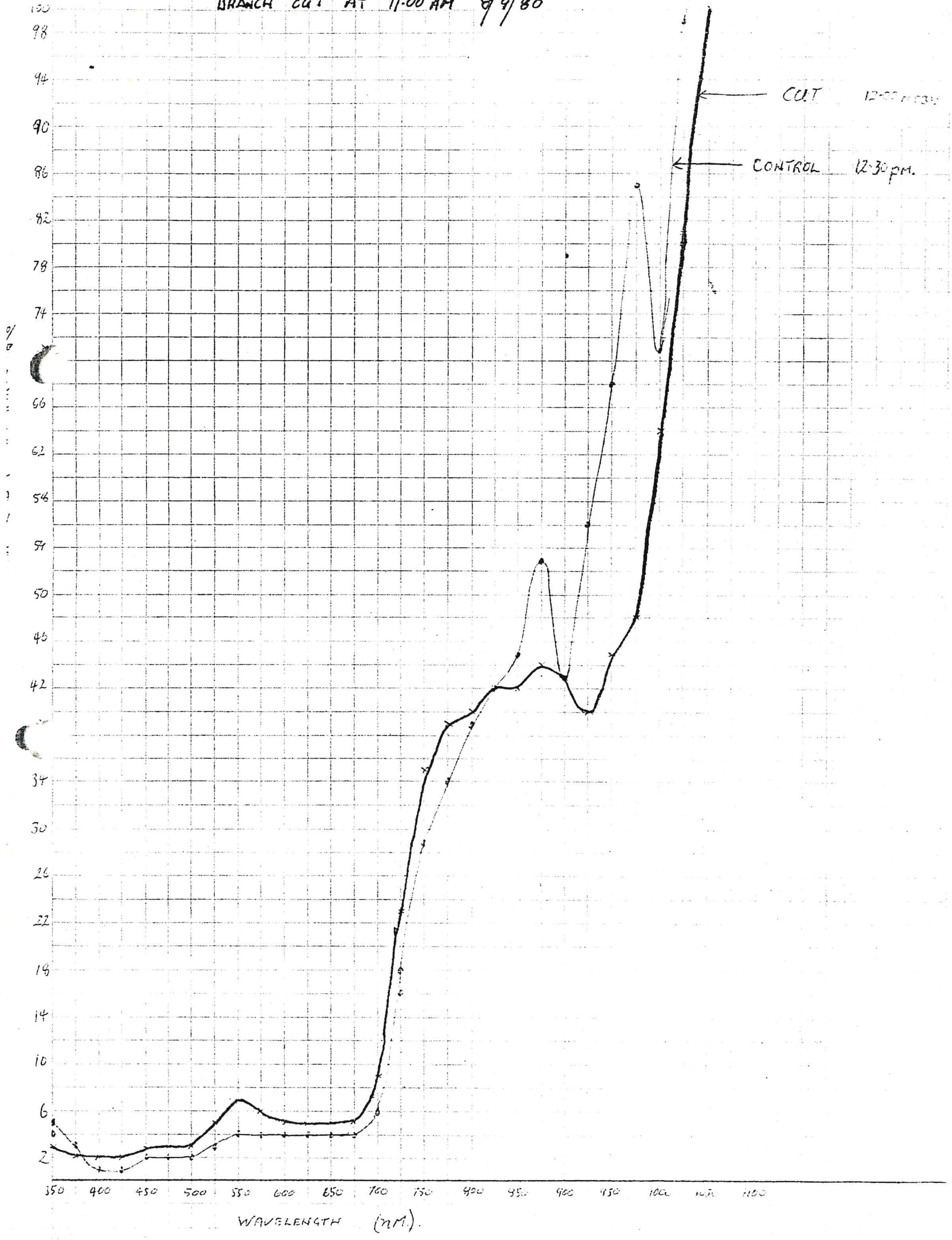
BRANCH CUT AT 11·00 A.M.



BANKSIA GRANDIS SPEC. 3. JANDAKOT

9/9/80

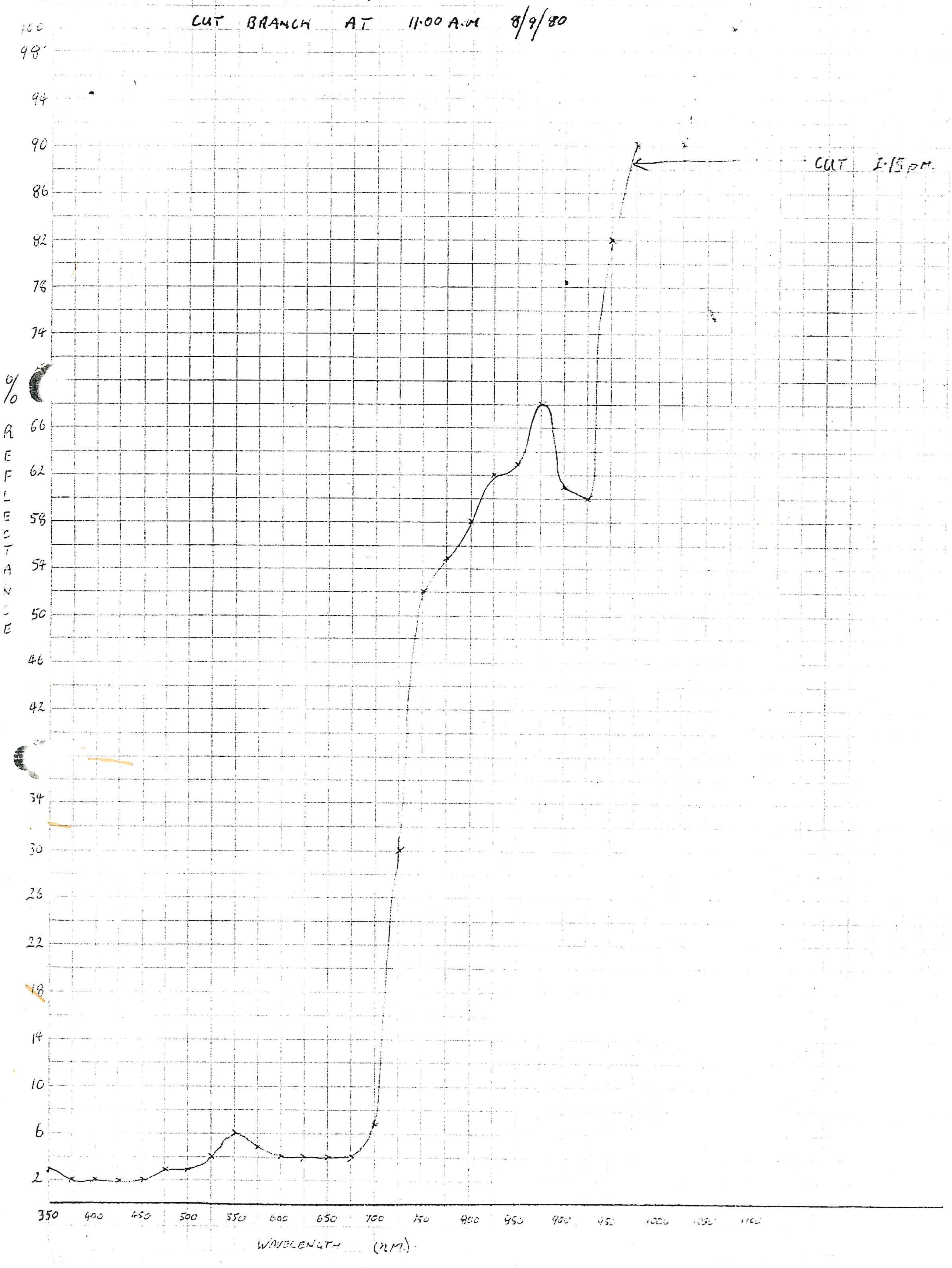
BRANCH CUT AT 11·00 AM 8/9/80



BANKSIA GRANDIS SPEC. 3 JANDAKOT

9/9/80

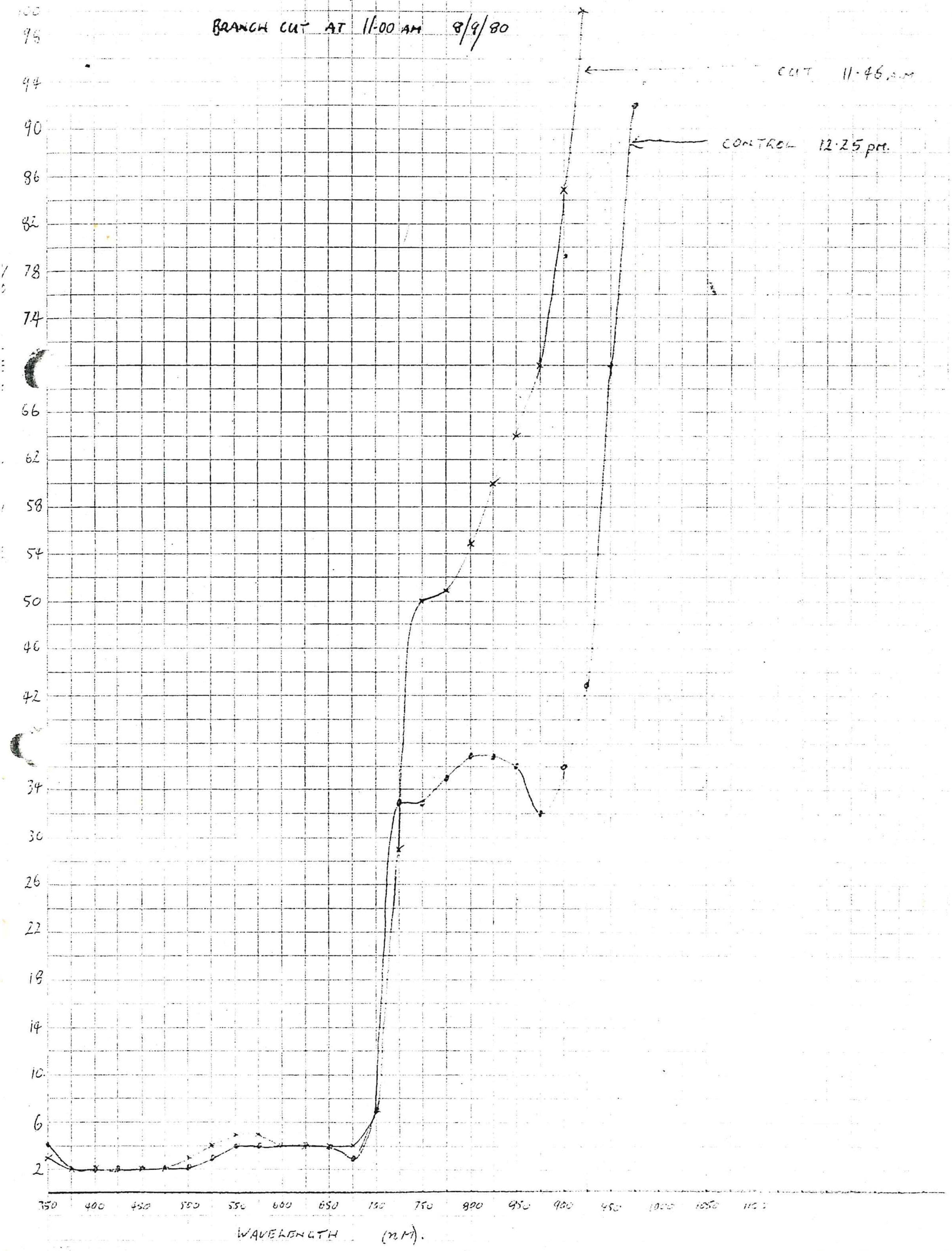
CUT BRANCH AT 11.00 A.M 8/9/80



BANKSIA GRANDIS SPEC. 3. JANDAKOT

10/9/80

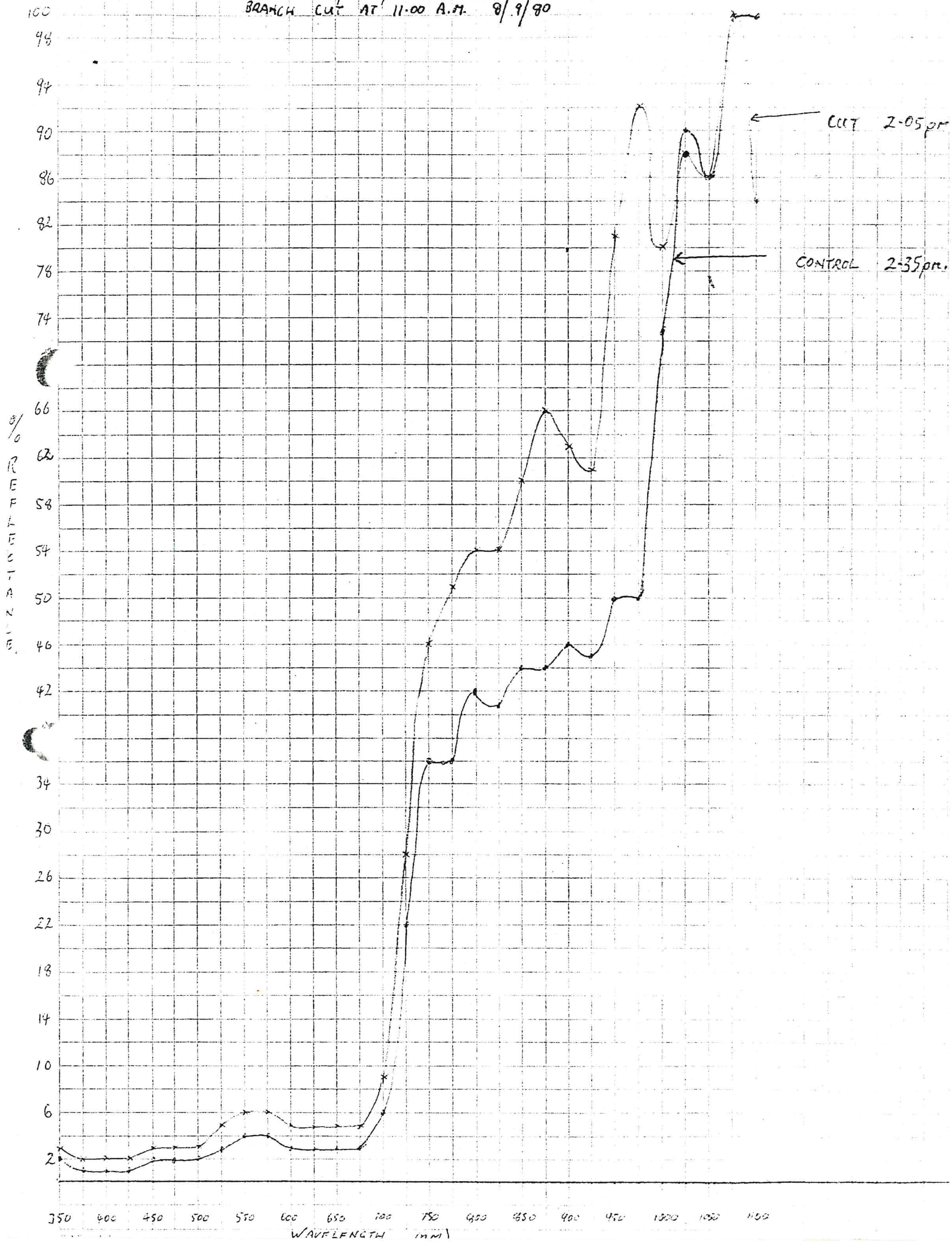
BRANCH CUT AT 11·00 AM 8/9/80



B. GRANDIS SPEC. 3. JANDAKOT

10/9/80

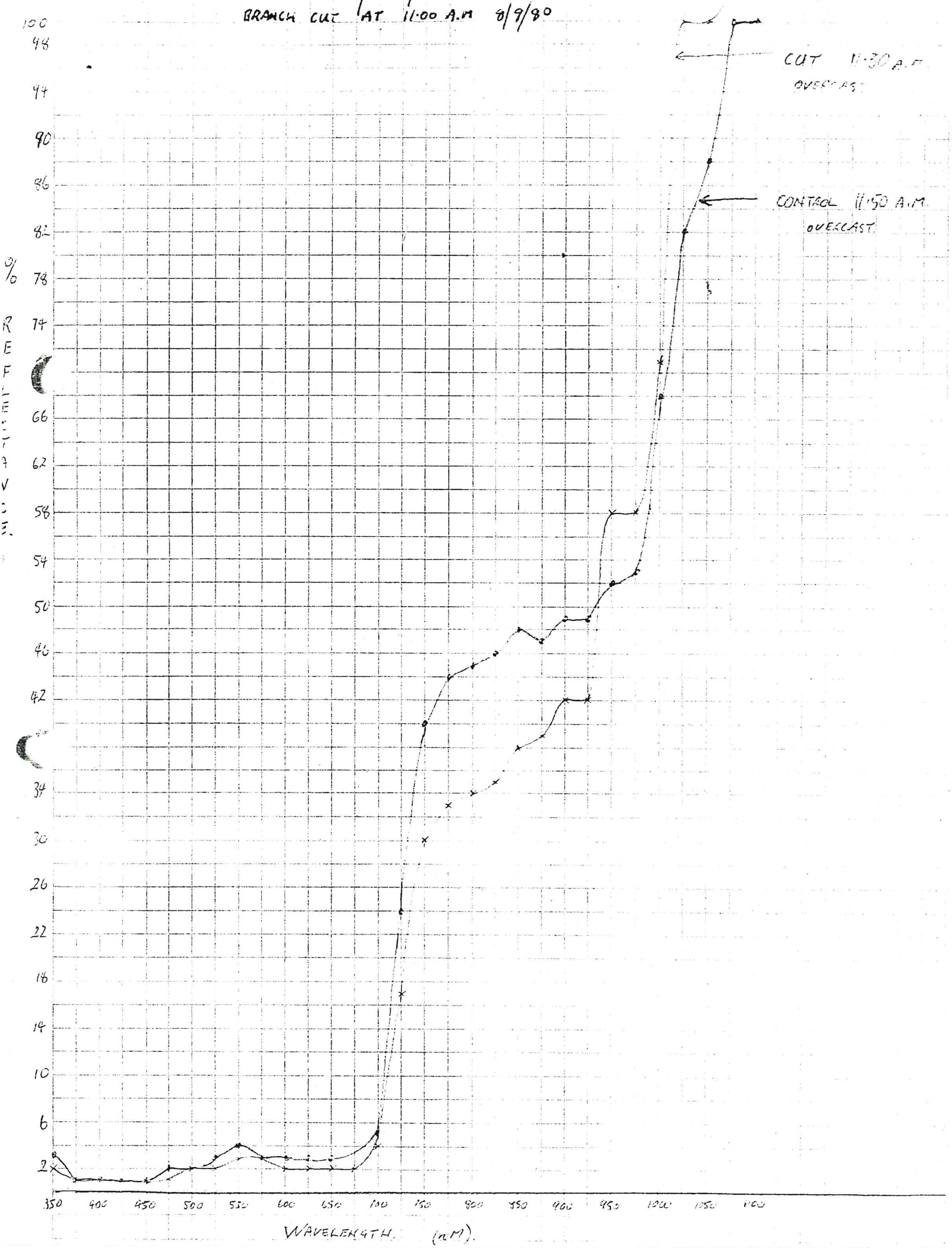
BRANCH CUT AT 11.00 A.M. 8/9/80



BANKSIA GRANDIS SPEC. 3. JANDAKOT

11/9/80

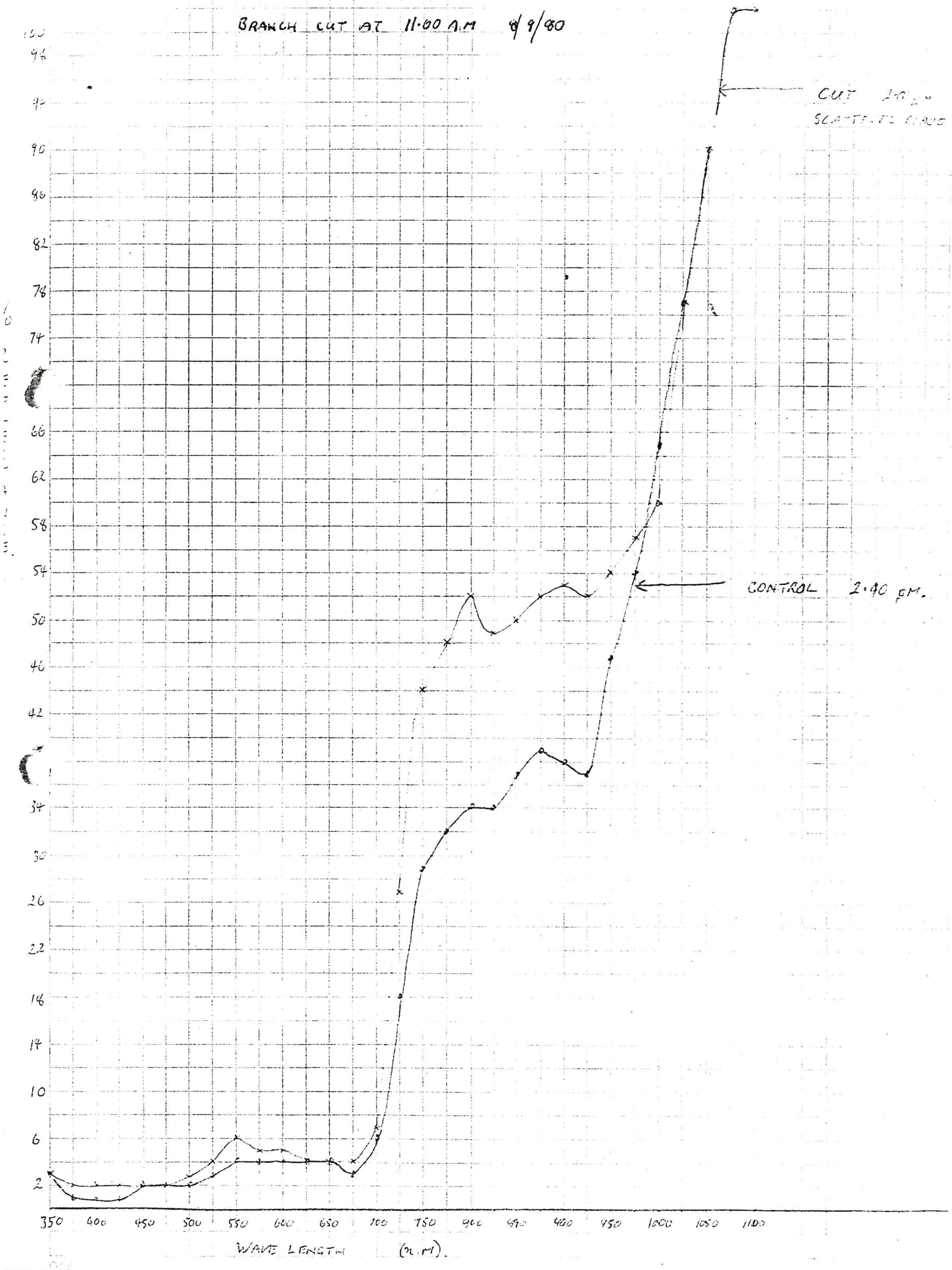
BRANCH CUT AT 11:00 A.M 8/9/80



BANKSIA GRANDIS SPEC. 3. JANDAKOT

11/9/80

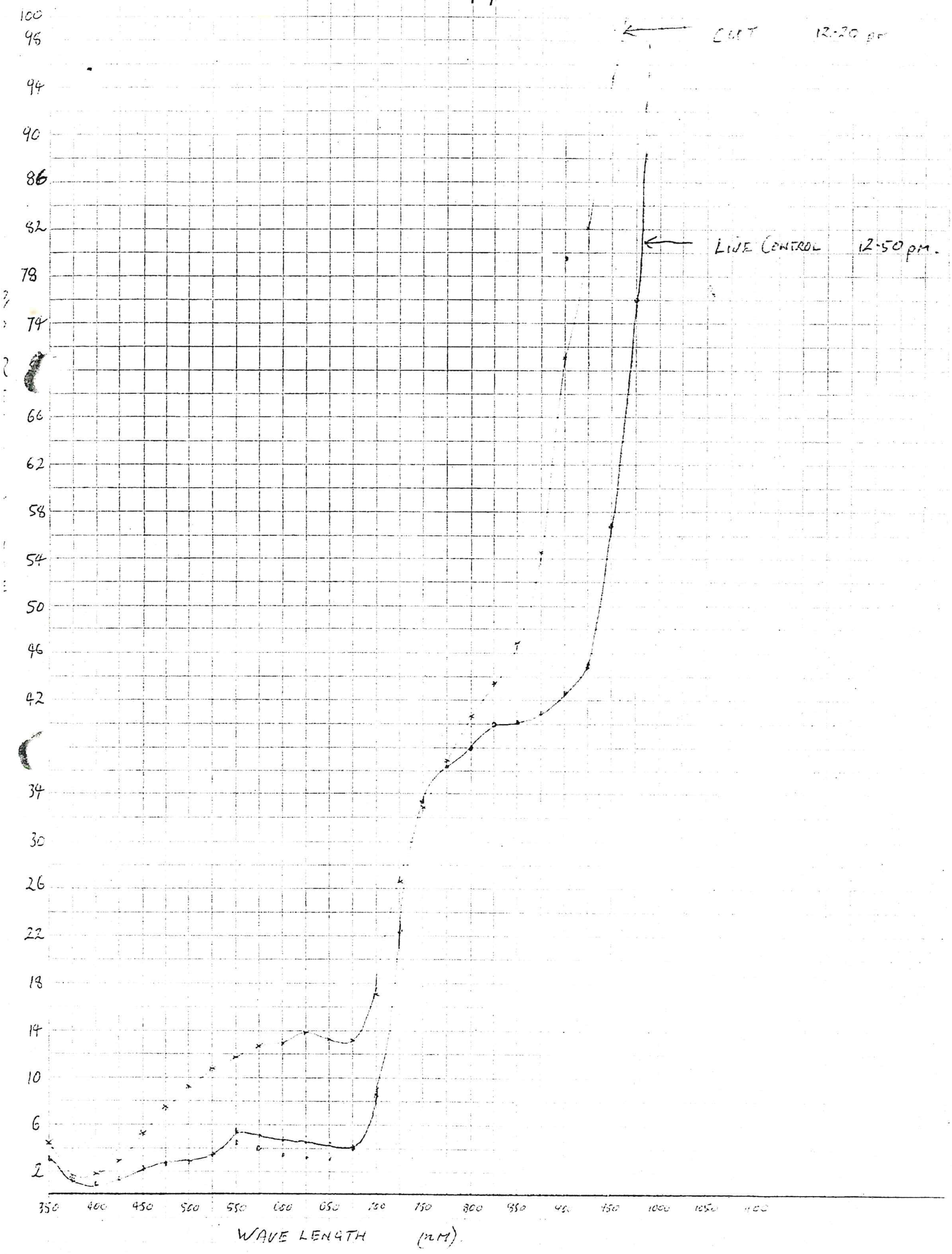
BRANCH CUT AT 11·00 A.M 11/9/80



BANKSIA GRANDIS SPEC 3. JANDAKOT

20/9/80

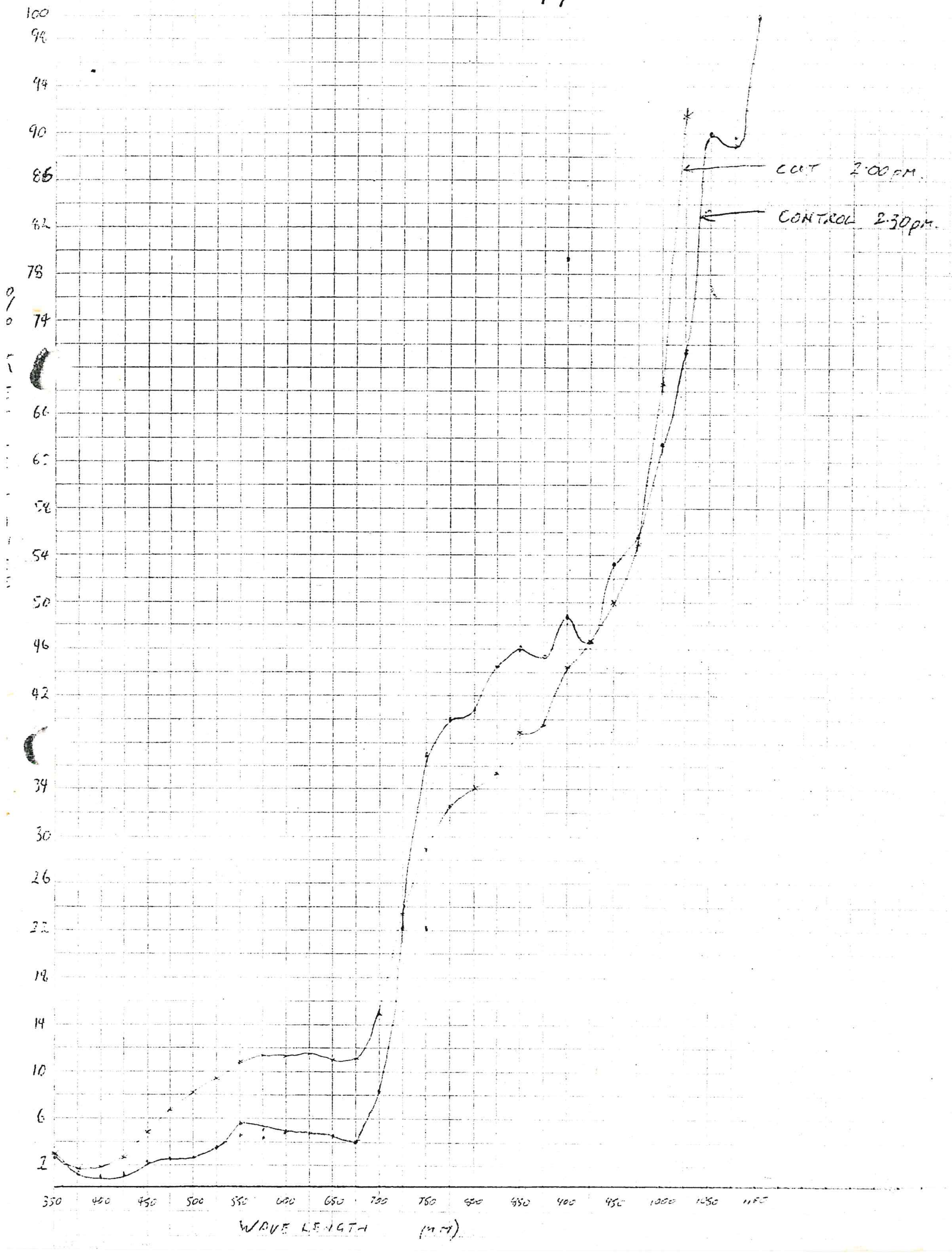
BRANCH CUT AT 11-00 AM 8/9/80

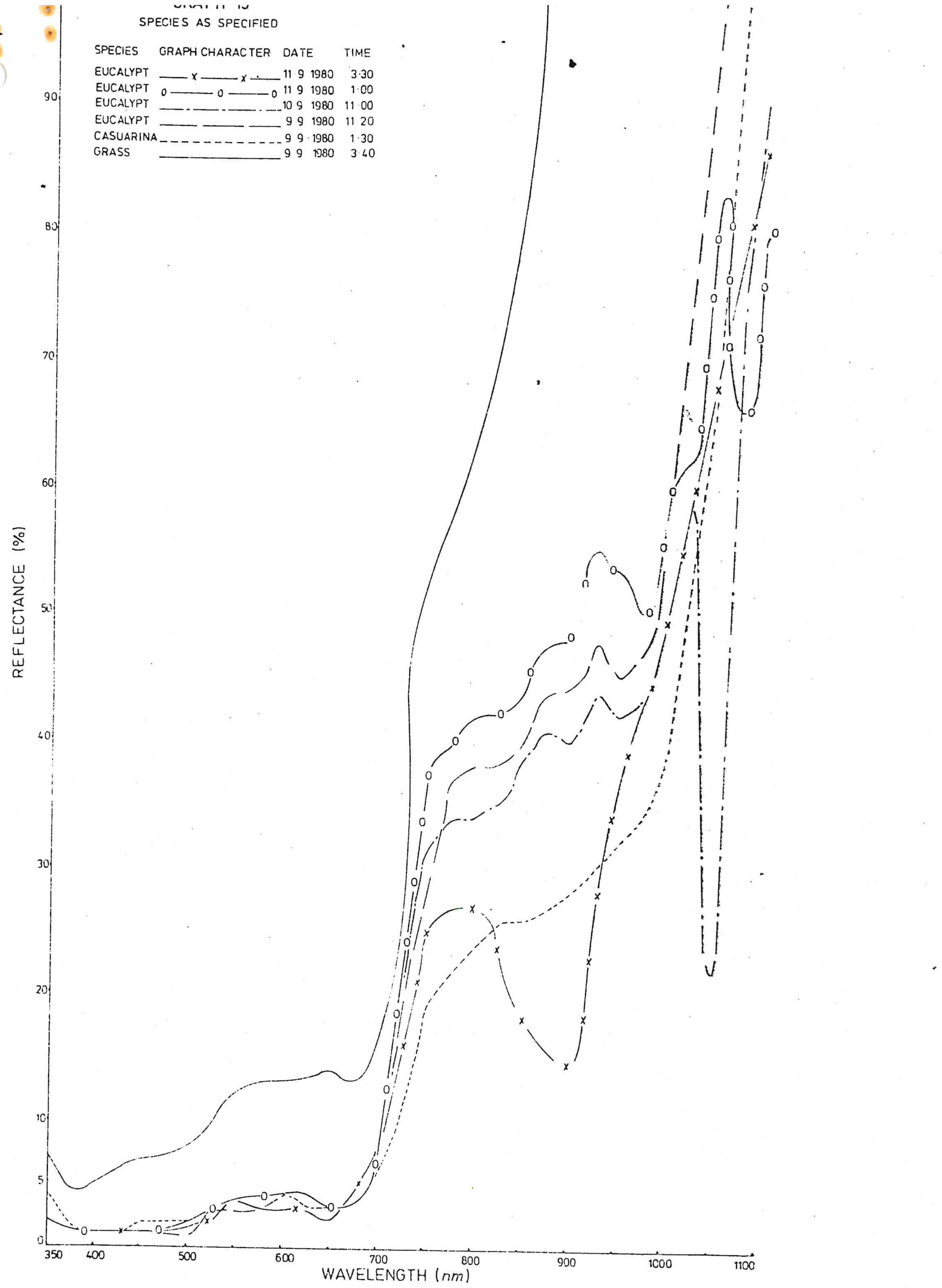


BANKSIA GRANDIS SPEC. 3 JANDAKOT

20/9/80

BRANCH CUT AT 11.00 AM. 8/9/80





SPECIES AS SPECIFIED
SPECIES
GRAPH CHARACTER
DATE
TIME
EUCALYPT 11 9 1980 3·30
EUCALYPT 11 9 1980 1·00
EUCALYPT 10 9 1980 11·00
EUCALYPT 9 9 1980 11·20
CASUARINA 9 9 1980 1·30
GRASS 9 9 1980 3·40
REFLECTANCE (%)
WAVELENGTH (nm)
350
400
500
600
700
800
900
1000
1100

Questions Arising from these Results:-

(1) Why do the reflectance levels in the near infrared increase from near noon to mid afternoon for all the results of the cut branch?

(2) Why did the same trend not occur on each day with the live part of the specimen? It did occur on three of the five days. The extra day was not measured?

(3) Why has the reflectance in the afternoon reading decreased from day to day?

(4) Why do the readings not plateau and then reduce? Instead they plateau and then increase???

Although the overall trend for the cut branch was that the reflectance decreased, in fact on three of the days the afternoon reading was higher than the reading for the morning of the following day within the 750 - 850 nm range.

Mostly, above 725 nm, the reflectance of the live specimen was below the reflectance of the cut specimen. The exceptions occurred two days apart for the noon time readings.

DISCUSSION:-

GENERAL REFLECTANCE LEVELS:-

Krinov describes four characteristic curves for vegetation reflectance depending on the type of tree considered (deciduous or evergreen) and the stage in the growth cycle of the species concerned, viz. young, semi-mature, mature.

The reflectance pattern of *Banksia grandis* falls into his type III reflectance pattern which is characterised by the gradual upward slant from 400 - 500 nm, then a sharp upswing to 550 nm with a maximum occurring at 550 nm. Then the curve slants gradually downward but remains higher in the region above 550 nm than in the region below 550 nm.

Reflectance in the infrared region, beginning at 700 nm varies with the species. However, it generally increases sharply and remains high across most of the spectrum. A slight plateau region usually occurs after 750 nm. Beyond this the curve begins a slow decrease towards 2500 nm. In between there are three dpressions where water absorption takes place.

Other workers (Ahlricks J.S. et al. 1978, Boehnel H.J. et al. 1978 and Emori Y. and Yasuda Y. 1978) show the spectral signatures for different crops, all of which conform to Krinov's type III pattern.

Reichert P.G. (1978) shows the spectral signatures for Douglas fir, Birch and Red Oak. Reflectance levels in the visible were very low for all three species and do not exceed 50% in the infrared region to 1000 nm. These reflectance levels were achieved from a satellite. The reflectance values as measured here also conform to Krinov's type III.

The reflectances as observed on the *B. grandis* trees do not reach a maximum value around the 750 - 850 nm region. They give a slight plateau over this region but then continue to increase sometimes beyond 100% reflectance. According to the above authors there should not be much variation between 750 and 1000 nm. The percentage reflectance and range over which the plateau occur are quite variable.

Other species exhibited the same degree of variation in their reflectance patterns. See graph 11.

LEAF EFFECTS ON REFLECTANCE:-

Most of this discussion pertains to work done by Gates et al. 1965.

Factors affecting the Spectral Signature include characteristics of the plant under consideration as well as factors relating to the geometry of the viewing system.

The biological characteristics include:-

- Individual leaf and Canopy characteristics

Individual leaves influence the particular bidirectional reflectance due to their morphological make-up which include the cuticle and appended structures; the epidermis; the pallisade and mesophyll cell size and arrangement; the cell wall constituent and the types of cells present throughout the leaf.

Cell structure is extremely variable depending upon species and environmental conditions during growth. But typical cell dimensions will be 15 x 15 x 60 μ for pallisade cells and 18 x 15 x 20 μ for spongy mesophyll cells. Epidermal cells are of the same size as mesophyll cells usually. The cuticle is usually 3 to 5 μ thick.

Chloroplasts, suspended within cell cytoplasm are generally 5 - 8 μ in diameter and approximately 1 μ wide. Up to 50 chloroplasts may be present in parenchyma cells. Constituents of the chloroplasts are of the order of the wavelength of light and may produce considerable scattering of light entering the chloroplast.

The leaf typically has a large volume of open space which contains saturated air.

The materials which are important from the standpoint of light and radiation interaction are, the cellulose of the cell wall, water containing solutes within the cells, intercellular spaces and pigments.

50% of the energy from the sun is in the infrared beyond .72μ. Reflectance in the infrared region is very high demonstrating the ability of the leaf to ward off possible damage from the high radiation levels in the infrared region.

Scattering of light in the leaf is caused by the structures which are of the dimension of the wavelength of light. Such structures include mitochondria, ribosomes, nuclei, starch grains and other plastids. As a consequence of scattering more light is absorbed by the chlorophyll and other pigments in the leaf leading to the low reflectance in the .400 - .500 μ region and in the .650 - .700 μ region.

Lack of chlorophyll causes reflectance in the 500 - 700 nm region to increase markedly as can be seen in the graph for the 20/9/80 for the cut *B. grandis* branch of Specimen 3.

The position of the edge at 700 nm may be a good indication of the amount of chlorophyll in the leaf. As the leaf matures, and increases in chlorophyll content the edge moves towards the right according to Gates et al. (1965).

The near-infrared reflectance behaviour of the mature leaf is less easy to understand. The reflectance in this region is probably a function of the cell shape as well as the intercellular spaces. Young leaves which are quite compact with few air spaces have lower reflectance than older leaves which are more spongy and have many air spaces (Gausman H.W. 1973). Due to the effect of maturity Gausman (1973) found that if leaf maturation was not considered, stressed leaves had higher reflectance than non-stressed leaves, whereas if leaf maturation was considered, stressed leaves had lower reflectance than non-stressed leaves.

Gausman (1973) also found that diseased leaves had higher infrared reflectance than normal leaves. Dehydration would cause collapse of the tissue which would lead to an increase in the number of air voids and consequently a higher infrared reflectance. The contribution of subcellular particles in leaves to the reflectance of infrared light is small compared to the reflectance caused by the cell wall-air interfaces.

Discolourous leaves such as those of *Banksia grandis* are known to have differentially reflecting surfaces. The upper surface is reasonably glossy and smooth and a bright green colour. The under surface is rough with many hairs and depressions where the stomata are between the veins. Yates (1980) found that a glossy leaf had less reflectance than a dull leaf and that for both leaves, the under surface had higher reflectance than the upper surface.

Yates (1980) quoting Shalgin and Khazanov 1961, states that they found dull leaves (typical diffusing leaves) to reflect equal amounts of light from the surface as from the internal structures at normal incidents. Glossy leaves on the other hand reflect more light from the surface than from the internal structures particularly at more oblique angles of incidence. Yates (1980) does not specify the wavelengths he was working with.

Wooley (1971) found that the lower surface (dull) of a leaf had higher reflectance in the visible than the upper (glossy surface) but the converse occurred for the near infrared light. The epidermal layers may play an important part in the reflectance properties of the leaves.

The lower epidermis not being attached as closely to the mesophyll as the upper epidermis allows for reflection and refraction from both the external and internal faces of the cells. The upper epidermis permits more light to pass into the mesophyll of the leaf. It is not stated specifically if this is the case for both visible and near infrared light.

These reflectance characteristics we would expect from mature *B. grandis* leaves since it has a glossy upper surface and a dull lower surface.

VEGETATION CANOPY REFLECTANCE:-

Colwell J.E. (1974) has given a good resumé of the properties of plant canopies which affect reflectance.

Vegetation targets are mixtures of different components viz., leaves, stems, bark, soil and shadow and background. The projected area of each component illuminated depends on zenith angle, look angle and azimuth.

In the present study the look angle was kept constant, so the important factors remaining are zenith angle and azimuth, both of which are changing throughout the observation period. Both of these have influences on the reflectance depending on the wavelength, considered.

The bidirectional spectral reflectance measurements can be helpful in predicting the optimum conditions (solar zenith angle, look angle and azimuth and hence time of year) for collecting aerial data. However, improperly interpreted these measurements can be very misleading.

As well as the individual leaf characteristics already considered, the factors of the canopy must also be considered. The factors include the amount and arrangement of leaves, the characteristics of stems, branches, flowers and fruit and the characteristics of the background and the various angles of importance.

The correlation between these factors may be difficult to establish, since they may be positively correlated in one situation and negatively correlated in another, especially depending on look angle in relation to the sun.

PERCENT VEGETATION COVER:-

Colwell (1974) discussed the relationship between the hemisperical reflectance of leaves and the bidirectional reflectance of canopies. He states that some investigations have found that the hemispherical reflectance of leaves under stress decreases in the near infrared spectral region and increases in the red. (Note that this contradicts Gausman quoted earlier.) This change in leaf hemispherical reflectance may cause a corresponding change in canopy bidirectional reflectance but a decrease in the bidirectional reflectance of the canopy may not necessarily be accompanied by a corresponding decrease in leaf reflectance.

This appears to be a contradiction in saying that a decrease in canopy reflectance due to stress does not of necessity mean a change in the individual leaf reflectance although it would seem that it is the overall effect of the change in all the leaves that produces the change in the canopy??

Colwell (1973) showed by analytical modelling as well as by empirical measurements that a decrease in the leaf area index (L.A.I.) can cause canopy relfectance to decrease in the near infrared and increase in the red without any change occurring in the hemispherical reflectance of individual leaves.

Reflectance measurements are being correlated with L.A.I. and biomass by many authors. As biomass and L.A.I. decrease so does reflectance in the near infrared. This is acceptable since it is the change in total vegetation present that is causing the reduction in reflectance. Subtle changes may be occurring in the leaves but these changes are having little influence on canopy reflectance. This could well be the case with the canopy reflectance of *B. grandis* since it appears that little change occurs in the structure, biomass and L.A.I. of the plant even though changes must be occurring in the leaves. It may be that a change in near infrared reflectance would not be observed until an advanced stage of leaf fall had occurred??

The dependence of reflectance in the red region was found to be dependent on percent cover depending on the solar zenith angle.

At a solar zenith angle below 50^{0}, the ref reflectance was dependent on percent cover below 65%. At a 10^{o} solar zenith angle however, the red reflectance was sensitive to a change in percent cover below 81%. So red canopy reflectance becomes insensitive to changes in percent cover at increasingly lower values of percent cover as the look angle deviates from 0^{o} (the zenith). Near infrared reflectance is much more sensitive to percent cover due to the multiple scattering effect of the canopy.

BACKGROUND AND SHADOW:-

Background reflectance may be quite important in affecting canopy reflectance, especially at low values of percent vegetation cover where the soil or grassy background can be seen through the canopy. Soil colour had a marked effect on the reflectance of green and red light. Near infrared reflectance however is more correlated with the percent canopy and hence is less affected by background. Usually there is a positive correlation between percent cover and near infrared reflectance, however, there may be a negative correlation if the increase in vegetation cover is accompanied by an increase in shadow.

In this study, very little background was seen through the live canopy of Specimen 3, due to the oblique angle of look. More background was seen through the canopy of the cut branch as it was closer to the ground and had more gaps due to the more perpendicular angle of view to the canopy.

The amount of shadow in a vegetation canopy is very important in affecting reflectance. There is obvious correlation between amount of shadow and the various angles associated with the observation geometry.

Colwell (1974) states that a grass canopy smoothed out with the hand had a bidirectional reflectance in the red 50% higher than before smoothing, most probably due to the great reduction in shadow.

In the present study this may aid in explaining the increase in the near infrared reflectance from noon to afternoon. In this time the sun has moved through its zenith to a large angle. Possibly the amount of shadow as observed from the platform decreased sufficiently to explain this increase.

The relative shadow darkness is different for different spectral bands. This occurs because of the different amount of light reflected or transmitted in the different bands. As well as the light transmitted and reflected from leaf to leaf, irradiance from the sky will also alter the relative darkness of shadows with more of a contribution from the shortwave regions.

Colwell (1974) also points out the relationship between leaf hemispherical transmittance and canopy bidirectional reflectance. Hemispherical reflectance is negatively correlated with hemispherical transmittance in the near infrared region. He states that changes in the near infrared leaf reflectance and transmittance are partially compensating factors in the effects on vegetation canopy reflectance.

A decrease in the reflectance of the individual components of the canopy leads to an increase in the diffuse flux of radiation within the canopy and vice versa - thus a change in the near infrared hemispherical reflectance of the leaves may not lead to a significant change in canopy reflectance if there is no concommitant change in the canopy structure or leaf area index.

ANGULAR VARIATION IN BIDIRECTIONAL REFLECTANCE:-

The angular variation is dependent on the structure of the canopy. Canopies with many vertical components have significant variations in reflectance as a function of the look angle and solar zenith angle.

Canopies with many horizontal components have been found not to have marked angular variations. Also those with a high percentage cover have less angular dependence than those with low percentage cover.

BIOMASS AND LEAF WATER CONTENT:-

Tucker C.J. (1977) used regression analysis to correlate leaf water content and biomass variables with reflectance. His findings indicated that leaf water content was well correlated with reflectance in the 450 - 500 nm and 630 - 690 nm regions of the spectrum. He states that his leaf water content parameter is an indication of photosynthetically active vegetation. As there is little dead material present in the canopy of a Banksia tree, this relationship may be a good one to pursue in the present study. The importance of leaf water content on the interaction of light with a canopy has been discussed by many authors. It appears that leaf water content may have possible correlation with reflectance in the visible regions just mentioned. It certainly has good correlation beyond 1100 nm to 2500 nm in the water absorption bands. Also the 750 nm and 900 - 950 nm region are areas worthy of close scrutinization.

The amount of biomass is an important factor in these studies but is less easy to determine than leaf water content.

Knipling (1970) indicated that the predominant factor in stress detection and thus the distinction between healthy and unhealthy vegetation is differences in leaf area and foliage density which may arise from a direct loss of foliage or suppression of growth. As pointed out earlier, due to the nature of cell types in the leaves of *B. grandis* these apparent changes which exhibit themselves readily in other plants, may have no expression in *B. grandis* canopies for a good while after stress is initiated.

Knipling also concluded that some relationship probably exists between leaf water content and reflectance although he found that water loss had an insignificant effect on the reflectance properties as measured with a spectrophotometer.

Gausman et al. (1978) looked at the reflectance of cotton plants stressed with nematode infection. He found that stressed plants had lower reflectance over the whole range from 500 to 2500 nm than non stressed plants. The factors causing this were darker green foliage, smaller leaves with more compact internal structure and more succulent (i.e. greater water content) foliage. In his study the whole canopy reflectance correlated well with individual leaf reflectance.

Cantaloupe which was damaged with ozone on the other hand did not show significant differences in the reflectance over the visible range until severe damage had been caused. In the near infrared, no significant difference occurred between healthy or treated plants. In the infrared between 1450 and 2200 nm significant differences did occur between all treatments due to the reduction of water content in the leaves.

Press N.P. (1974) worked on the detection of toxic effects of metals on vegetation by remote sensing. His studies showed that the effect of the toxic metals was to cause chlorosis which increased the visible reflectance above 550 nm, affecting the health of the plant causing a reduction in leaf area index thus reducing the near infrared reflectance.

EFFECTS OF VIEWING ANGLE AND AZIMUTH:-

Emori and Yasuda (1978) looked at the effect of viewing angle on reflectance as part of their study on rice. The pattern and magnitude of change in the various wavelengths considered is fairly similar for all the wavelengths. Mostly, as the viewing angle is changed away from the zenith the reflectance increased slightly. So there was no great distinction between the different wavelengths.

Boehnel H.J.(1978) however demonstrated with a wheat field that marked differences occurred due to the angle of observation between the infrared, red and green wavelengths. The smallest variation occurred in the infrared and the largest occurred in the red with green somewhere in between. The highest reflectance values in the visible were observed for angles of observation which correspond to the incident sun's radiation. This is probably due to the drastic reduction in the shadowed parts within the field of view.

He showed that the dependence of reflectance on azimuth was large for the red region at 675 nm and small for the infrared region with observation directions looking more or less with the sun. Observations made looking into the sun produced smaller differences between the three regions considered.

It would appear from this that to reduce the dependence of reflectance on azimuth, it is best to look into the sun.

Vickery et al. (1980) considered the effect of zenith angle on reflectance measurements using a radiometer which employed the four Landsat MSS bands. The reflectance of all four bands declined linearly with increasing zenith angle. The magnitude of the zenith angle effect was generally small, being largest (9.8% change in reflectance for a 20^{o} change in angle) in the blue region and smallest (4.1% for a 20^{o} change in angle) in the near infrared. These observations comply with the general principles associated with the scattering properties of the atmosphere.

In the present study the effect of zenith angle will not be determined unless a moving platform can be employed. The effect of changing zenith angle and changing look angle however may be assessed and should be assessed.

CORRELATION BETWEEN SPECTRO-RADIOMETRIC MEASUREMENTS AND AERIAL PHOTOGRAPHY:-

The spectroradiometric measurements allow for the evaluation of reflectance for particular wavelengths over very narrow wavelength bands. Thus differences in the reflectance values due to varying conditions can be seen readily and identified as occurring in specific regions of the spectrum. These regions may be used in the detection of the conditions which bring about the differences. So the advantage of this type of instrument lies in the amount of detail which can be obtained with it.

Imaging systems such as aerial photographs on the other hand provide only an image which is the integration of the amount of light over all wavelengths sensed by the particular system. These imaging systems can and usually operate over a wide range of wavelengths thus losing detail in particular regions of interest. Their advantage lies in their ease of employment and adaptation to particular circumstances.

Interpretation of the results of both systems is quite difficult however depending on the combination of factors as discussed in the above sections. Use of the spectroradiometer can be made in interpreting the photographs and hence make the images on the photographs more sensible. The spectroradiometer is also a useful tool in determining the best situation for taking photographs so that the greatest amount of detail can be captured.

Both systems therefore have useful application to the study of plant reflectance, be it for species discrimination, stress detection, biomass determination or whatever.

It has been pointed out by Knipling (1970) that when differences in the reflectance properties of individual leaves develop, the changes in the visible reflectance often occur as soon as and are as sensitive indicators of physiological stress as changes in the near infrared. This view is supported by reports that photo interpreters find many incipient reflective differences of vegetation apparent on conventional colour as well as on colour infrared photography. Even when the colour differences appear earlier or more prominently on the latter type of imagery. These differences can be attributed to the ability of the colour infrared emulsion to discriminate more distinctly between foliage and background surfaces and to amplify the tonal rendition of visible spectral changes rather than the changes in the infrared reflectivity of the individual leaves alone.

These changes as depicted on infrared photography should be recognizable changes in the reflectance factor as obtained by a spectroradiometer. However the correlation between the two imaging systems is not easy.

Duggin et al. working on pastures found that when related to real conditions on the ground, the colour infrared photographs gave useful qualitative estimates of pasture condition, including insect damage. However, the relation between this imagery and the ground truth has been variable. The reflectance factor for a vegetative canopy is angle dependent, which explains much of the variation in the relationship between information contained in the oblique images and the ground truth. In his study no dependence of reflectance factor on zenith angle was found for the landsat MSS channels 5, 6 and 7, but the effect on MSS band 4 could cause a 9% error in reflectance factor for two pastures measured late in the day.

The correlation between the reflectance factors of the ground viewed vertically and the film emulsion density was dependent on azimuth, zenith angle of look, solar zenith and bandpass.

Under certain conditions, the information contained on images obtained by oblique photography will be very weakly related to the reflectance properties of the pasture as viewed from above. The significant regression relationships between the oblique photographs and reflectance occurred for:-

a) the green sensitive emulsion for azimuths close to the solar plane, but not at right angles to it

b) the red sensitive emulsion at all azimuths

c) the infrared sensitive emulsion at right angles to the solar plane. This last one was the weakest regression.

All these relationships decreased with an increase in solar zenith angle.

Obviously a) and c) cannot be satisfied at the same time so some compromise has to be found.

It is this compromise that the study will hopefully attain.

Press N.P. (1974) also attempted to correlate photography with spectroradiometric measurements in his work on the toxic effects of metals on vegetation as described earlier. The sorts of reflectance changes noted in the stury could be picked up by the spectroradiometer, but were not so conclusive in photography. The spectroradiometer has advantages, he says, in that it extends the range of the photography further into the infrared to where more information on the moisture content of the vegetation may be obtained. He concluded that no one sensor is capable of solving the detection problem and repetitive remote sensing to monitor seasonal changes is a necessity in most cases.

Hogg et al. (1975) attempted to use colour infrared photography to detect dieback disease in Eucalypt forest in the Brisbane Ranges, Victoria. They noted that although discolouration was observed in the disease affected trees at ground level, the discolouration was not detected on colour infrared photography and no consistent differences in colour were observed between normal and disease affected trees. These results were obtained for one flight at one time of the year and the need for more detail on seasonal changes is required.

Other workers in America (Williams and Leaphart 1978, U.S.D.A. Forest Service 1973) have used aerial photography to detect and estimate the centres of root diseases in forests. Their interpretation relies on obvious visible symptoms such as openings in the canopy, dead trees, wind thrown trees etc. as the sign of the presence of the disease rather than the incipient changes in reflectance that may occur before visible symptoms show.

It would appear therefore that not enough work has been done in correlating the radiometric data with aerial photographs. Obvious anomalies have occurred in previous studies which have prohibited good correlation between the different imaging systems.

In this study, photographs are obtained during the period of reflectance measurements on sample trees. The photos are taken at the same distance and angle of observation as the radiometric data so correlation may be possible between these systems.

Infrared photography has not proved itself in previous studies as a detection system for incipient disease damage.

CONCLUSION

The study carried out to date has not progressed very far into resolving the problems associated with the factors influencing spectral signatures of plants.

Questions arise also as to whether the spectroradiometer is performing correctly. It appears as though the readings are acceptable as far into the near infrared as 850 nm. Above this range the pattern is confused and very high reflectance values are obtained.

As stated earlier, the only real variables affecting the measurements are the zenith angle of the sun and the azimuth angle, neither of which should contribute the amount of variation as observed in the reflectance patterns.

Other errors are introduced into the readings by various aspects of the measuring process.

These include:-

1) Scan time. It takes approximately ten minutes to do a single scan with one detector on one sample. During this time the sun zenith angle and the azimuth have both changed slightly. Whether these changes are significant or not will be difficult to resolve. The important difference is the effect on the standard reflectance. If this is changing significantly during a set of readings then large errors will be being introduced. This requires more thorough investigation.

2) At this scan rate readings are only taken every 25 nm. Ideally readings should be obtained for closer intervals. This is difficult to achieve though as more readings would mean a longer period for each scan allowing for greater changes to occur. This problem should sort itself out once the regions of particular interest in the reflectance pattern show themselves. More detailed readings would then be taken in these regions.

3) Errors are introduced into the readings by the wind, which is usually blowing, making it difficult to pick accurately the actual energy level. While the wind blows it increases the time for each scan thus possibly compounding those errors and inaccuracies. Again it is not clear whether the changes due to wind are really significant or if the inaccuracies are within acceptable limits. It is suspected that these changes would be within reasonable limits.

4) Comparisons are being made between different specimens being considered from different angles in order to evaluate the best angle of observation.

Realising now that biomass and percent ground cover are significant factors of the reflectance of a plant it is queried whether in fact the look angle can be evaluated successfully using different plants. The changes due to varying distance, change in background, ammount of shadow and change in zenith angle of observation will all influence the readings obtained. The variations in the reflectance for the different specimens will therefore be due to a combination of these factors and not just the change in look angle.

5) To have full confidence in the readings, it has been pointed out to the author that an average of many readings should be taken. This is because the variation due to noise diminishes as the square of the number of readings. It is impossible to take many readings without the configuration of the experiment changing even over a short period of time.

Should, therefore, the readings taken for the same time over several days be averaged to give the final accepted result? This question is difficult to resolve in the light of the present experiment in which a branch is severed from the tree and the scans taken over a number of days following cutting. The branch and so possibly the reflectance starts changing characteristics as soon as the branch is cut. Therefore it is not practical to average the scans of a few days for this situation.

6) Readings have not been continuous enough due to the interruption of wet weather and cloudy conditions to come to good conclusions on the reflectance expected for this species.

Taking readings under cloud due to the time taken for each scan is introducing further errors than those already mentioned. Fluctuations in intensity even under diffuse cloud are noticeable. Scattered cloud causes increases in scan times if the clouds are passing through the sunlight.

7) Another error of significance is that caused by the internal noise of the photometer. This is particularly so in the case of the infrared photomultiplier tube which requires a high voltage to give it the sensitivity required to pick up the low amounts of energy in the infrared. The higher the voltage on the photomultiplier the greater the noise in the ensuing signal. Although the noise can be suppressed easily on the machine it is not suppressed for each and every reading taken. The noise appears to increase sometimes the longer it is left unsuppressed and so can introduce large errors into the readings - as much as 50% for low intensity levels. Sometimes this noise is not as great an influence on the signal as others. It is not understood why this should be so. It is clear that the noise must be kept as low as possible so that the errors introduced by it are only small.

Determining the spectral signature of *Banksia grandis* with the spectroradiometer, although straight forward in theory is complicated by the necessity to ascribe variations in the reflectance pattern to the associated conditions of the biological system under observation and of the physical system accompanying the experimental set up.

PROPOSED WORK OUTLINE

1) Measurements and photographs of the five *B. grandis* around the platform shall be taken on an ongoing basis. The length of time required will depend on the weather.

2) Leaf specimens have been collected for morphological analysis. To date they have been in the process of embedding in resin. This process takes approximately two weeks or longer due to the time required for the resin to penetrate the leaf sections. Micrographs will be taken of these leaf sections.

3) Photographic interpretation must be enhanced by the use of the densitometer to check for changes in photographic density which are not visibly apparent. Use of the densitometer must be learnt.

4) Potted stock at present in the biology glasshouse shall be innoculated with *P. cinamomi* and observed as they are infected. Prior to this though they shall be observed over a couple of weeks to determine their spectral signatures. At present new growth is being put on these seedlings and so the spectral reflectance would be dynamic of the moment. These scans will be carried out in the open in full sunlight.

5) Appraisal of the transmittance of individual leaves shall be considered to determine their bidirectional reflectance characteristics to see how these reflectances correspond with the reflectance of the whole plant.

6) More detailed analysis on the effect of the plant canopy on light needs to be carried out. This action should include the measurements of reflectance as being obtained at present, measurement of light penetrating the canopy and measurement of diffuse light within the crown if this is possible.

7) Determining the leaf area index of individual canopies may also benefit analysis of the spectral signatures.

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DO'C:KMP

23 March 1981

Dr M Mulcahy
Department of Conservation and Environment
1 Mount Street
PERTH 6000

Dear Dr Mulcahy

I enclose a progress report on the work achieved to date on our study of remote sensing applied to Jarrah Dieback. The report describes work carried out during the first year, and should not be regarded as suitable for publication.

Sincerely yours

Desmond O'Connor

Desmond C O'Connor
Foundation Professor of Environmental Studies

Encl:

Coralie
Please remove graphs & copy for each member of TAG Dieback

Copies To C'ttee - 2/3/81 - c