INSTITUTE of
HYDROLOGY

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Hydrological Impacts of Hardwood Plantation on Lowland Britain

INSTITUTE OF HYDROLOGY REPORT
TO THE
DEPARTMENT OF THE ENVIRONMENT

Report No.1

June 1989

1. Background

It is expected that there will be an increase in hardwood plantations in the next decade as a response to pressure to reduce agricultural surpluses. Work by the Institute of Hydrology in the north and west of the UK has shown that coniferous afforestation can lead to large decreases in water yield and substantial changes in the runoff chemistry. While it is likely that the water use from deciduous trees is larger than agricultural crops and the scavenging of pollutants is greater, very little is known about these processes. It should also be borne in mind that whereas in upland Britain the difference between rainfall and evaporation is large in lowland Britain this difference is small. Consequently the water available for river flow and aquifer recharge is very sensitive to small changes in evaporation.

The future nature of plantation in Britain will be deciduous hardwoods in small blocks scattered in a mosaic over the countryside. This poses a number of scientific questions: firstly edge effects may be important, leading to an enhancement of the evaporation from and the transfer of atmospheric pollutants to the canopy. Secondly the evaporation from the ground vegetation will be higher than in a coniferous forest, especially in the spring. Thirdly in lowland Britain the trees are likely to be water stressed in the summer months.

The project 'The Hydrological Impacts of Hardwood Plantation in Lowland Britain' was started in 1988 to address the problems outlined above. The project's specific objectives are:

a) to assess the hydrological effects of small-scale hardwood plantations in lowland Britain by studying the evaporative processes (interception and transpiration).

b) to assess the hydrochemical effects both temporally and spatially by determining the chemistry associated with rainfall, throughfall and stemflow.

The main products of the research will be : 1) to provide a proven hydrological model to calculate the effects of afforestation in all regions of lowland Britain; 2) to provide new information on the hydrochemistry of deciduous plantation especially chemical gradients arising from edge effects.

2. Review of Previous Work

A national symposium "Hydrological impacts of hardwood plantation on lowland Britain" was organised and held at the Institute of Hydrology on 16 September 1988. This provided a forum for people from different disciplines and organisations to consider the likely form new plantation would take and the possible hydrological consequences. It was thought that the majority of new plantations would be small (1-5 ha) and of ash, sycamore, sweet chestnut and some cherry. But also a significant amount of naturally regenerated mixed woodland would develop on fallow land.

The results of a literature review on the water use of hardwood trees was presented the main points of which were:

a) There have been very few studies of any sort on the tree species likely to be planted viz. ash, sycamore. There are no reports on the effect of plantation size on relative water use of hardwood plantation.

b) The majority of interception studies of hardwoods so far have produced either an annual interception loss or a regression relationship between interception loss and rainfall.

c) Annual interception losses from deciduous hardwoods are less than from conifers but there is very large scatter between species and rainfall regimes (see Fig. 1).

d) Evaporation from ground vegetation can be a significant fraction of the total evaporation.

e) To be able to predict interception loss and total water use for different locations it is necessary to make process measurements, the results of which can be incorporated into mathematical models.

f) Several models have been applied with varying degrees of success. Generally given good measurements, of the appropriate parameters interception can be well modelled on the annual time scale.

g) On an annual basis transpiration from European forests seems to be a conservative process having a mean value of 325 +/- 18 mm (n=8). The average for temperate broadleaf stands outside of Europe is 439 +/- 90 mm (n=7) while the mean of two tropical studies is 958 +/- 101 mm.

h) There is a wide range of values of maximum stomatal conductance measured on individual leaves ranging from values as low as 1.3 mm s^{-1} (*Acer platanoides*) to above 10 mm s^{-1} in *Quercus robur* and *Populus* species. The range in leaf area index (LAI) of forests is from 2.0 in a stand of *Quercus robur* to values exceeding 8 in both a *Quercus petraea* stand and a southern beech forest in New Zealand. With such a wide variation particularly in the levels of maximum stomatal conductance the reasons for the conservative nature of annual transpiration should be sought. One clear possibility is the action of compensating factors within and between parameters which control transpiration. For example, it is now well documented that when maximum stomatal conductance of a species is high the rate of decline of the conductance in response to a controlling environmental variable is greater than in a species with a lower maximum conductance (Fig. 2).

The work on throughfall and stemflow chemistry in broadleaved woodlands has also been reviewed. Data for edge effects on chemistry are scarce and the available data are for relatively unpolluted sites.

ANNUAL INTERCEPTION LOSS OF MAINLY EUROPEAN DECIDUOUS TREES.

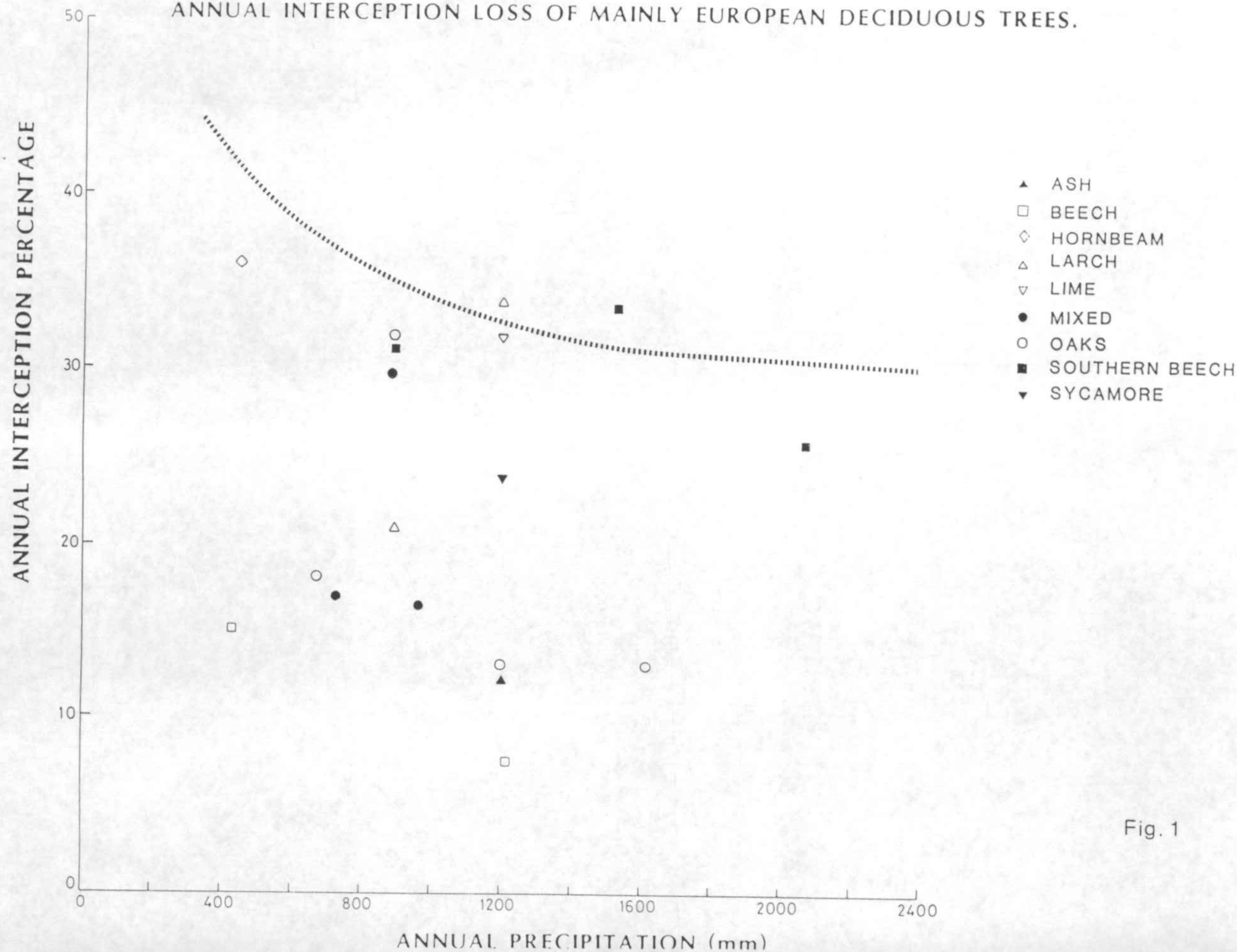

Fig. 1

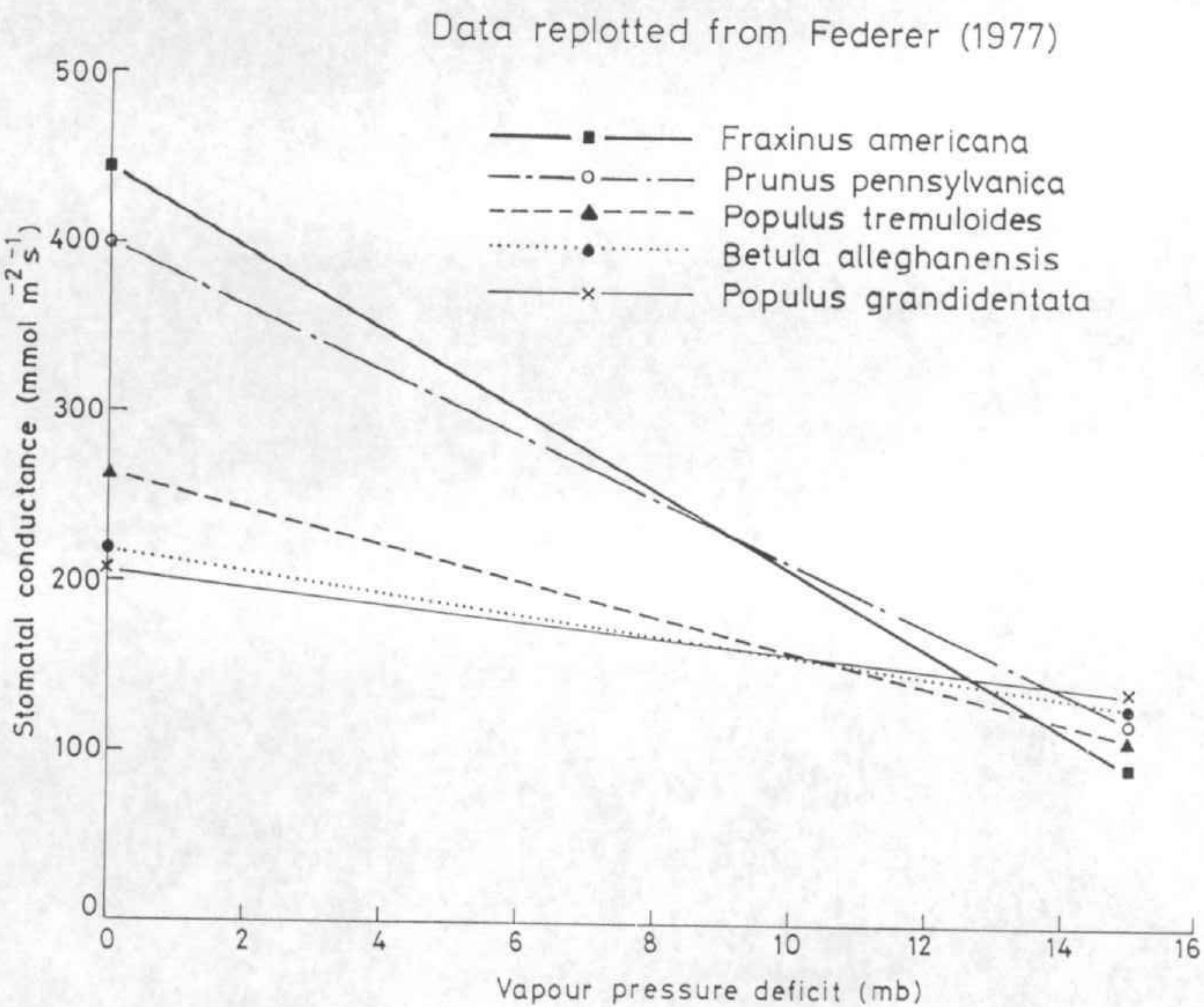
Data replotted from Federer (1977)
Fraxinus americana
Prunus pennsylvanica
Populus tremuloides
Betula alleghanensis
Populus grandidentata
Stomatal conductance (mmol m-2 s-1)
500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
Vapour pressure deficit (mb)

Fig. 2

There is some general information: throughfall and stemflow of native broadleaved trees are generally enriched with Ca, Mg and K (Cape & Lightowler 1988), although birch trees adsorb Ca in the summer months (Alcock & Morton 1985). On an annual basis, broadleaves (birch, oak, alder) remove nitrate and ammonium ions from rain as it passes through the canopy; increase deposition of sulphate and free hydrogen ions relative to rainfall and tend to show anion deficits below the canopy. There is insufficient data on the the leaching of inorganic ions such as chloride and sulphate from the forest canopy.

Large changes in throughfall composition have been found with distance from the forest edge into the closed canopy (Grennfelt & Hultberg 1986) and this has been attributed to differences in branch form, stem spacing etc. Solute input to the forest floor in stemflow may be 50% of the throughfall input (Cape et al. 1987). The input from this source is significant and may also vary with distance into the forest.

3. Site Selection

To ensure that experimental sites would, as far as possible, be representative of future hardwood plantation and allow the dominant effects on the hydrological processes to be measured the following criteria were used in choosing sites:

1. The sites must be situated in flat topography to make possible the accurate measurement of rainfall and micrometeorological variables.

2. The sites should be within a two hour's drive of the Institute of Hydrology at Wallingford to allow frequent visits to ensure that the data collected are of high quality.

3. One site should be within a small plantation of less than 5 ha and a second within a larger plantation of at least 15 ha to allow edge effects to be studied.

4. At least one site should be over a shallow water table and one over a deep water table to allow the effect of water tables on transpiration rates to be studied.

5. Following discussions with various forestry interests (public and private) and the Symposium in September it was decided that the species most likely for increased plantation would be ash, sycamore, sweet chestnut and some cherry. Therefore the sites for measurements should be within plantations of these species. To simplify interpretation of the results, especially of the chemical studies, the stands should be as pure as possible.

In searching for sites several sources of information were used both within and outside the forestry industry. The Forestry Commission were especially helpful and provided a list of all their hardwood plantations within an 80 km radius of Wallingford. Despite this, finding suitable sites proved to be more difficult than expected. In particular no isolated pure (> 80%) plantations of the species listed in criterion 5 were found within a reasonable distance of Wallingford (see 2 above).

However two good compromise sites were found. One is at Potton wood, east of Bedford, where old ash coppice is mixed with occasional oak standards and hazel understorey. The site is flat, secure and overlies a shallow water table. The other site is within Blackwood between Basingstoke and Winchester (Nat. grid ref. SU534428) and closer to Wallingford than Potton.

Blackwood is a large Forestry Commission wood of primarily beech but with a small plantation of ash, with occasional birch, in the centre. This was chosen as the first site for intensive instrumentation and installation work is now well advanced as described below. Although it will not allow measurements of the edge effect in ash such measurements within the beech will be made and also comparative studies between the ash and beech will be undertaken. The site is close to Bridgets farm where water use studies of grassland were made by the Institute of Hydrology in the past. The results of that study will be available for comparison. Additionally the Blackwood site makes possible a study by British Geological Survey of the NO_3 and Cl profiles within the underlying chalk which will complement the chemical studies being done within this project.

The search for a small ash plantation on shallow water table for the second experimental site will continue. If no better candidate is found then Potton wood will be used.

4. Experimental Design

4.1 INTERCEPTION OF RAINFALL AND POLLUTANTS

The objectives of the interception studies are : (1) to understand the process of rainfall interception in beech and ash plantation, (2) to investigate the changes in rainfall and chemical pollutant interception by beech plantation with respect to the distance from the forest edge and (3) to design and validate models to predict the hydrological impacts of broadleaf plantations

Rainfall interception loss is defined as the evaporation from the wetted surfaces of the forest and is measured as the difference between the rainfall input and the net rainfall at the forest floor.

The experimental design has been tailored to meet the combined demands of volumetric accuracy and chemical hygiene, necessitating the development of new techniques and instrumentation.

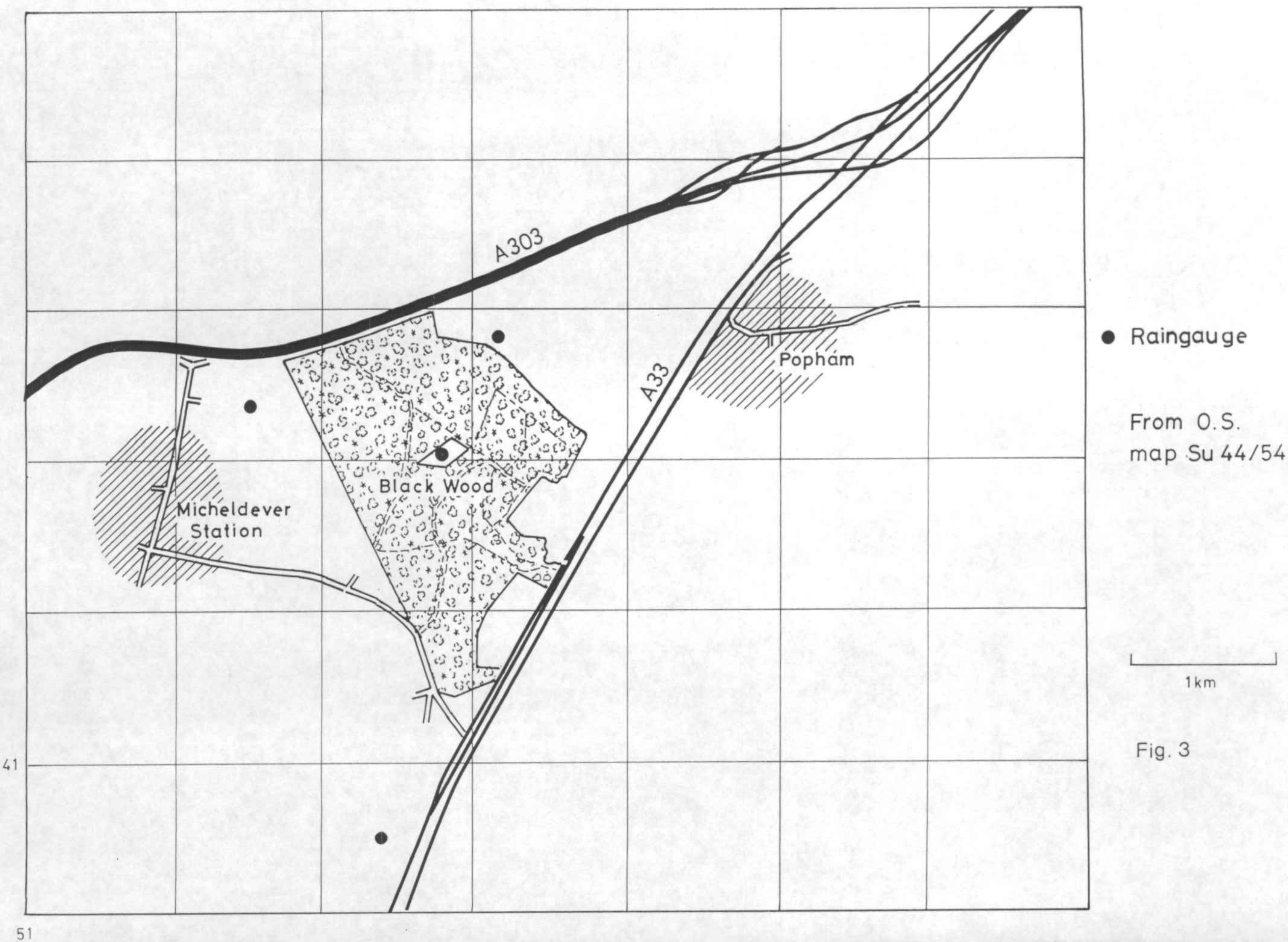
A303
A33
Popham
Black Wood
Micheldever
Station
41
51
Raingauge
From O.S.
map Su 44/54
1km

Fig. 3

Blackwood

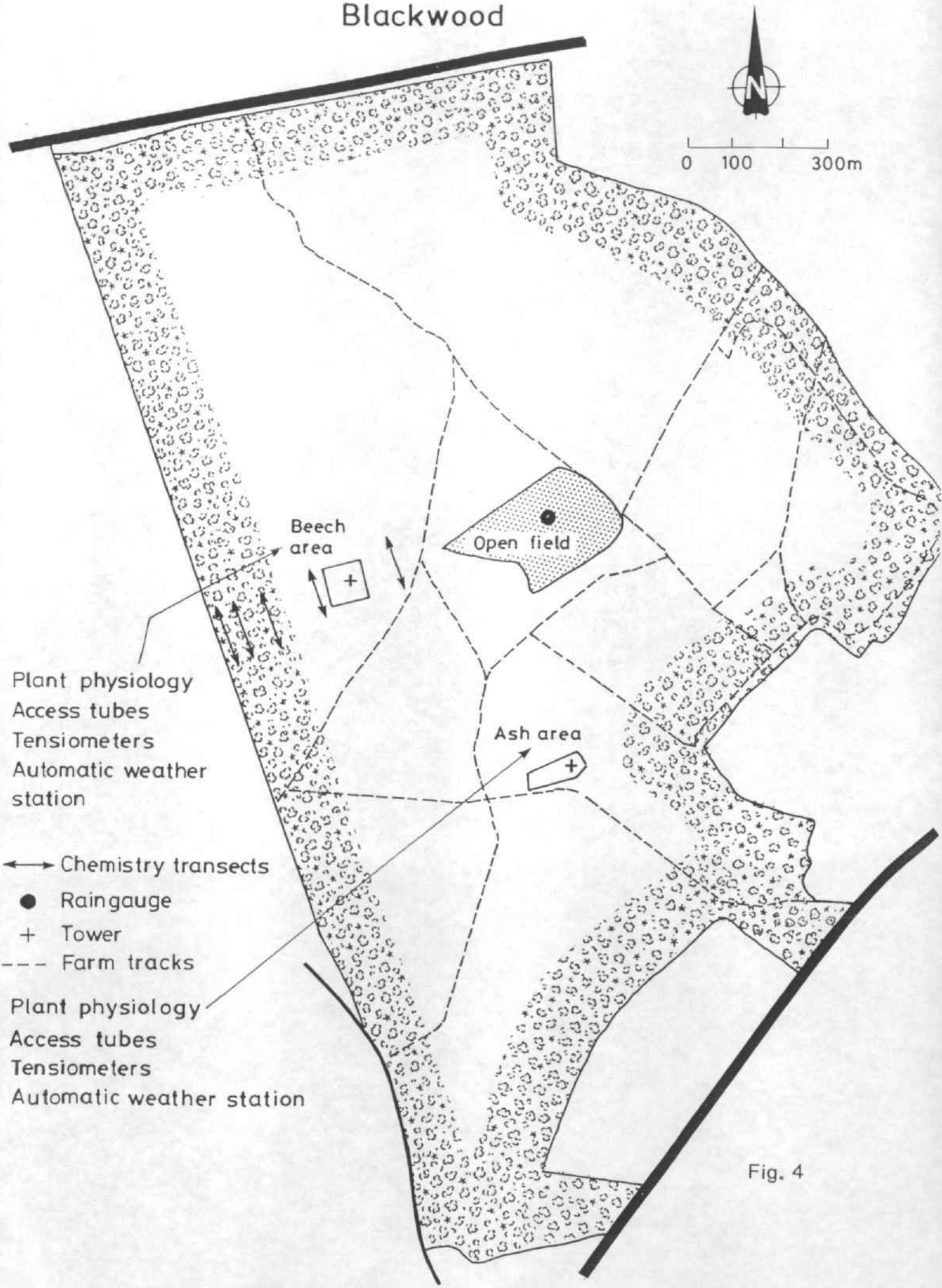

Fig. 4

Rainfall input to the forest will be estimated using a network of recording raingauges sited at ground level around the forest with an additional gauge in the large clearing within Blackwood (Fig. 3). The height of each gauge will be adjusted to keep the orifice level with the surrounding vegetation/crop. It is anticipated that these ground mounted gauges will give the most accurate rainfall catches but are likely to be chemically contaminated by crop spraying. Consequently, further gauges will mounted above the forest canopy for chemical analysis, and their volumetric performance compared with that of the ground mounted gauges.

Determination of pollutant gradients near the forest edge is difficult owing to the very variable nature of stemflow and throughfall chemistry and water fluxes. For this reason, a network of sites has been established to minimise the uncertainties (Fig. 4). In the beech plantation, net rainfall (stemflow and throughfall), is volumetrically and chemically sampled (since mid-April), within 15 selected areas, each of approximately 110 square metres. To determine any gradients of pollutants and interception loss these sites are at five distances from the edge (20, 50, 100, 200, 300 m). To provide a good spatial average net rainfall there are three sites at each distance.

At each site, weekly totals are recorded of stemflow, collected by tree collars, (4 in each plot) and throughfall collected by randomly relocated 155mm collectors (8 in each plot). The samples will be bulked to give random composition. Gas adsorption tubes will be installed in each plot for NOX, SOX and NH_4 assay.

For the detailed analysis of net rainfall from individual storms a large plastic sheet gauge (90 m^2) has been installed. The outfall from this gauge is metered by a tipping-bucket flowmeter and recorded at 5 minute intervals on the logger of the automatic weather station.

In the ash plantation net rainfall will be measured using a large plastic-sheet gauge and a single area of stemflow collars and relocated throughfall samplers.

An automatic weather station will be mounted above the canopies of both plantations on multipurpose towers. The weather stations provide measurements of energy, humidity and wind parameters necessary to estimate the evaporation rate from the forest canopy using the Penman Monteith equation (see Section 4.2.1.1.). These estimates will be compared with the measured rate of evaporation. A weather station will also be mounted above the forest near to the forest edge and on the forest floor (50 and 200 m)at the main beech site.

To date the 15 beech sites have been chosen and the construction and installation of the stemflow and throughfall gauging is complete. The towers and plastic-sheet net-rainfall gauges have been installed in both the beech and ash plantations.

Sites have been chosen for the network of raingauges and permission to use these sites has been granted. Installation will proceed as soon as the gauges are delivered to IH.

4.2 PLANT PHYSIOLOGY

4.2.1 Plant physiological studies to be carried out at broadleaf sites in lowland Britain.

Physiological studies will be carried out in both an ash and beech stand in Blackwood forest. There are four main objectives in the physiology programme.

4.2.1.1. Use of physiological methods to determine transpiration from the forest stands.

This method is independent from the other methods proposed within the whole project namely from (i) soil moisture abstraction data obtained with the neutron probe (see section 4.3) and (ii) from the deuterium tracing method (see Section 4.2.2). The data requirements to calculate transpiration from physiology data are those determined by the Monteith version of the Penman formula which will be employed for calculation of transpiration.

$$E_t = \frac{sA + c_p \rho D g_a}{\lambda(s + c_p/\lambda(1 + g_a/g_c)}$$

Where A = the available radiative energy above the forest canopy
c_p = specific heat of air at constant pressure
E_t = transpiration rate
g_a = aerodynamic conductance
g_c = canopy conductance
D = specific humidity deficit
s = rate of change of saturated specific humidity with temperature
λ = latent heat of evaporation of water and
ρ = density of air

The canopy conductance (g_c) will be calculated from stomatal conductance (g_s) and leaf area index (LAI) using the formula

$$g_c = \sum_i (g^u{}_{si} + g^l{}_{di})L_i$$

Where LAI (L_i) is the leaf area index for a particular canopy level. $g^l{}_{si}$ and $g^u{}_{si}$ are the stomatal conductances of the lower and upper leaf surfaces respectively. Stomatal conductance and leaf area index will be measured in three canopy layers in each forest stand.

Aerodynamic conductance g_a is determined from wetted replicas of ash and beech leaves made from blotting paper whose weight loss is determined at intervals while the wet surface temperature and the absolute humidity of the air above is known. g_a is calculated from the following expression

$$g_a = E/(x' - x)$$

where E is the water loss rate, x' is the absolute humidity of air saturated at leaf temperature and x is the absolute humidity of the ambient air.

It will be necessary to make determinations of the canopy and aerodynamic conductance on sample days throughout the vegetative period of the forest canopy. Ideally up to 20 sample days for each of the tree species would be necessary. Canopy conductance will be related to ambient weather variables determined with an automatic weather station while aerodynamic conductance will be related to windspeed. A model of canopy conductance in relation to weather will be formulated and this used to calculate transpiration over the period of the experiment from the record of the automatic weather station.

Similar studies will be undertaken in the understory layer (a vigorous growth of *Mercurialis perennis*, Dog's mercury) which occurs in the ash stand and evaporation losses from the litter layer will also be quantified.

4.2.1.2 Plant-water relations studies.

Studies will also be made of the plant-water relations during the leafy period in both the beech and the ash stand. These data on plant-water relations will link the behaviour of stomata to changing soil water conditions throughout the growing season. Measurements will be made of plant water potential and its components: osmotic and turgor potential on the same days as stomatal conductances are sampled.

4.2.1.3 Leaf litter area, litter dynamics, above-ground and below-ground biomass.

The main objective of this work is to validate the leaf area indices determined from destructive sampling by measuring the area of leaf litter collected. Measurements will also be made of dry weight of above and below ground fractions of the trees in each stand. There would be great value in understanding the rates and patterns of nutrient movements within the trees and litter in the two forest stands but staff commitments and allocations to the project do not allow this at present. One approach to overcome this shortcoming would be to formulate a research programme suitable for a postgraduate student to follow as part-fulfilment of a higher degree.

4.2.1.4 Related studies at IH to investigate species differences and tree age effects.

In addition to the studies directly funded by DOE some related work is proceeding funded from NERC science budget funds. One of these is a project for a sandwich course student from Coventry Polytechnic, in which the stomatal conductances and leaf water relations of some broadleaf species will be examined at the IH site at Wallingford. The species chosen will be as far as possible those of relevance to the DOE project and although the trees will be parkland individuals it is likely that an interesting insight may well be gained particularly on the influence of tree age on the magnitude of stomatal conductance in different species and how conductance responds to weather variables in different species/age combinations.

4.2.2 Validation of deuterium tracing method for transpiration estimation.

One of the techniques for measuring transpiration in the broadleaf plantations under study in this project involves injection of deuterium as a tracer into trees. Transpiration is calculated from a knowledge of the concentration of deuterium labelled water in ordinary water in water condensed in sample polythene bags placed on selected branchlets throughout the tree crowns. This approach has been undergoing further development at IH particularly for use with eucalypts in India. Some validation of this technique is still necessary and in the current year an experiment has been established in which moderately sized young trees of sycamore, ash and beech have been placed in large polythene tanks. These single tree lysimeters can be weighed continuously on a load cell system adequate to provide daily transpiration values. In rain-free periods, with adequate precautions to prevent soil evaporation from the container, any losses from the tree/container system can be directly compared with transpiration calculated from the deuterium tracing method. Progress to date has been construction of a platform system for the load cells and container and testing of the load cell system against addition and removal of known weights. The system is fully operational and experiments will begin in May or June 1989 with an ash tree initially.

4.3 SOIL MOISTURE

Two sites have been selected for the installation of access tubes and tensiometers for the measurement of soil moisture at Blackwood, one in the ash and the other in the beech. The sites marked on Figure 4 double up as litter collection areas and have dimensions of 10 x 30 m for the ash and 15 x 30 m for the beech. Ten access tube positions (for each site) were located randomly using A x 10 (1st dimension) and B x 30 (2nd dimension) for the Ash site, and A x 15 (1st dimension) and B x 30 (2nd dimension) for the Beech site (where A and B are random numbers between 0 and 1). Details of the access tube positions are given in Tables 1 and 2 in Appendix 1.

The original intention was to install 10 access tubes at each site to give a good spatial average of the soil moisture beneath each tree type. However, because of the presence of numerous flints in the soil profile this number has been reduced to five. The remaining five tubes will be installed, if necessary, after an analysis of the spatial variablity of the first five. The selection of the first five access tubes for each site was determined by the distance of the access tube position from the nearest tree. Details are given in Tables 3 and 4 in Appendix 1.

Five access tubes have already been installed in the beech site and observations on a weekly basis were started on 3rd March 1989.

A set of tensiometers has also been installed at each site, (see Figures 3a and 3b) at the following depths, 20, 40, 60, 80, 100, 120, 150, 180, 210, 240, 270 and 300 cm. These have been installed close to the position of an access tube, and a tree. Observations are made at the same time as the access tubes are read.

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Appendix 1

Table 1 Beech site.

Tube No.	A	x 15 m (1st dim)	B	x 30 m (2nd dim)
1	.815	12.22	.659	19.77
2	.325	4.87	.146	4.38
3	.611	9.16	.854	25.62
4	.231	3.46	.108	3.24
5	.999	14.98	.136	4.08
6	.765	11.47	.574	17.22
7	.638	9.57	.415	12.45
8	.821	12.31	.300	9.00
9	.377	5.65	.705	21.15
10	.877	13.15	.148	4.44

Table 2 Ash site

Tube No.	A	x 10 m (1st dim)	B	x 30 m (2nd dim
1	.877	8.77	.423	12.69
2	.567	5.67	.453	13.59
3	.984	9.84	.027	0.81
4	.450	4.50	.983	29.49
5	.449	4.49	.555	16.65
6	.327	3.27	.047	1.41
7	.984	9.84	.858	25.74
8	.815	8.15	.725	21.75
9	.032	0.32	.283	8.49
10	.889	8.89	.201	6.03

Table 3 ***Beech site.***

Tube No.	Distance from nearest tree (m)
1	5.8
2	1.6
3	5.8
4	2.0
5	2.6
6	2.4
7	4.2
8	5.2
9	3.8
10	4.4

Range distance from tree (m)	No. of Tubes in range
0.0 - 1.99	1
2.0 - 3.99	4
4.0 - 5.99	5

Tubes selected for the Beech site are 2,4,5,7 and 9.

Tube No.	Last reading depth (cm)
2	360
4	350
5	360
7	360
9	360

Table 4 Ash site.

Tube No.	Distance from nearest tree (m)
1	1.4
2	1.2
3	7.4
4	1.4
5	2.0
6	5.6
7	3.2
8	4.0
9	2.6
10	5.4

Range distance from tree (m)	No. of Tubes in range
0.0 - 1.99	3
2.0 - 3.99	3
4.0 - 5.99	3
6.0 - 7.99	1

Tubes selected for the ash site are 1, 2, 3, 6 and 9

Appendix 2

PERSONNEL AND ORGANISATIONAL STRUCTURE

1. Water use studies

Richard HARDING	Supervisor
Robin HALL	Coordinator
Cynthia LANCELOTT) John ROBERTS)	Tree Physiology
Paul ROSIER	Soil Moisture
Catriona PULLEN	Data Collection
Ivan WRIGHT	Consultant

2. Pollutant studies

Colin NEAL	Supervisor
Amanda RAMSEY	

Hydrological Impacts of Hardwood plantation on Lowland Britain: Report No. 1

Appendix 3: Progress Update

Summary

A comprehensive set of meteorological, interception (quantity and quality), soil moisture and plant physiological measurements have been made through this year's growing season.

Analysis of the meteorological observations indicate the possibility of reducing the network of weather stations; however measurements will be continued through the winter period to confirm this.

The number of interception measurements have been limited due to the very dry conditions. Therefore the rationalisation of the extensive interception network will not take place until next year.

The dry weather has provided a good opportunity to monitor the effects of extreme water stress on transpiration and a comprehensive set of plant physiological data have been collected.

Changes in soil moisture have been found at depth under the ash plantation. This may be due to continuing drainage from the unsaturated chalk or deep abstraction by the roots. Additional measurements, including a deep neutron probe access tube, gypsum block measurements and laboratory conductivity measurements are planned to quantify these effects.

Selection of a second site is continuing; preferably a small ash plantation on a non-calcareous soil. Installation should be in March and April 1990.

Data collection April – August 1989

The main report describes the experimental plan and progress up to April 1989. Data collection started during April 1989, Table A1 presents the various measurements. Where appropriate samples of this data are shown, and in some cases a few early analyses are presented.

The summer of 1989 has been exceptionally dry with higher than average temperatures and radiation totals. It has provided an excellent opportunity to study the transpiration of the forest and its response to water stress. Although this has meant that interception measurements have been limited, and so far only six rainfall events have been measured. It would be misleading to present data from the rainfall events sampled so far.

TABLE A1: MEASUREMENTS MADE AT THE BLACKWOOD SITE

Measurement	Start Date	Frequency	Start Date	Frequency
Rainfall (network)	20-07-89	1 min. during storms & storage gauges		
	beech		ash	
Interception				
stemflow & throughfall	03-05-89	storm	NA	NA
net-rainfall gauges	25-05-89 19-05-89	5 min. storm	22-06-89 19-05-89	5 min. storm
canopy-level rainfall	12-08-89	5 min.	24-08-89	5 min.
Meteorology				
above canopy	25-05-89	5 min. & hourly	22-06-89	5 min. & hourly
below canopy			08-06-89	"
Soil moisture				
neutron probe	03-03-89	weekly	14-04-89	weekly
tensiometers	03-03-89	"	03-03-89	"
Plant physiology				
stomatal conductance				
main canopy	16-05-89	fortnight	23-05-89	fortnight
understorey	NA		18-05-89	"
leaf water potential	16-05-89	"	08-06-89	"
leaf area index				
main canopy	to be done Oct. '89		to be done Oct. '89	
understorey	NA		25-05-89	

METEOROLOGY

The automatic weather stations above the beech and the ash and below the ash canopy were installed in May and June. The weather station at the edge of the beech forest was installed in September 1989.

Figures A1a to A1d show the daily totals from three weather stations, figures A2a to A2d show the diurnal patterns for a clear day in June. For the two canopy level stations the daily averages are very similar, the differences in the temperatures and radiation between the beech and the ash are within the calibration errors of the instruments. The wind speed is slightly lower over the beech. As expected the trunk space weather station shows considerably lower radiation and wind speeds and slightly lower temperatures. The data for 23 June show there are diurnal patterns to the differences between stations but more analysis is required on these to identify general trends. There is every prospect that the network of weather stations can be reduced in the future. However a full years observations need to be taken before this can be done.

These data will be used, in conjunction with the measurements of surface conductance, in a two layer model of the water use of the two tree species.

SOIL MOISTURE

Measurements of the soil water content (using the neutron scattering technique) and soil water potential (using tensiometers) were started in March and April. The tensiometers underneath the ash went off scale in early May, and in mid June under the beech. Large negative soil water potentials at low soil water deficits are to be expected in fine grained chalk. Nearby at Bridgets Farm (a chalk site) some drainage from the profile was measured even with negative potentials.

Figures A3a and A3b show the wettest and driest soil water profiles measured at the ash and beech sites, the wettest profiles occur in March and April and the driest in August. The profiles under the beech show soil water depletion in the top 240 cm with little change below this. Under the ash there are still some changes at the lowest measurement depth of 340 cm, this could be due to roots extending beyond this depth or to drainage from the profile in the deeper layers. The measurements at this site will be extended with deeper neutron probe measurements and gypsum block measurements of soil water potential.

Figure A4 shows the time series of the mean total water contents for the ash and the beech. Ignoring the drainage and abstraction by roots below the lowest measurement depth, the change of total water content plus the throughfall through the season will give total transpiration. For the ash site (begining of May to the end of August) this equals 340 mm, and for the beech site (mid April to the end of August) 327 mm. These are provisional estimates and more work will be required to confirm them.

RAINFALL INTERCEPTION

Rainfall measured since 20 June when the raingauges were installed has only reached 74 mm and is too small to allow any useful data analysis to be performed.

PLANT PHYSIOLOGICAL MEASUREMENTS

Measurements of leaf gas exchange (stomatal conductance and net photosynthesis) have been made throughout the season which, because of the dry soils and high evaporative demand has provided a good data set. Gas exchange data is available throughout the canopy space in the beech and ash stands, and in the latter case also includes measurements made on the field and shrub layers. Measurements are also available of the boundary layer conductance throughout the ash stand.

LAI determinations will be made on litter collected in each stand and in the case of the ash will be combined with determinations already made for the field layer in mid season.

Measurements have also been made throughout the season of plant water potential and its components, osmotic and turgor potential. Changes in plant water relations both seasonally and diurnally will be used with meteorological data to evaluate the factors controlling stomatal conductance.

Stomatal conductance (g_s) of ash, beech and major constituents of the understorey are shown in Figures A5, A6 and A7 respectively. The maximum g_s in ash and beech are similar and in all cases show a gradual fall throughout each day. This response is probably associated with an increase in air vapour pressure deficit throughout the day. A consistent pattern also emerges in the fall of g_s down through the two tree species canopies. Although a substantial soil moisture deficit built up through the past summer a seasonal change in g_s not observed in response to this in ash(Figure A5 a,b and c) or beech (Figure A6 a and b). Much lower conductances were measured in the three understory species (Figure A7 a,b and c) and were affected by lowered soil moisture levels. Analysis of these data will proceed by modelling g_s relationships to climate and combining individual foliage measurements with LAI in a canopy model of transpirational water use. This model would form part of a forest water use model.

CHEMISTRY

Stemflow, throughfall and rainfall samples have been monitored for major element chemistry and SO_X, NO_X and NH_3 gas sampling began in August. The chemistry of the samples is very variable; highest concentrations occurring in the order stemflow > throughfall > rainfall. Rainfall pH varies between 3.5 and 7, as does the pH of the throughfall, but the stemflow is most acidic its pH being typically less than 5. So far the data are too limited, due to the lack of rainfall, to allow firm conclusions to be drawn about the chemical fluxes.

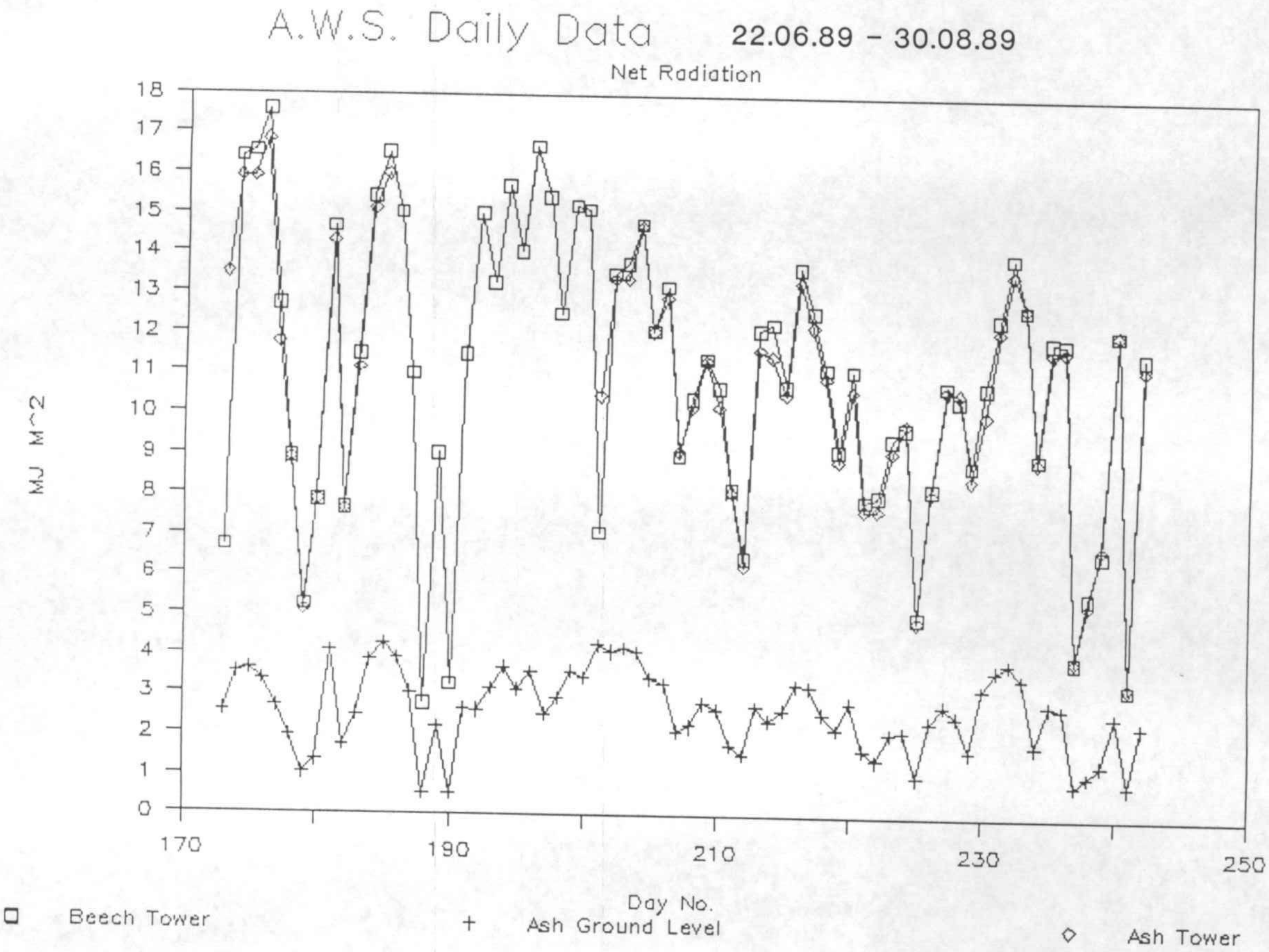
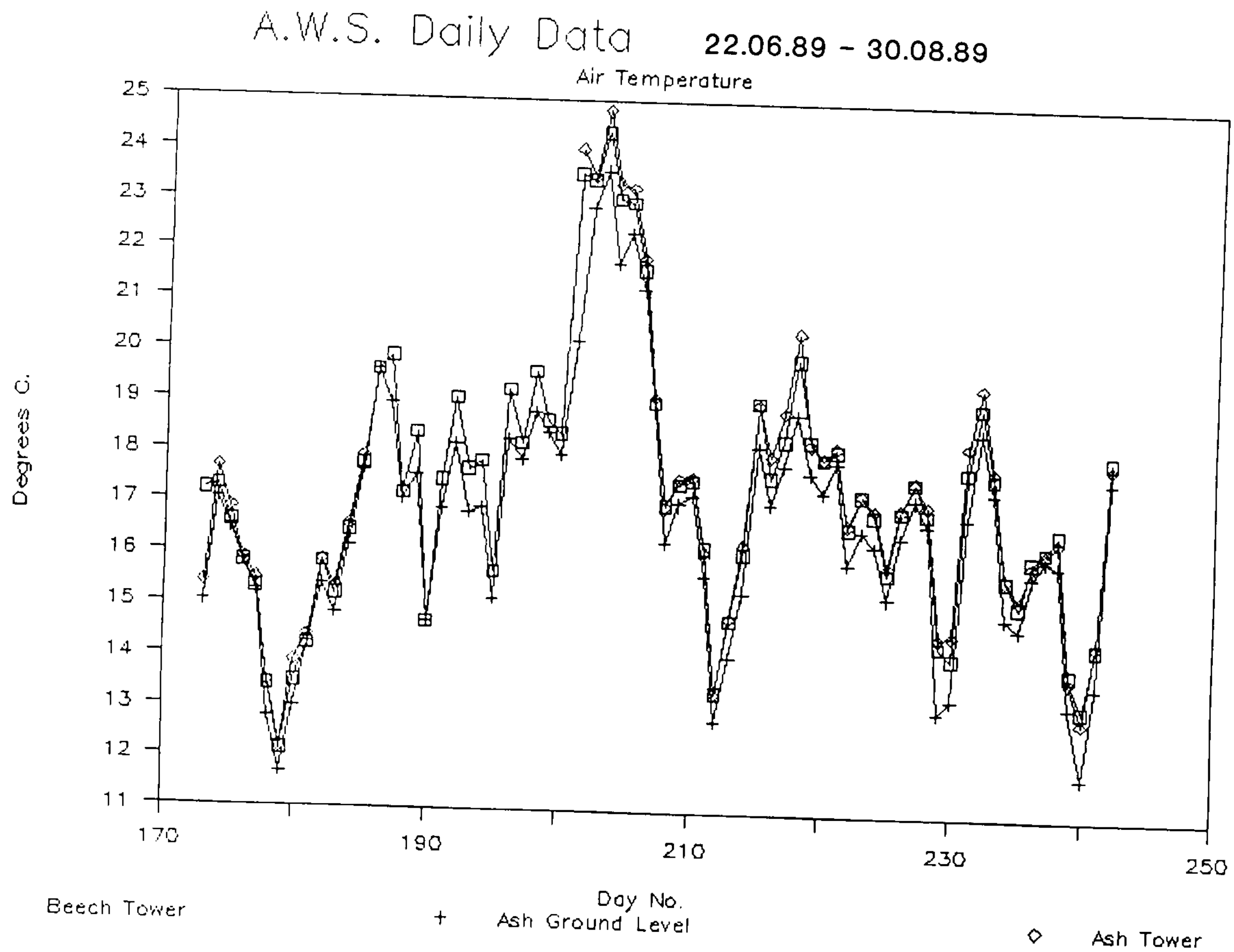

A.W.S. Daily Data
22.06.89 - 30.08.89
Net Radiation
MJ M^2
Day No.
Beech Tower
Ash Ground Level
Ash Tower

Fig. A1a



A.W.S. Daily Data
22.06.89 - 30.08.89
Air Temperature
Degrees C.
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
170
190
210
230
250
Day No.
Beech Tower
Ash Ground Level
Ash Tower

Fig. A1b

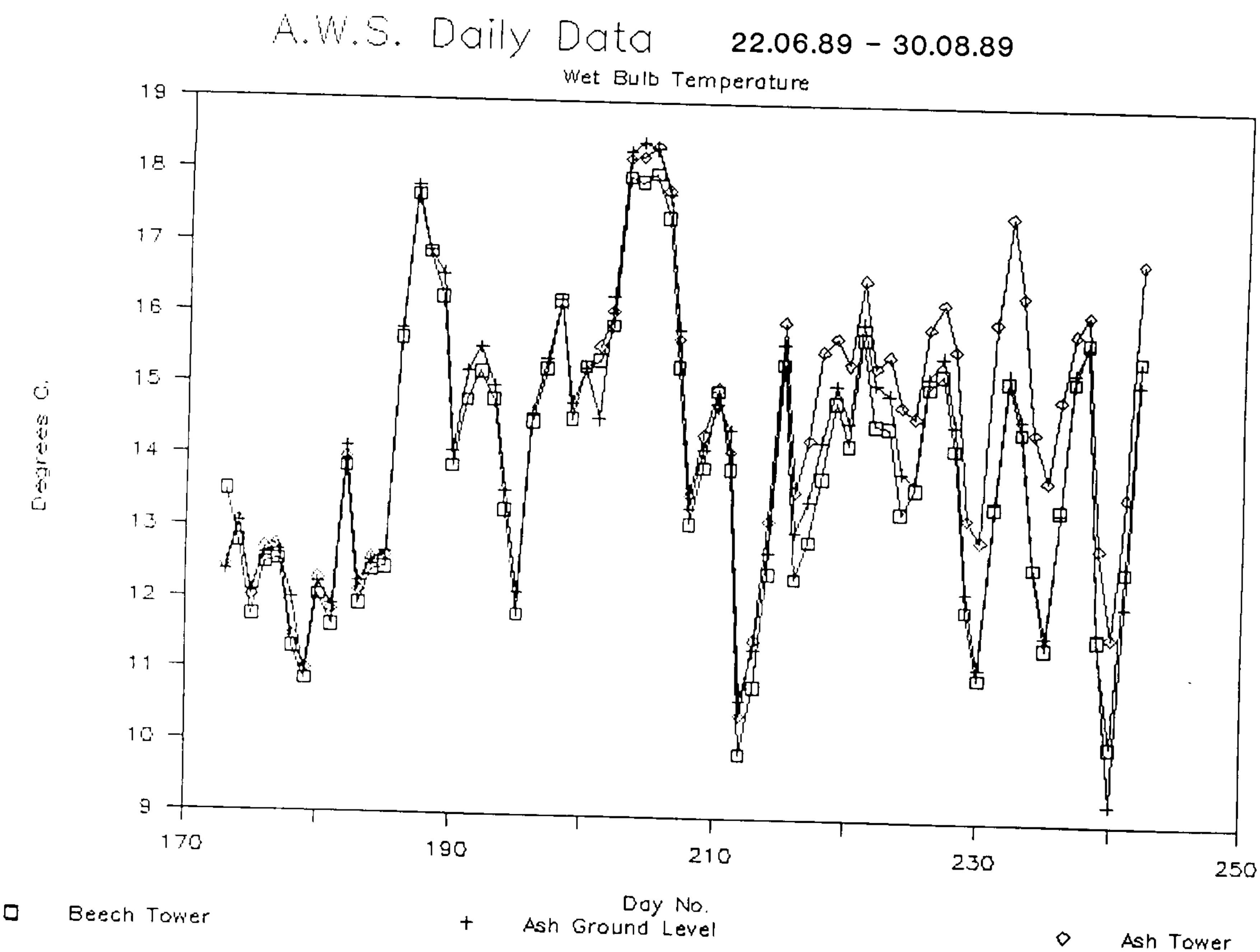

A.W.S. Daily Data 22.06.89 - 30.08.89
Wet Bulb Temperature
Degrees C.
19
18
17
16
15
14
13
12
11
10
9
170
190
210
230
250
Day No.
Beech Tower
Ash Ground Level
Ash Tower

Fig. A1c

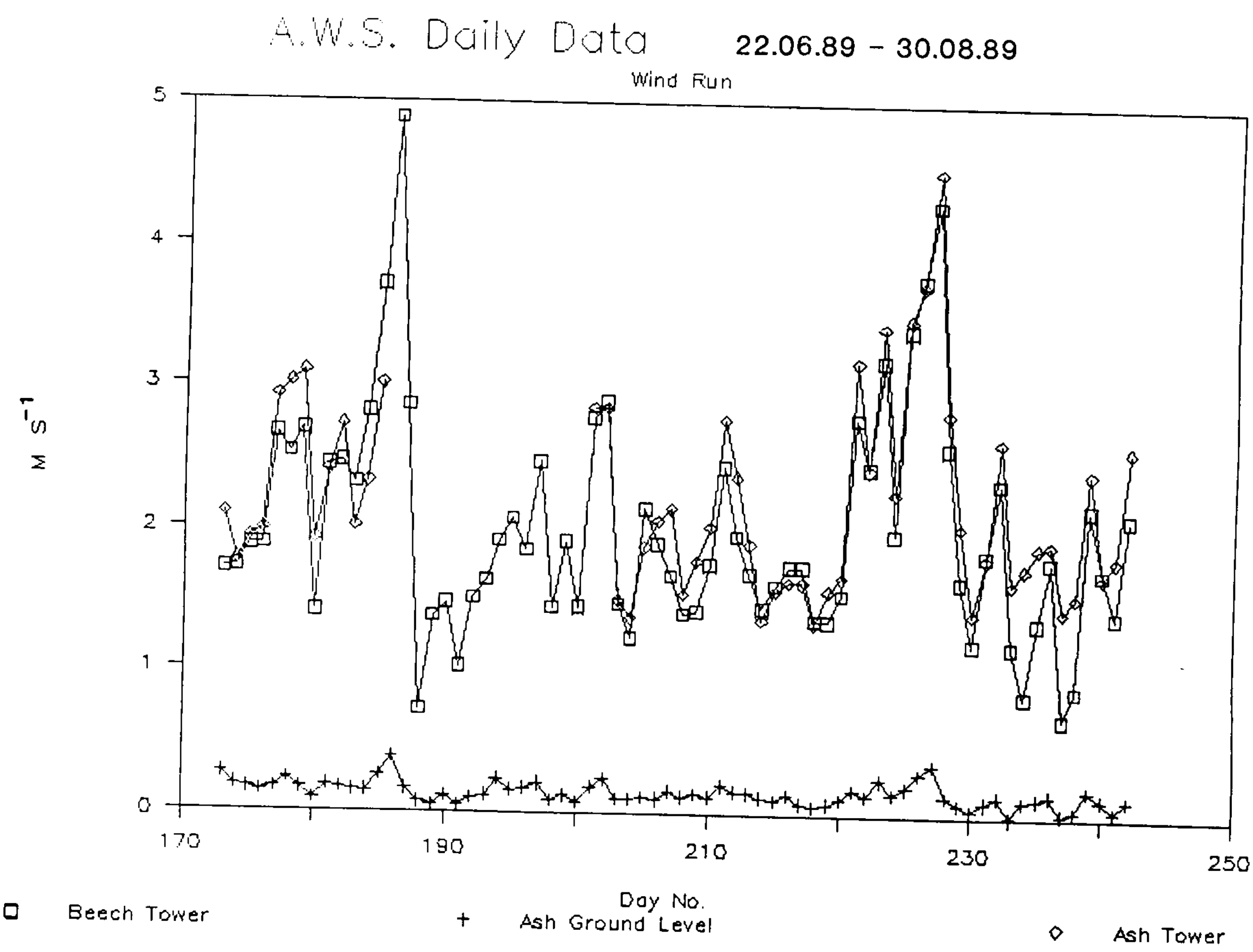

A.W.S. Daily Data 22.06.89 - 30.08.89
Wind Run
M S-1
5
4
3
2
1
0
170
190
210
230
250
Day No.
Beech Tower
Ash Ground Level
Ash Tower

Fig. A1d

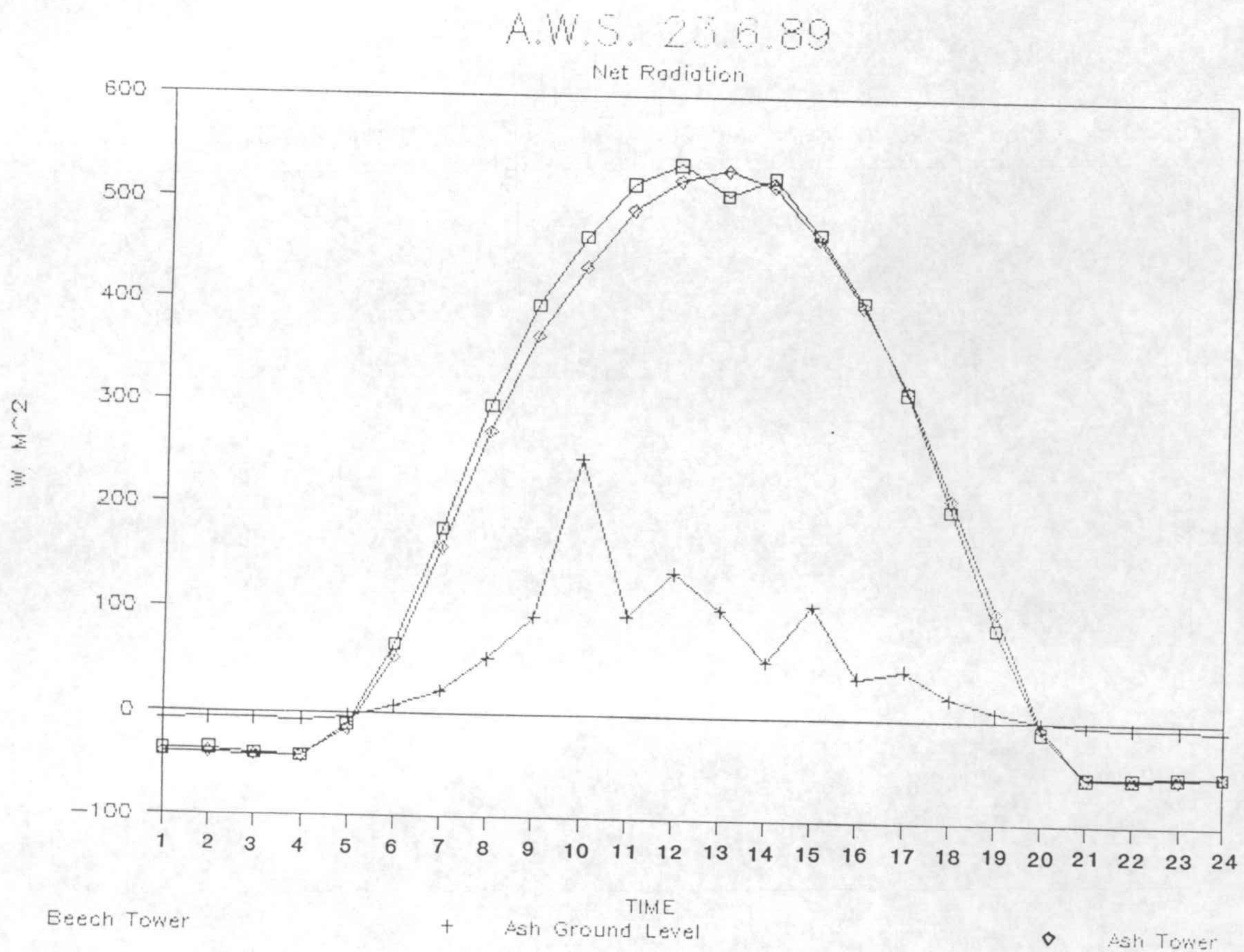

A.W.S. 23.6.89
Net Radiation
W M^2
600
500
400
300
200
100
0
−100
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
TIME
Beech Tower
Ash Ground Level
Ash Tower

Fig. A2a

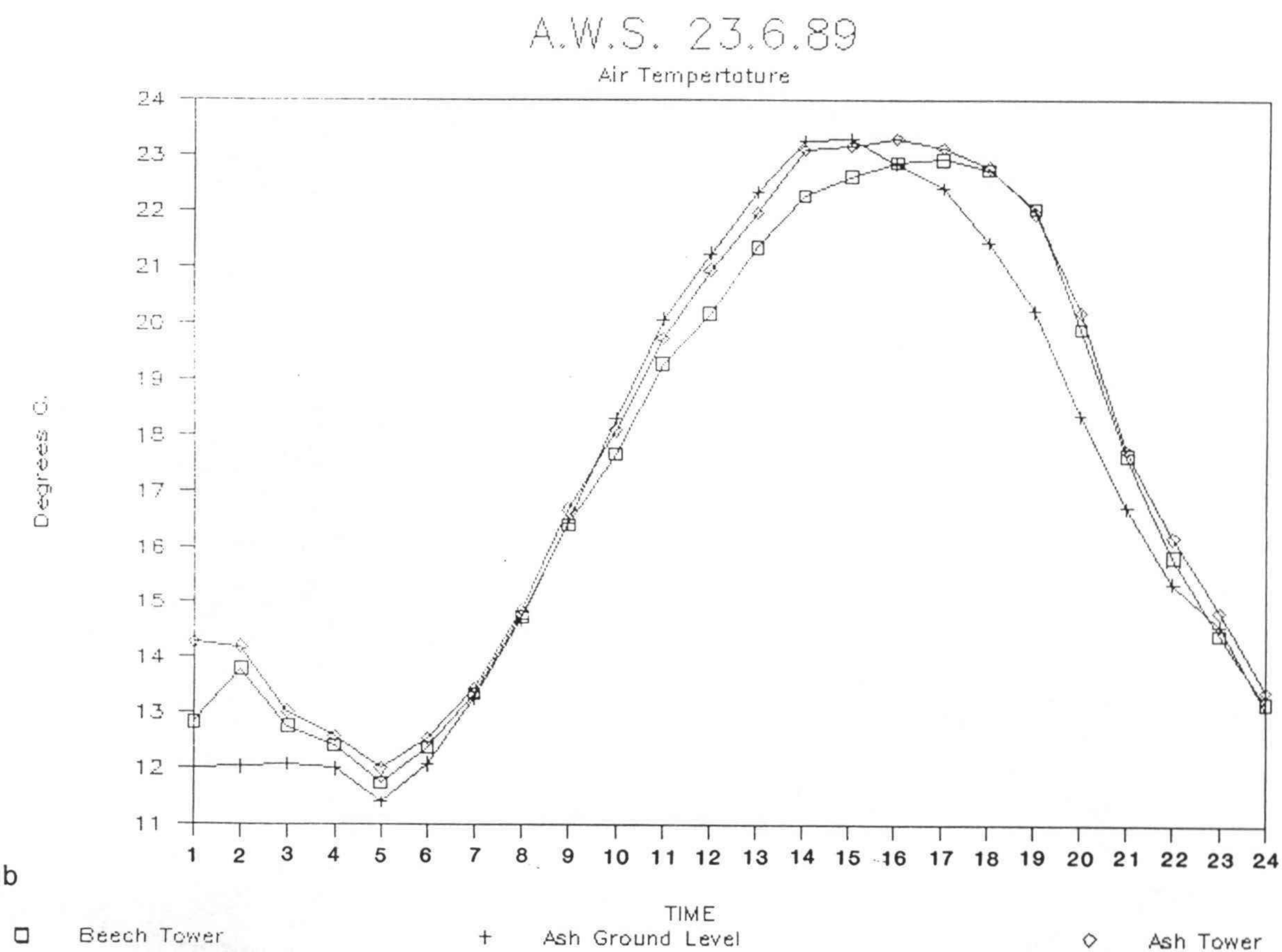

A.W.S. 23.6.89
Air Tempertoture
Degrees C.
24
23
22
21
20
19
18
17
16
15
14
13
12
11
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
TIME
□ Beech Tower
+ Ash Ground Level
◇ Ash Tower

Fig A2b

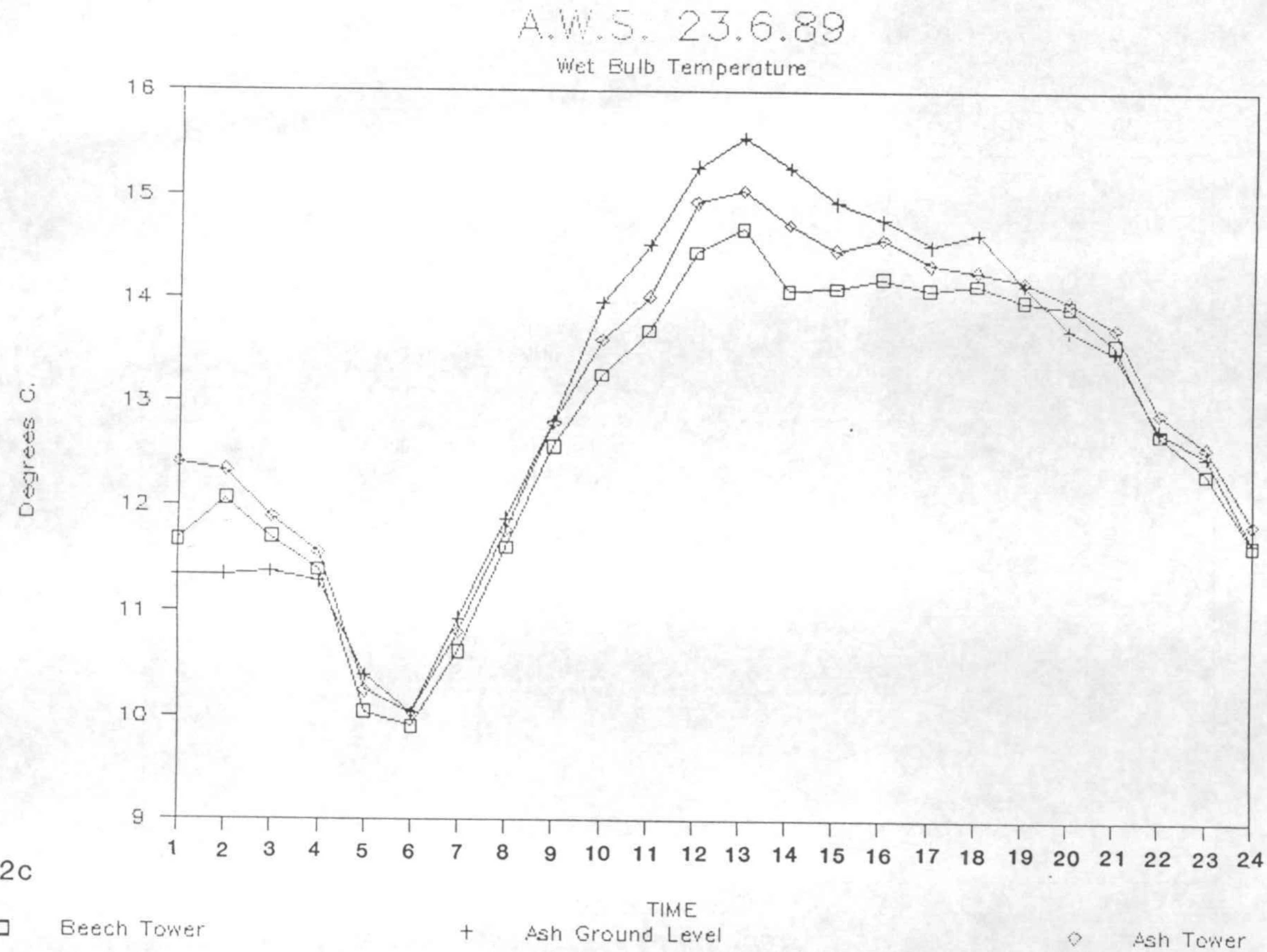

A.W.S. 23.6.89
Wet Bulb Temperature
Degrees C.
16
15
14
13
12
11
10
9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
TIME
Beech Tower
Ash Ground Level
Ash Tower

Fig. A2c

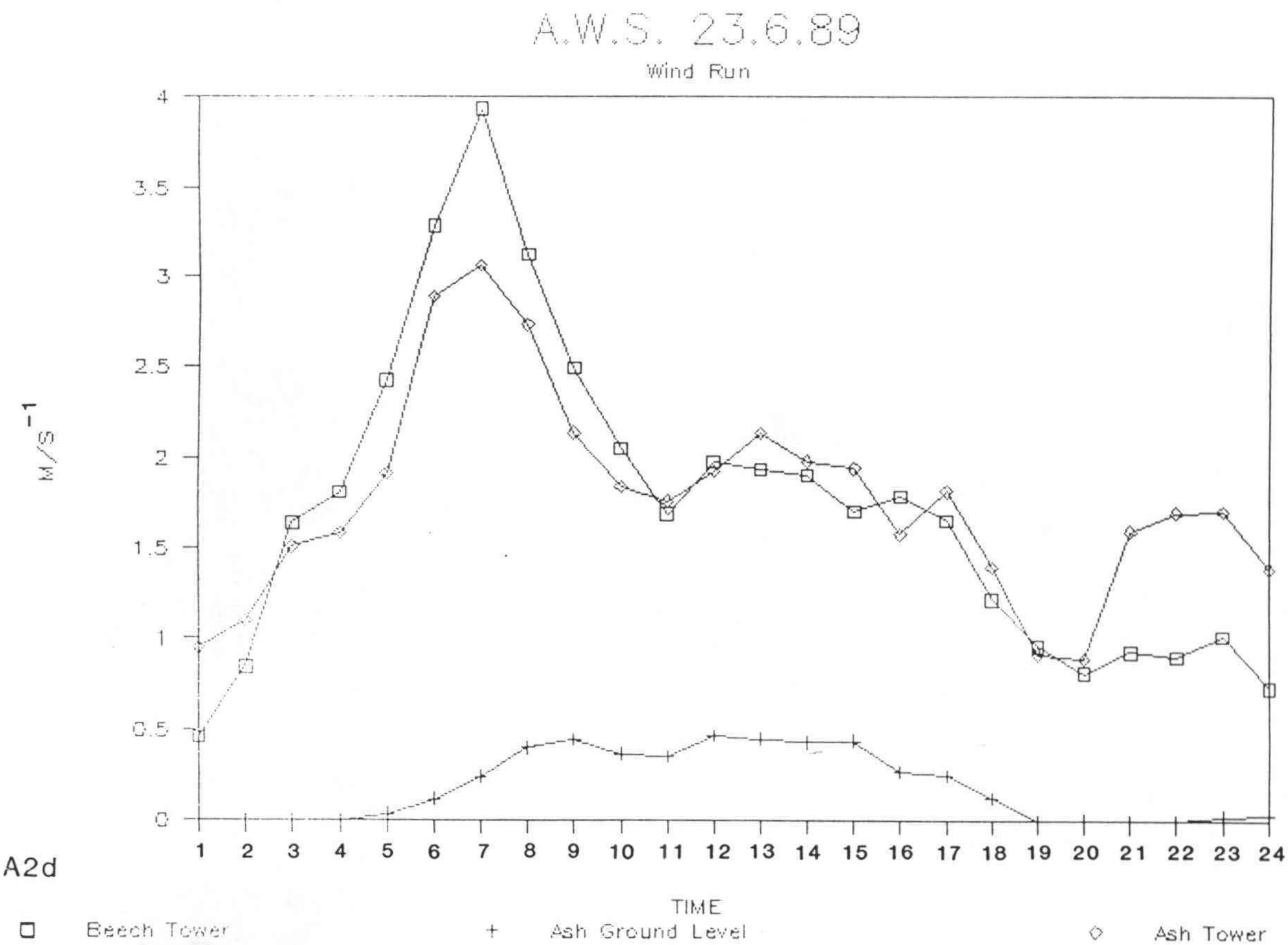
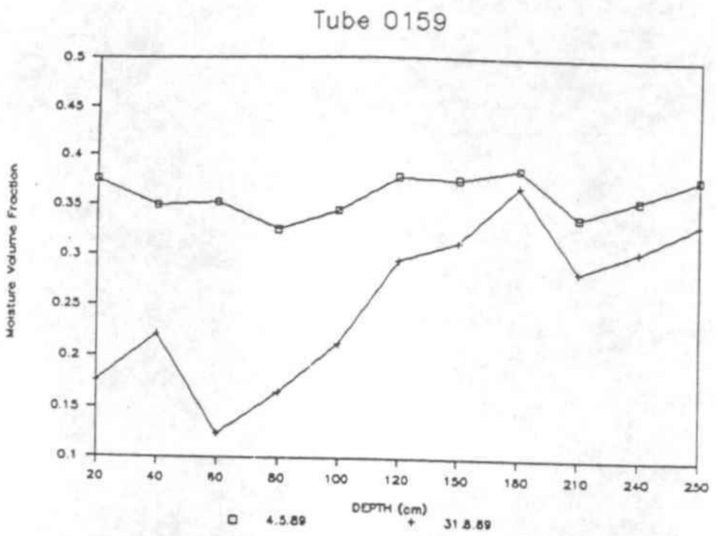
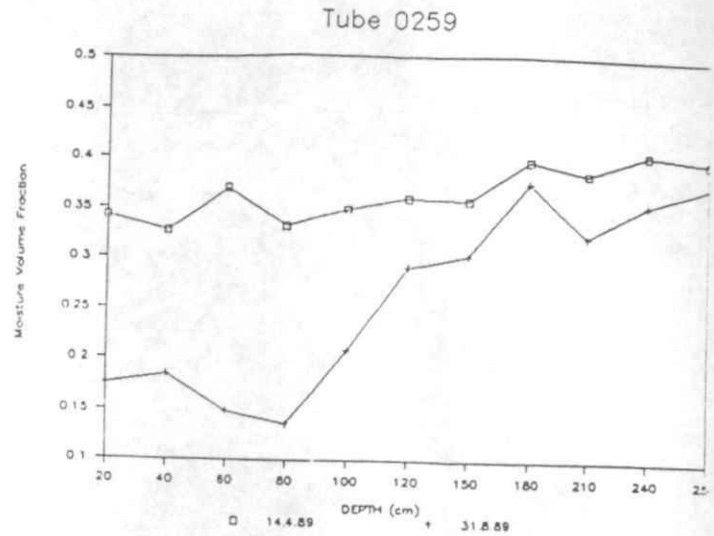
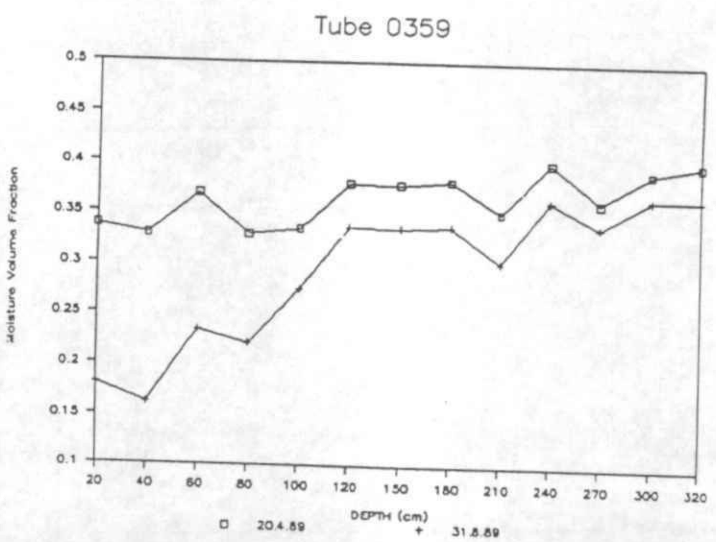

A.W.S. 23.6.89
Wind Run
4
3.5
3
2.5
2
1.5
1
0.5
0
M/S -1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
TIME
Beech Tower
Ash Ground Level
Ash Tower

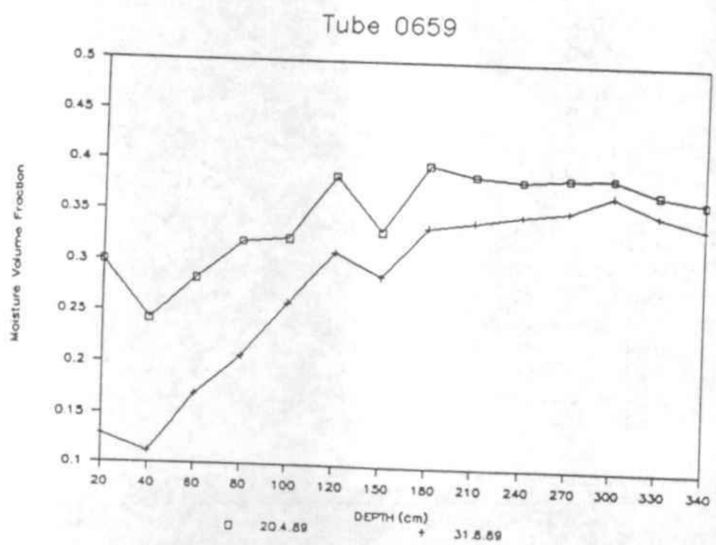
Fig. A2d

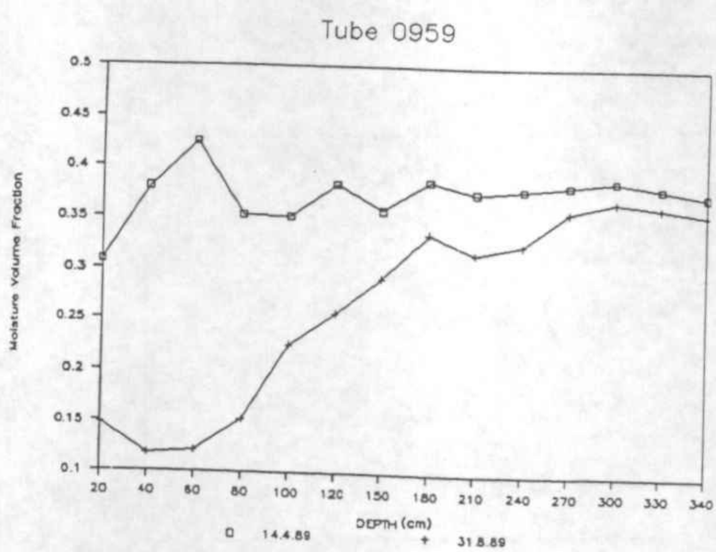
Fig.A3a **Soil Moisture Profiles Ash Site**





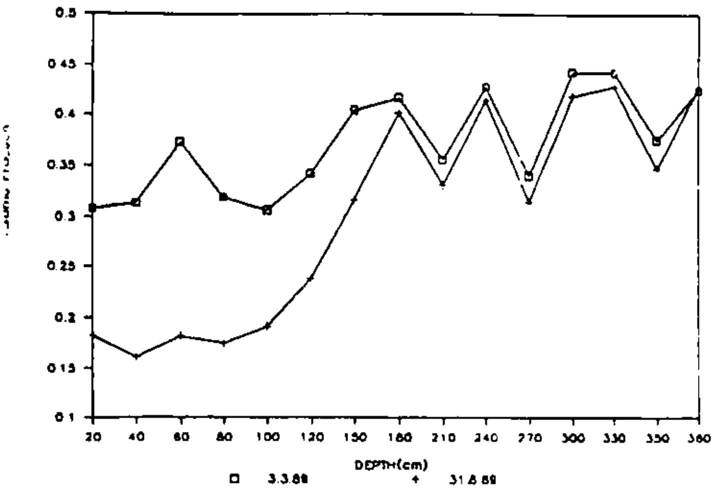




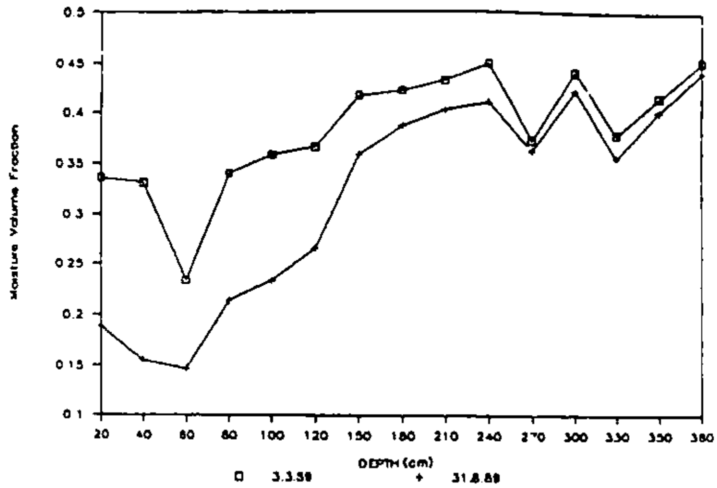


'ig.A3b **Soil Moisture Profiles Beech Site**

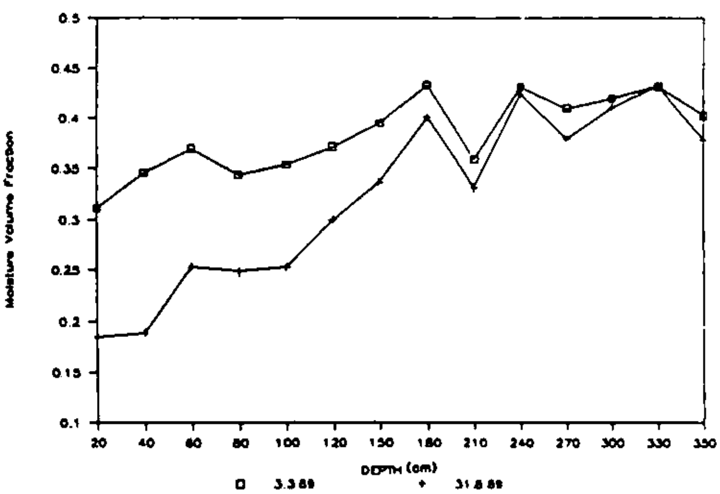
Tube 0258



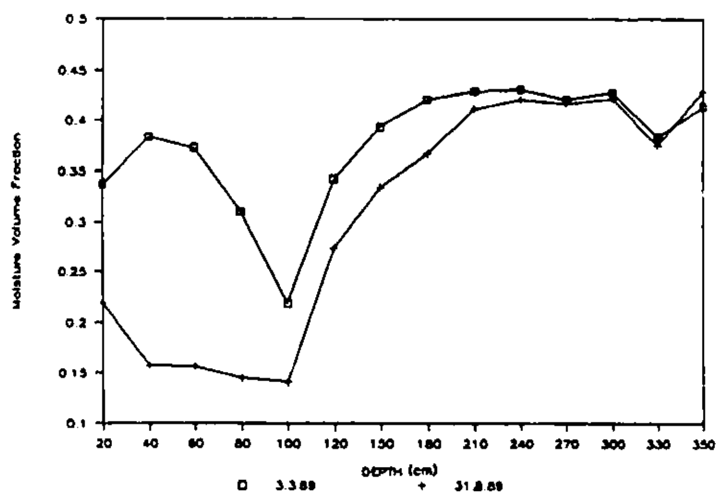
Tube 0458



Tube 0558



Tube 0758



Tube 0958

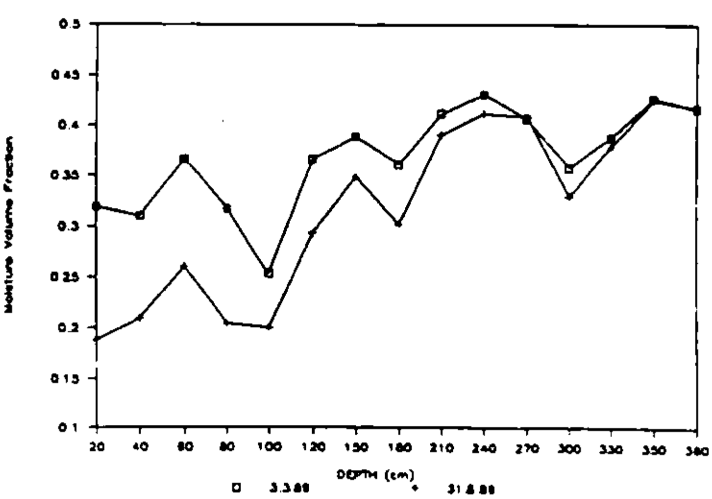
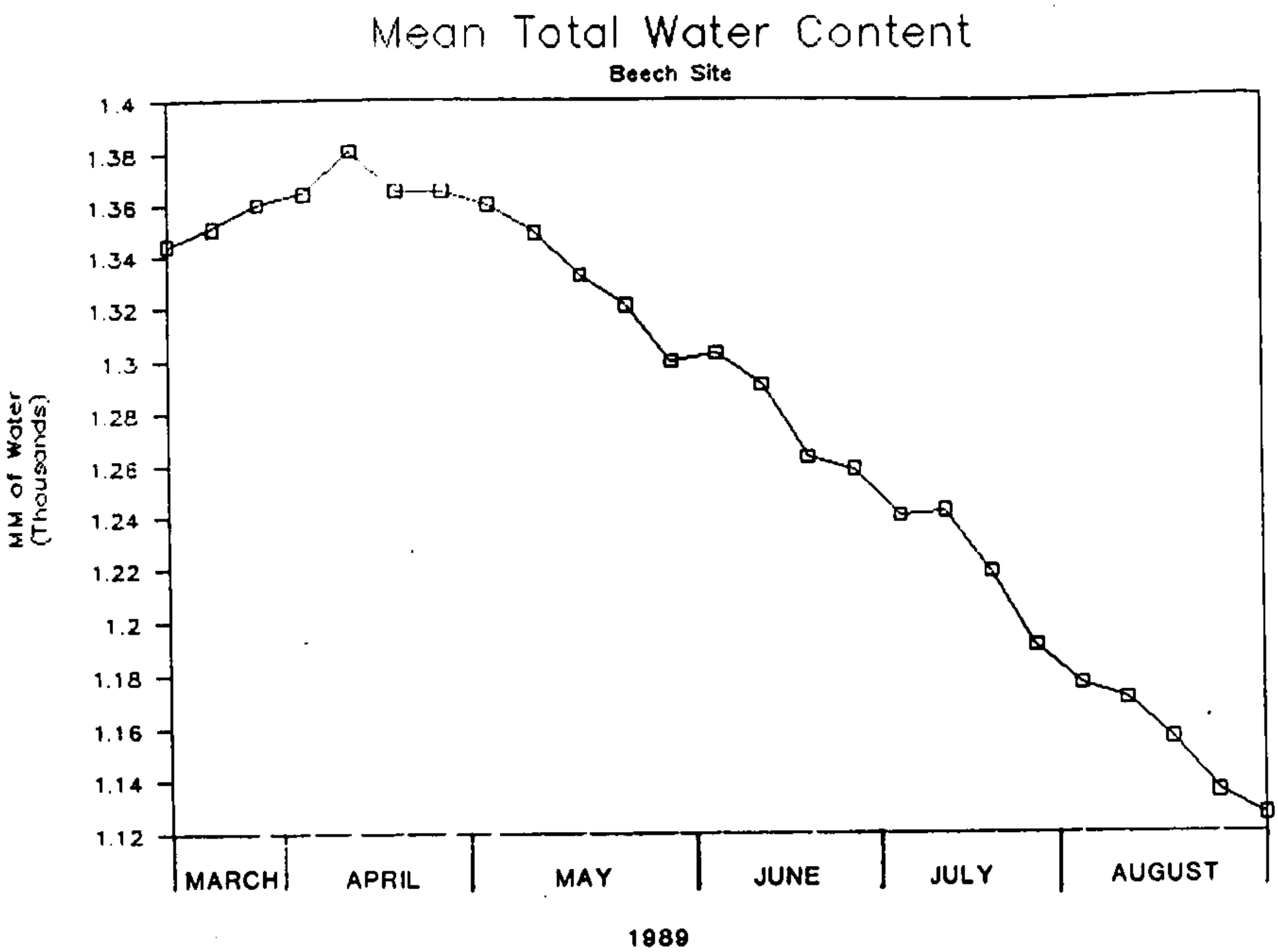
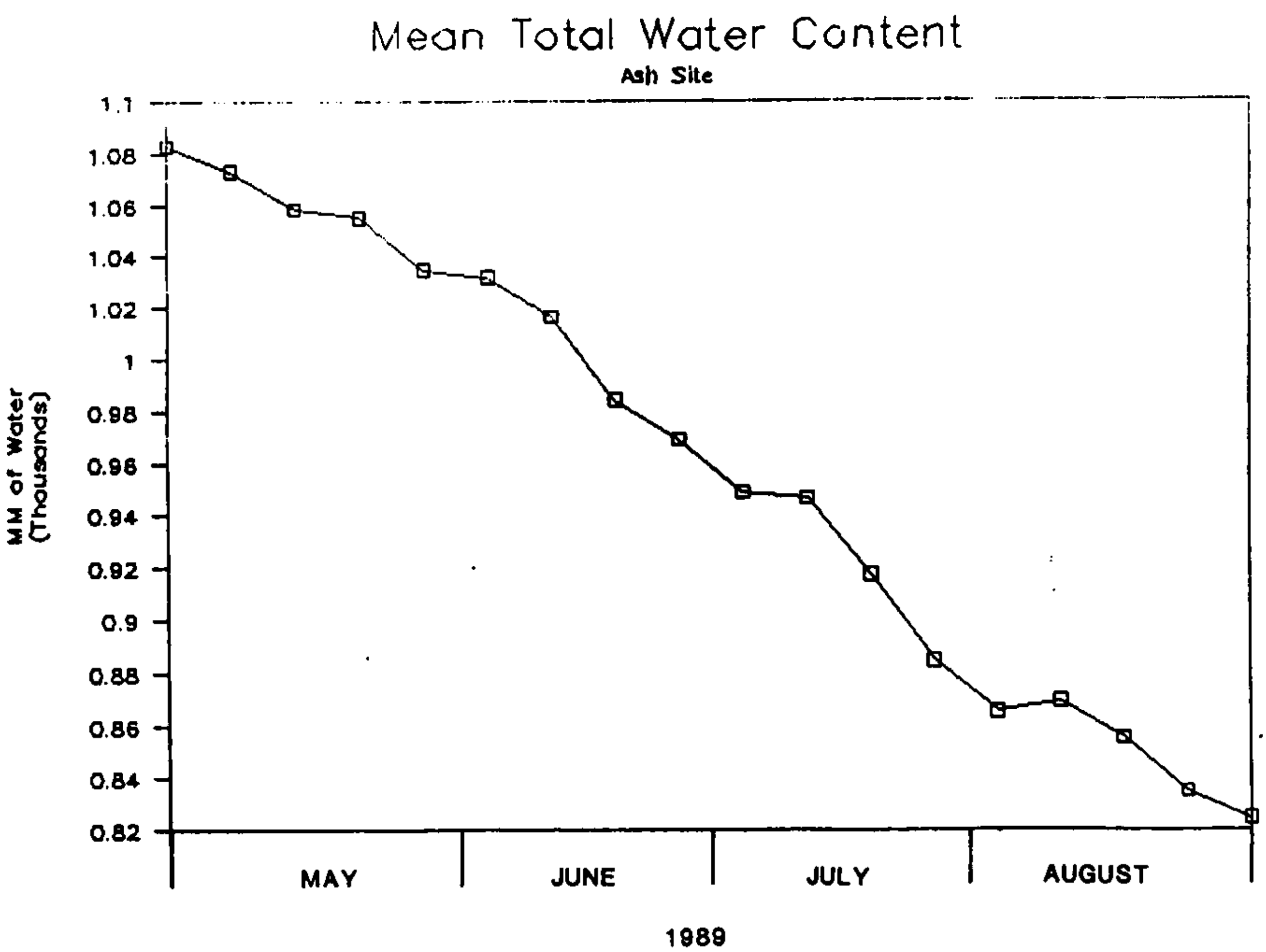


Fig.A4



Mean Total Water Content
Beech Site
MM of Water (Thousands)
1.4
1.38
1.36
1.34
1.32
1.3
1.28
1.26
1.24
1.22
1.2
1.18
1.16
1.14
1.12
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
1989



Mean Total Water Content
Ash Site
MM of Water (Thousands)
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
MAY
JUNE
JULY
AUGUST
1989

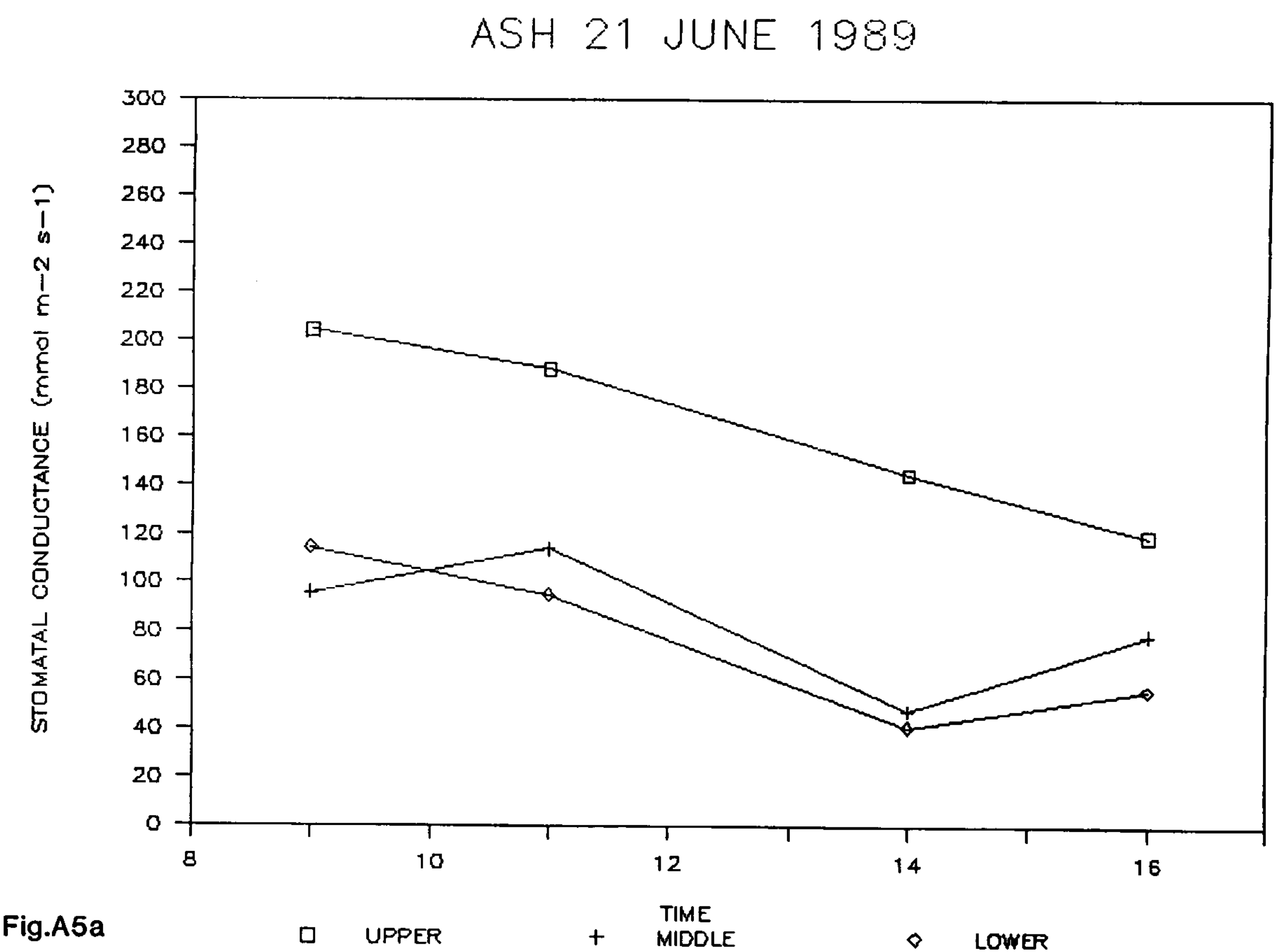

ASH 21 JUNE 1989
STOMATAL CONDUCTANCE (mmol m−2 s−1)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
8
10
12
14
16
TIME
UPPER
MIDDLE
LOWER

Fig.A5a

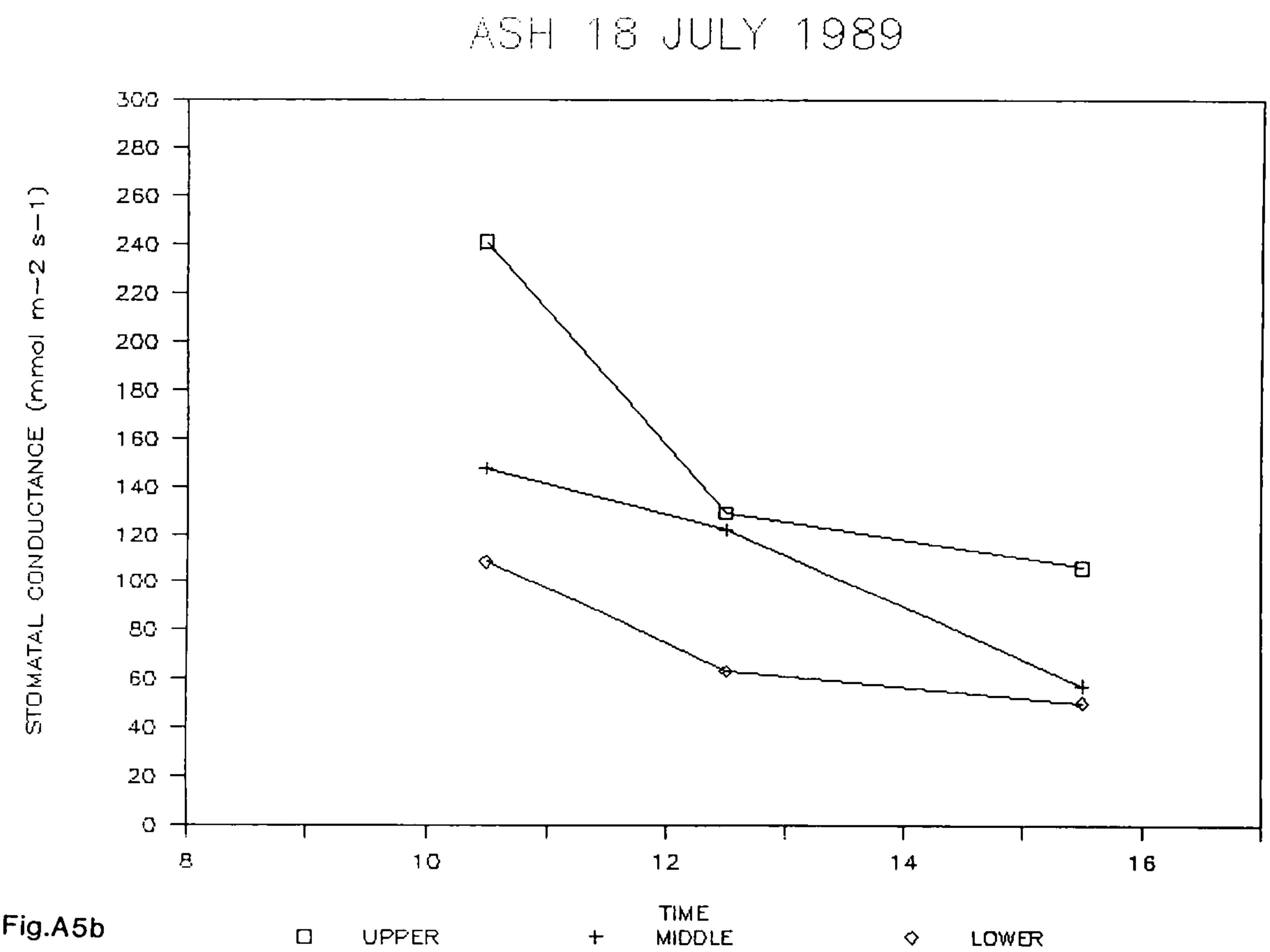

ASH 18 JULY 1989
STOMATAL CONDUCTANCE (mmol m−2 s−1)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
8
10
12
14
16
TIME
UPPER
MIDDLE
LOWER

Fig.A5b

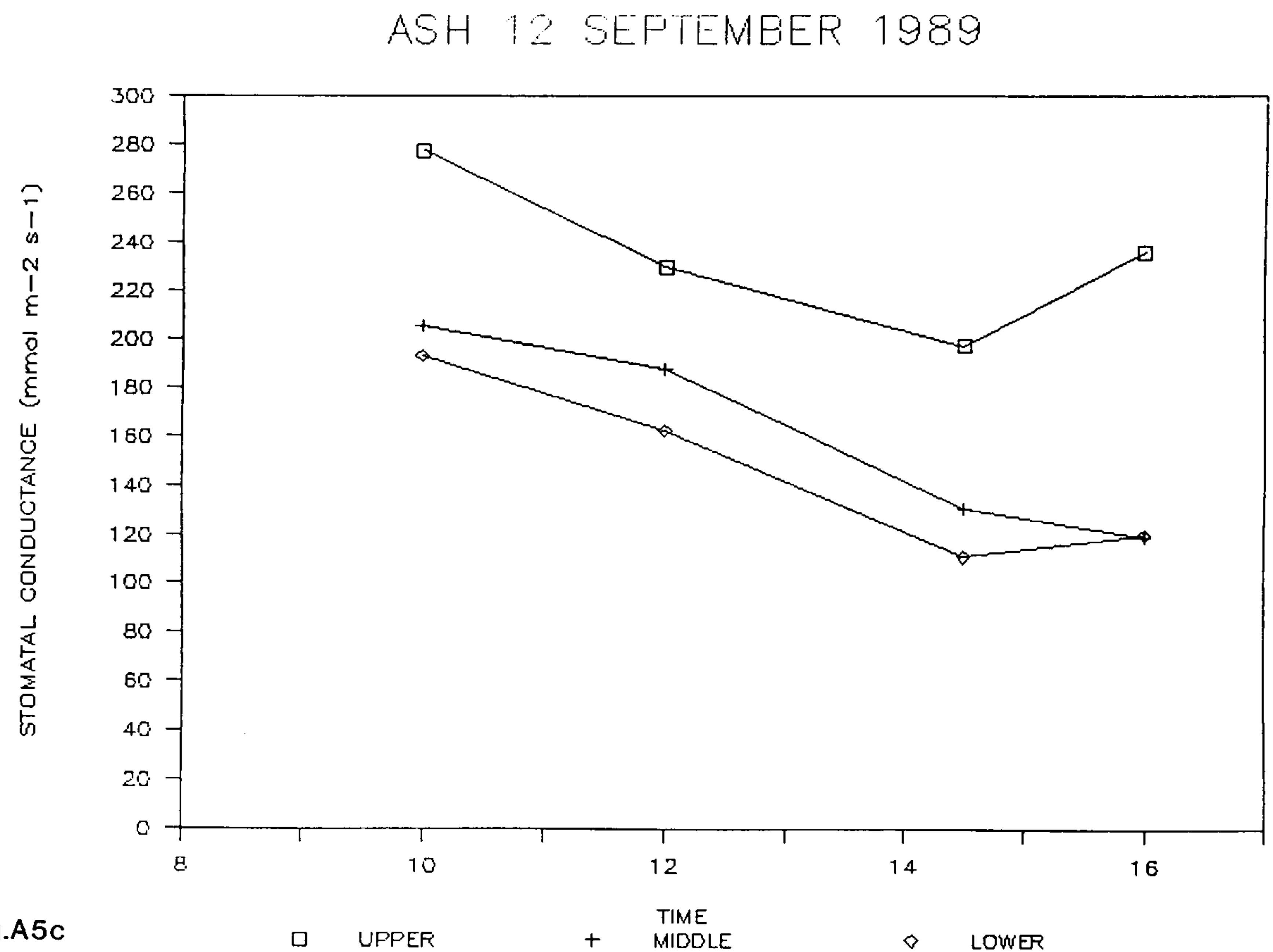

ASH 12 SEPTEMBER 1989
STOMATAL CONDUCTANCE (mmol m−2 s−1)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
8
10
12
14
16
TIME
UPPER
MIDDLE
LOWER

Fig.A5c

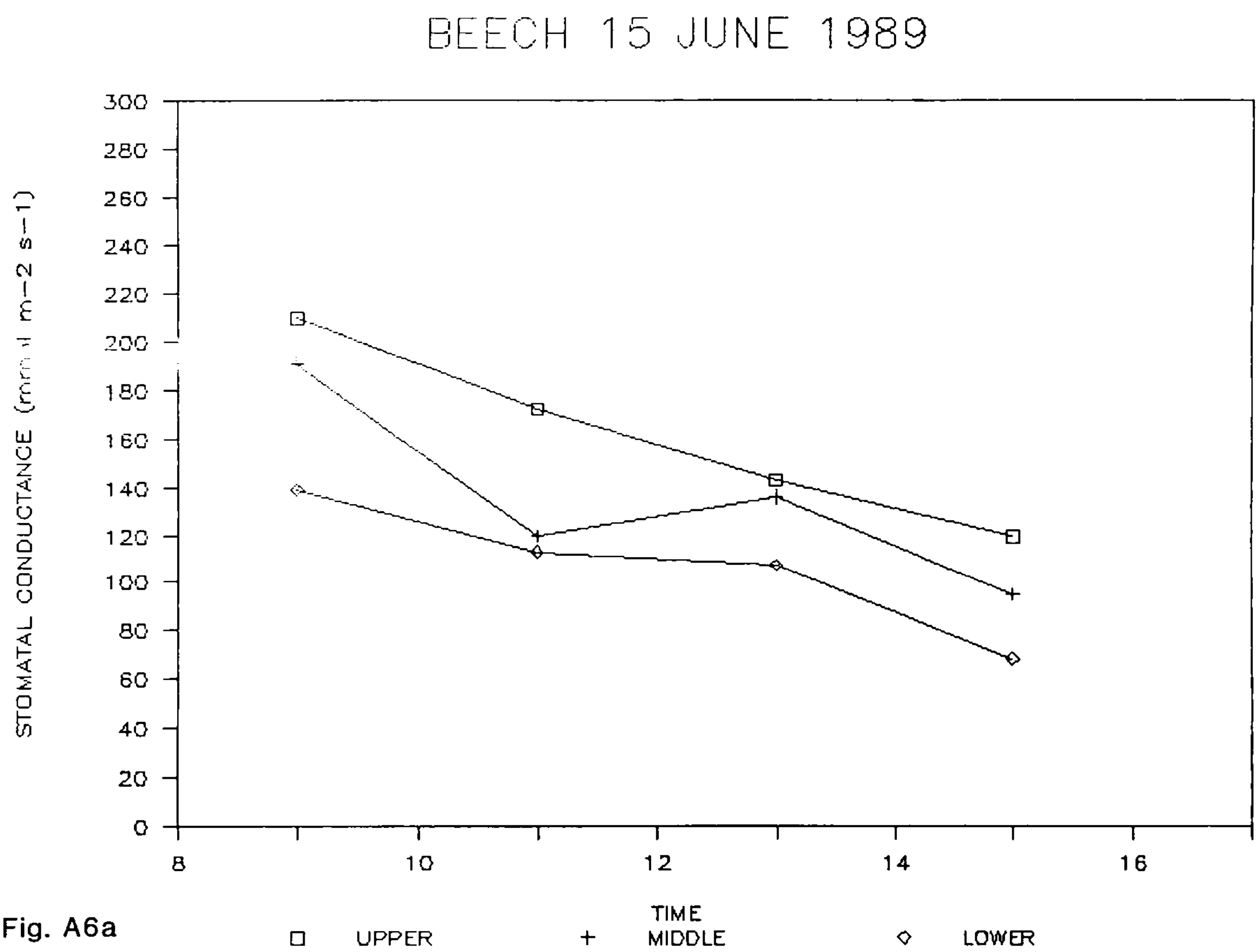

BEECH 15 JUNE 1989
STOMATAL CONDUCTANCE (mmol m−2 s−1)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
8
10
12
14
16
TIME
UPPER
MIDDLE
LOWER

Fig. A6a

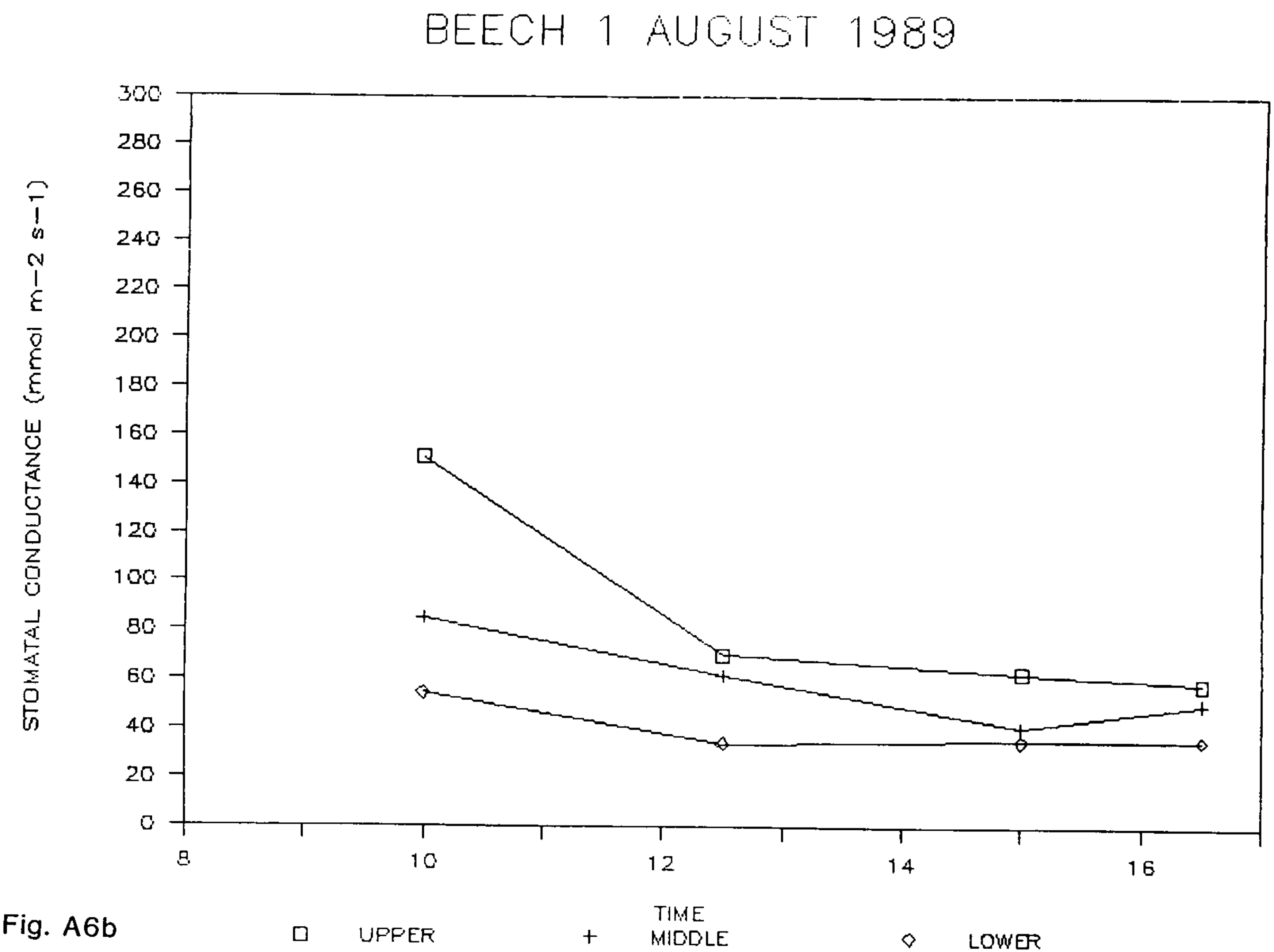

BEECH 1 AUGUST 1989
STOMATAL CONDUCTANCE (mmol m−2 s−1)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
8
10
12
14
16
TIME
UPPER
MIDDLE
LOWER

Fig. A6b

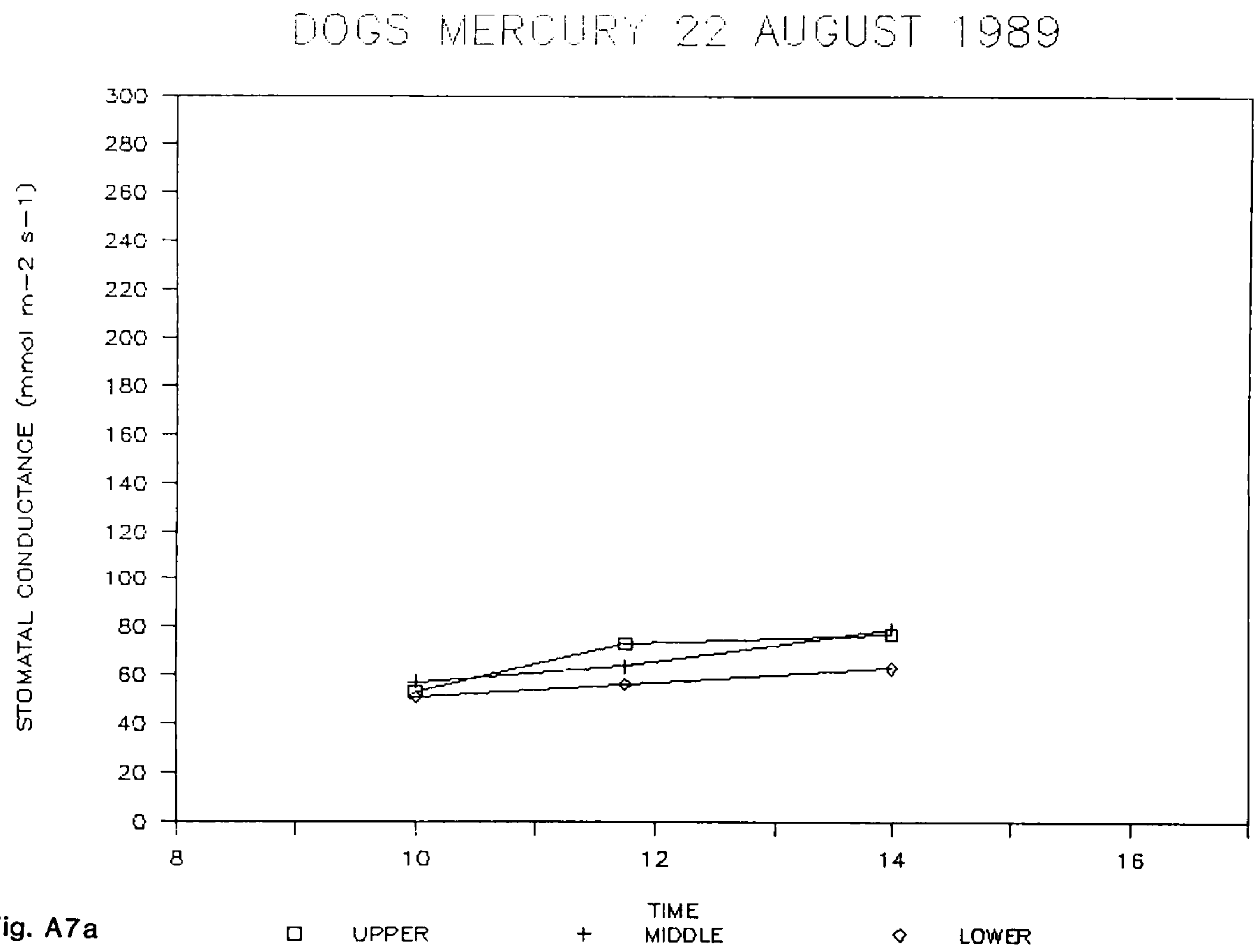

DOGS MERCURY 22 AUGUST 1989
STOMATAL CONDUCTANCE (mmol m−2 s−1)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
8
10
12
14
16
TIME
UPPER
MIDDLE
LOWER

Fig. A7a

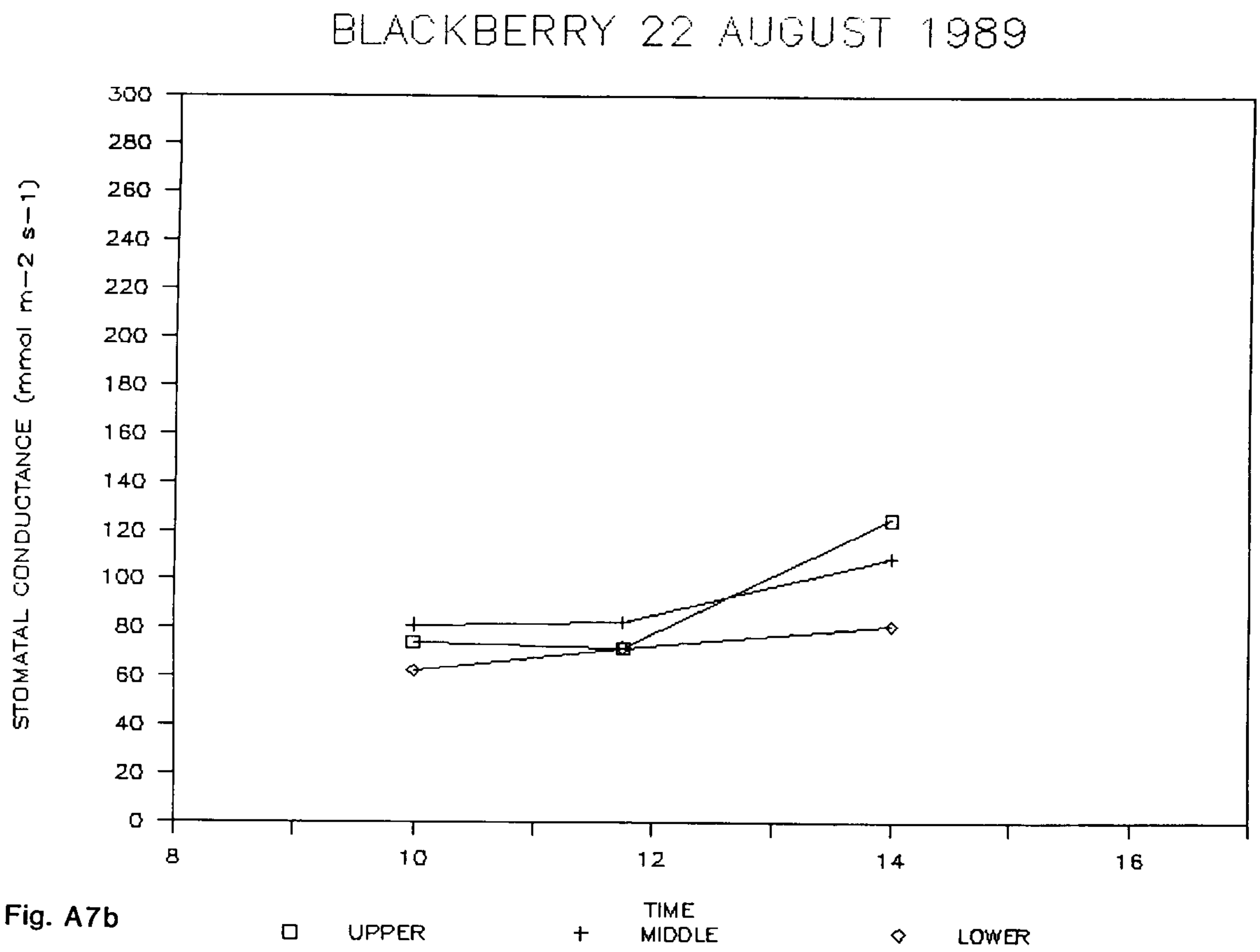

BLACKBERRY 22 AUGUST 1989
STOMATAL CONDUCTANCE (mmol m-2 s-1)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
8
10
12
14
16
TIME
UPPER
MIDDLE
LOWER

Fig. A7b

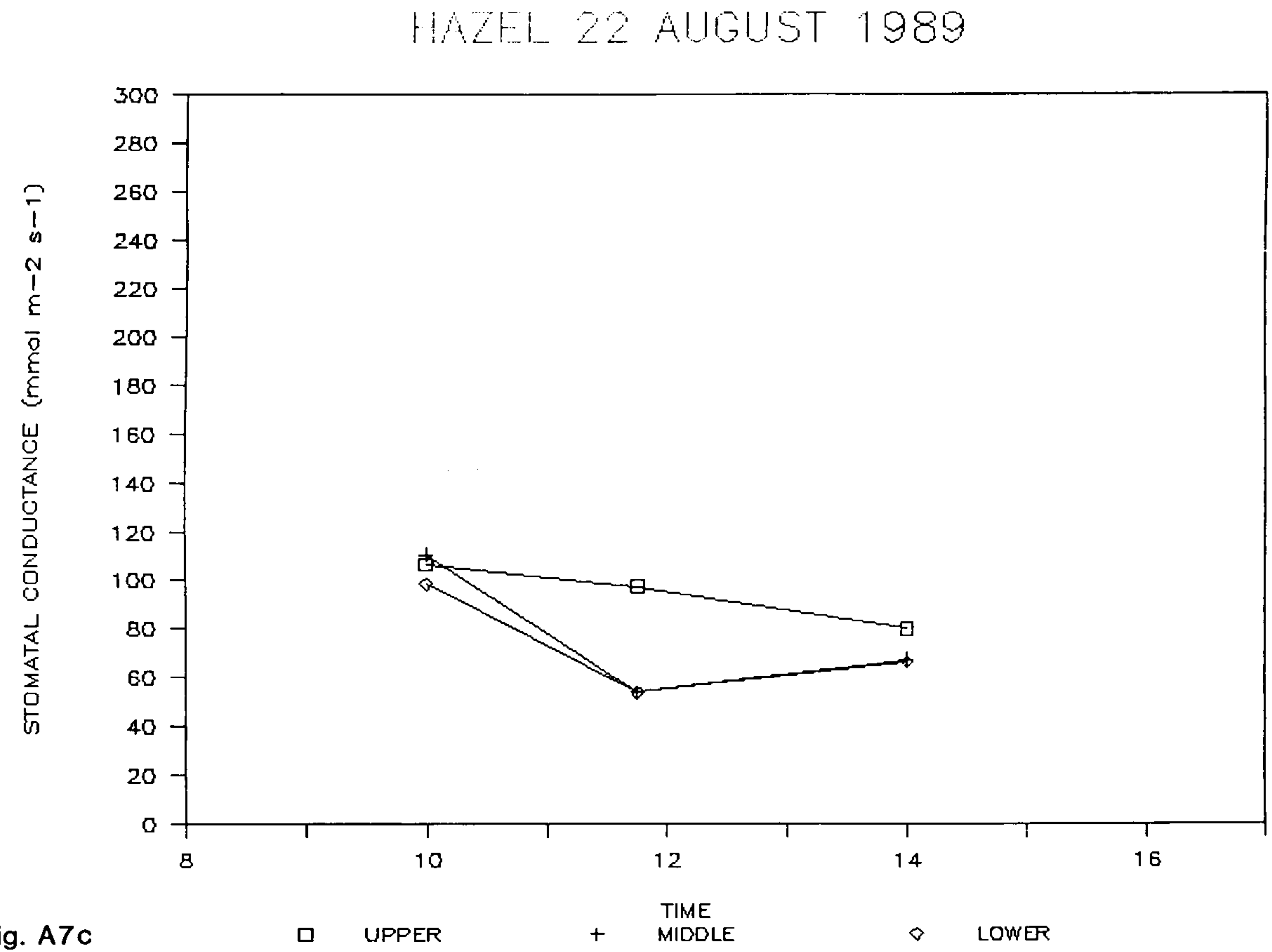

HAZEL 22 AUGUST 1989
STOMATAL CONDUCTANCE (mmol m−2 s−1)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
8
10
12
14
16
TIME
UPPER
MIDDLE
LOWER

Fig. A7c