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A SYSTEM FOR MONITORING ENVIRONMENTAL FACTORS IN CONTROLLED ENVIRONMENT CHAMBERS AND GLASSHOUSES

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## INTRODUCTION

Experimenters rely on controlled environment chambers to provide constant patterns of temperature, humidity and light. They require confirmation that the chambers are doing this correctly, and warning when a malfunction occurs. In addition, uncontrolled or semi-controlled environments such as glasshouses or cold frames may need to be monitored. A wide range of sensors, data loggers and small computers are now available to do these tasks. The purpose of this report is to describe a system that has evolved over a number of years, gives the information required by experimenters, and has software designed to make it easy to use. It discusses some of the problems, and provides a starting point for researchers wishing to start their own system.

## USER REQUIREMENTS

Controlled Environment users wish to display the current conditions for a given environment and to check data from the previous 24 hours. It is helpful if measurements which deviate significantly from the desired values are identified clearly in both the current and past displays. In the case of glasshouses and outdoor areas, checking against preset values is clearly not appropriate, but a printed record of the conditions is often required.

## EQUIPMENT

### (a) Sensors

Miniature wet and dry bulb thermistor psychrometers are used to measure temperature and humidity.

The psychrometers are manufactured by Delta-T devices and contain two identical thermistors mounted in a metal tube. A fan at the end of the tube draws air over the sensors. One thermistor has a woven cotton wick over it, the wick leading from a small reservoir of distilled water. The fan is operated for one minute prior to the measurement being taken to ensure that equilibrium is reached, then switched off when the measurement is complete. Miniature fans do not have a very long life, so switching them off when not required prolongs the service life considerably. The fans are also run at only 80% of the rated voltage, again to prolong the life of the unit.

The provision of a system with calculating ability allows a simple thermometer to be used (Simmons 1978) and the output is corrected for nonlinearity by a subprogram in the data logger. Wet bulb psychrometers need careful maintenance in order to remain accurate and several types of electronic humidity sensor have been examined as possible alternatives; however, none of the commercial units offer reliable enough performance to justify the relatively high cost.

Miniature tube solarimeters are used to measure light intensity, as they are convenient to place both above and amongst foliage, and offer minimal obstruction to light. The units are a thermopile type and are also manufactured by Delta-T devices. These sensors are expensive, and therefore for routine checking of controlled environment chambers a cheaper and smaller cell is being introduced. This is based on the BPW21 silicon photodiode. Although primarily intended for illumination measurements, the BPW21 has a sufficiently good spectral response in the 400-700 nm region to allow its use in the checking of growth chamber lighting.

Calibration of light sensors is done against a Kipp CM5 solarimeter.

Temperature, humidity and light are the only measurements made regularly, but other instruments may be connected to the system provided their calibration characteristics are known. Examples of this type of measurement include airspeed, and carbon dioxide concentration.

(b) Interconnecting cables

Each environment chamber and glasshouse contains a socket box from which a screened multicore cable leads to a central distribution board adjacent to the logger installation. The logger inputs and thermometer connections are also connected to terminals on this board. Connections between incoming sensor signals and logger inputs are made by jumper cables, routed via other signal processors e.g. thermometer units, as necessary.

5V DC to operate the psychrometer fans is also supplied via the multicore cables. A separate telephone pair is provided to the glasshouses to facilitate setting up and testing of monitoring equipment, as at the time of installation low cost hand-held radio transceivers were not legally available in the U.K.

To minimise interference, signal cables run in floor ducts which do not contain mains voltage cables or other A.C. carrying cables. The individual cables are allocated in pairs for each sensor, even where it is theoretically possible to use a common return wire, so that sensor current, and hence voltage drops, are similar in both legs of a pair, and common mode rejection of unwanted signals is maximised. Screens of the cables are terminated in a common point at the distribution board, and left floating at the distant end, to minimise problems with earth loops. The use of high impedance temperature sensors means that cable resistance is not a significant error, even when loop resistances are of several ohms.

Both the thermistors and solarimeters used at WRO are supplied with 3.5 mm jack plugs. The socket boxes therefore contain a number of 3.5 mm sockets, and also a 6-pin DIN socket used to connect the wet and dry bulb psychrometer. Some difficulty is experienced making reliable contact between sockets and plugs, particularly if the plugs have been out of use for some time. Financial considerations prevent the replacement of these items by more reliable equivalents, as large numbers are in use. The problem is therefore minimised by the use of proprietary contact lubricants and gentle cleaning of plugs which have not been used recently.

(c) Data logger

The unit which samples the sensor signals, digitises them and sends them to the computer is a Micro Consultants IMP logger. This unit has its own clock, program and data stores and output devices, and can therefore function independently of the computer if required. Although most of the functions of the IMP could be done by the computer, allowing a simple multiplexer and A-D converter to be used, the flexibility afforded by the more elaborate logger is useful. Small quantities of data for special experiments may be programmed to appear on the logger's own printer without interfering with the main monitoring functions, and the logger can perform quite complex calculations on these data if necessary. The logger has output channels which can energise alarms in the main alarm system and also switch ancillary equipment on and off. One of these channels is used to switch on the fans in the psychrometers one minute before taking a measurement. The serial output port of the logger is connected via an interface unit to one of the computer's IEEE (IEEE 1978) input channels.

(d) Computer

At the time when the system was designed, only two makes of micro-computer were considered suitable for the task. These were the Commodore 8032 and the Apple II. Each has a similar structure and capabilities but with some differences of emphasis. The Apple has good graphics and error handling while the Commodore gives an 80 column upper and lower case display as standard, with simpler input and output protocol, easier screen editing and a real time clock. Although a graph option is offered in the user menu, most of the information is presented in tabular forms and therefore the Commodore machine was chosen. There would be no great difficulty in implementing the program on either machine, or indeed any similar microcomputer.

The program occupies just over 20k of store. In order to accommodate this, plus working space for arrays of data, tables and so on, a memory size of 32k or larger is required. The program is kept permanently in the memory, and reloads are only required in case of power failure, so a disc drive was not thought necessary. If data has to be stored for future retrieval, it would be desirable to add one or more disc drives to the system. A light-duty dot-matrix printer is also attached to the system. Even when several users request daily printouts for their own records the printing workload is only a few pages a day so a long life can be expected. It is possible to obtain thermal image printers for some microcomputers, but the long term stability of the image is not certain. Since the output of, say, glasshouse conditions may be required to be readable for several years, an ink printer is more suitable for this application.

PROGRAM FUNCTIONS

No details of the program coding are given here but copies of the program written in BASIC may be obtained from the author. The program was written by W Jenkins (ARC Letcombe Laboratory) with assistance from C J Stent (Research Engineering and Instrumentation Section, WRO) and the author.

The computer program is structured as a set of interconnecting modules. A background module controls the scanning initiation, data handling and display, but users can interrupt the background activity to run alternative subroutines to display or print measurements, or to do 'housekeeping' tasks like archiving onto tape.

(a) Background module

This section of the program reads the time from the internal clock and issues instructions to the logger to switch on psychrometers and to make readings. The incoming measurements are counted to ensure the logger has not stopped in mid cycle. If it has, then another scan is initiated. After five attempts to obtain a complete scan, the computer continues to the next stage of the program using whatever values it could obtain. Sensor linearising and scaling are done in the logger so that, in case of a computer failure, sensible readings can still be obtained from the logger alone. The computer therefore receives information in real units such as °C. The calculations for absolute and relative humidity are done in the computer, although a RH routine is also included in the logger for specific users. The program constructs a set of tables containing the most recent 24 hours readings for each environment, and these tables form the data base which is accessed by other subroutines. The basic screen display comprises the date, time, and time of last scan, the current readings for each environment and brief instructions on how to select other options. An example of the display is shown in figure 1. Measured and desired temperature and humidity are shown as well as absolute humidity deficit, (the difference between the measured absolute humidity and that of a free water surface at the same temperature). A.H.D. is a useful parameter for predicting water loss from plants.

(b) Options

The primary group of options are designed to display 24 hours' information for a given environment. The user presses a key to indicate the environment in which he is interested, followed by a further key to signify the option chosen. The options are:-

1. Show a graph of the most recent 24 hours temperatures on the screen. (Fig. 2).

2. Show a similar graph of relative humidities.

3. Show a table of temperatures and humidities on the screen. (Fig. 3).

4. Print a similar table on the printer.

```
      day number=  50   current time= 113103 last scan 110000 date is 19/ 2/ 82
environment  air temp  set temp  %rh   set rh  abs hd
room 1       15.58        16     78.59   75     1.1
room 2       16.1         16     77.48   75     1.18
room 3       12.11        11     66.45   64     1.58
cabinet a    26.13        26     75.91   85     1.57
cabinet b    19.3         20     [illegible]   65    19.26
cabinet c                 10             65
  gh 11      13.38               92.22           .37
spare 1
spare 2

which environment do you require?

type 1 for room 1
type 2 for room 2
type 3 for room 3
type 4 for cabinet a
type 5 for cabinet b
type 6 for cabinet c
type 7 for glasshouse 11
8 & 9 are spares. Options W,P,R,L,Z,T,I,D,S - see user guide
 11567  bytes remaining out of 31743
```

Fig. 1. Default Display.

Environments having no sensors plugged in (e.g. cabinet C) are given blank values. The error flagged humidity shown for cabinet b shows the program response to a faulty wet bulb sensor.

The space on the RH side of the display is reserved for future expansion to include light intensity measurements.

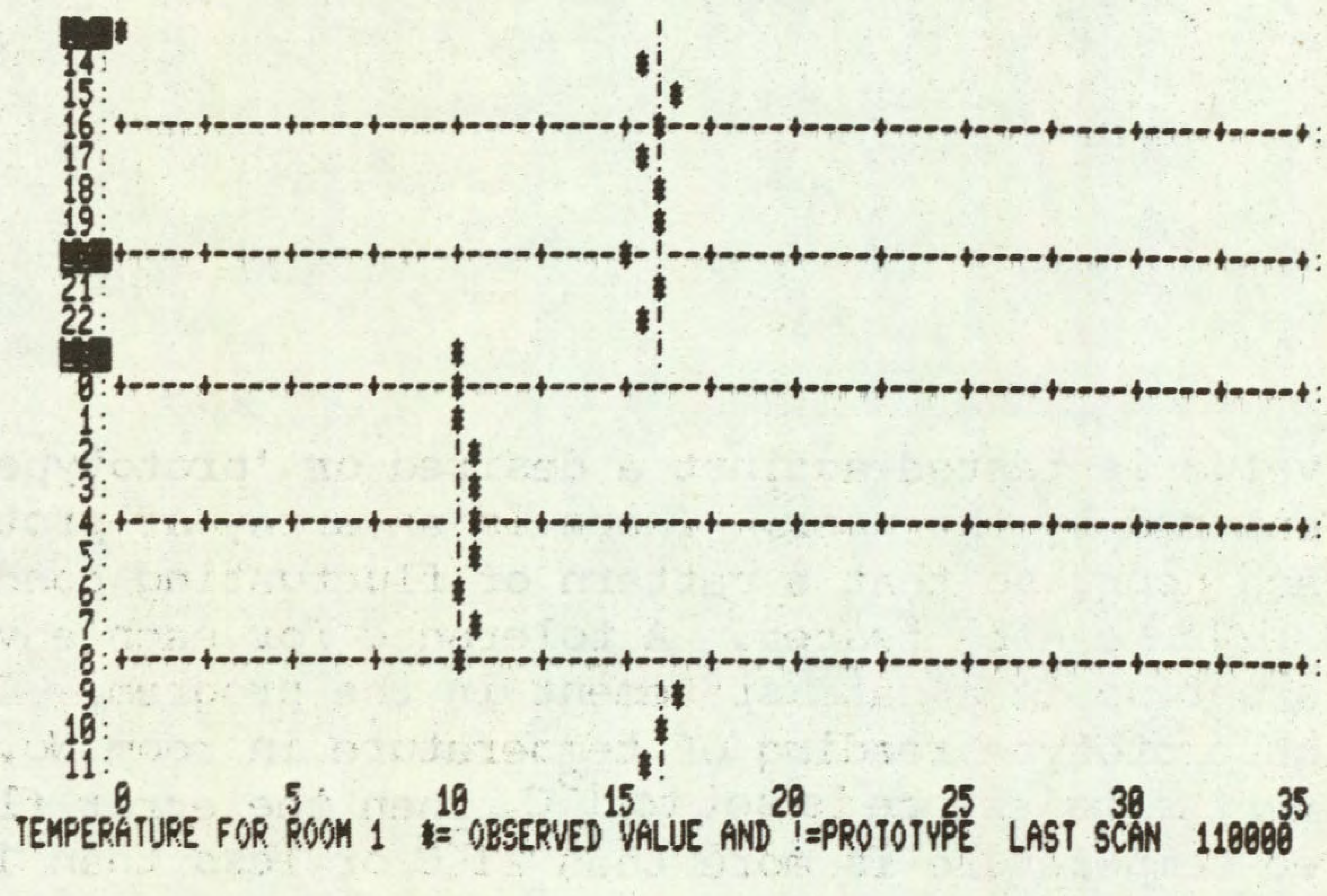


Fig. 2. Graphic display of one environment's temperature.

The ! line shows the expected or prototype display, the * line the measured values. Only 23 hours can be seen, the first hour is plotted, but is lost from the screen as the text is printed at the bottom.

room 2 day= 50 time= 113731 last scan 110000
19/ 2/ 82

| time | air temp | %rh | a.h.d. | time | air temp | %rh | a.h.d. |
|---|---|---|---|---|---|---|---|
| 12 | 16 | 74.98 | 1.31 | 0 | 10.64 | 87.02 | .57 |
| 13 | 16.08 | 77.69 | 1.16 | 1 | 10.71 | 87.59 | .54 |
| 14 | 15.78 | 77.54 | 1.16 | 2 | 10.66 | 85.1 | .65 |
| 15 | 15.7 | 79.55 | 1.05 | 3 | 10.74 | 86.23 | .6 |
| 16 | 15.83 | 81.43 | .96 | 4 | 10.76 | 86.24 | .6 |
| 17 | 15.63 | 80.9 | .98 | 5 | 10.74 | 85.41 | .64 |
| 18 | 15.68 | 81.84 | .93 | 6 | 10.64 | 84.55 | .68 |
| 19 | 15.55 | 82.71 | .88 | 7 | 10.76 | 85.96 | .62 |
| 20 | 15.5 | 80.16 | 1.01 | 8 | 10.71 | 84.85 | .67 |
| 21 | 15.63 | 79.98 | 1.03 | 9 | 15.88 | 79.4 | 1.07 |
| 22 | [illegible] | 73.63 | 1.3 | 10 | 16.18 | 79.08 | 1.09 |
| 23 | [illegible] | [illegible] | .52 | 11 | 16.1 | 77.48 | 1.18 |

Fig. 3.

Table of temperatures and humidities for a single environment. The inverse colour display indicates deviation from the preset tolerances.

Each hourly value is tested against a desired or 'prototype' value previously entered by the user. There is an array of prototype values, one for each hour, so that a pattern of fluctuating conditions (commonly day and night) can be tested. A tolerance for each environment and each factor is set up in a data statement in the program. Thus for example, if the prototype reading of temperature in room No. 3. at 10.00 is 20$^{\circ}$, and the tolerance is set to 1$^{\circ}$C, then the error flag is set if the measured temperature is more than 21$^{\circ}$C or less than 19$^{\circ}$C. The action taken on encountering an error flag varies from option to option. The basic display shows flagged values in inverse colour, as does option 3. Options 1 and 2 draw a line of prototype values, as well as a line of measured values, and indicate flagged measurements by inverting the colour of the corresponding hour digits on the time axis. Option 4 does not print in inverse, although there is a facility on the printer to do so if required.

Output cards on the logger connect to alarm indicators on the main alarm system module. Extra coding can be introduced to energise these alarms when an erroneous value is detected, though this facility is not currently employed, as an occasional sensor malfunction can result in an unnecessary and expensive maintenance call out at night. (It has been found that monitoring the electrical and mechanical performance of the environment equipment is a more reliable indication of malfunctions which require urgent maintenance. This is done with conventional overload trips, pressure switches and so on, operating audible and visual alarms.)

The secondary group of options are concerned with providing 'housekeeping' facilities. Each is selected by pressing a single character key, for example pressing 'T' enters the time and date setting routine allowing the user to correct these variables at will.

Options are provided for dumping all the current tables of values and prototype values on tape, and for retrieving them. This allows the computer to be switched off for example for maintenance of the mains supply, then put back into service with no loss of data.

Options are also available for storing and retrieving individual sets of prototype values on tape, so that particular patterns may be easily loaded. There are two ways of creating prototype values. One option is to copy the current day's measured readings and use these as a prototype for future days. This is fast, but any deviations in the chosen day's readings will be enshrined as part of the prototype pattern. Another option allows prototype readings to be created, or corrected, manually from the keyboard. Usually a combination of these methods is used when creating a new environment prototype.

The last option allows direct operation of the data logger from the computer keyboard. Once in this subroutine, the computer becomes 'transparent' to keystrokes, which are transmitted unaltered to the logger. Exceptions to this are certain logger command characters not present on the keyboard, which are generated by translating unused keyboard characters. Also, the symbol "?" is not transmitted but used to signal the end of the direct access routine. This direct access routine is the only one to have an explicit 'end' key. All the other option routines end either when they have finished their task, or if an interval timer within the program has timed out.

(c) <u>Presentation of options</u>

Originally the set of monitoring programs was intended for use by a limited number of trained staff, and required a certain degree of operator familiarity and a written guide. Later it was made available for all users of the controlled environment facility, and so the routines were re-written to allow unskilled users to operate them.

The main features of a program for general use are:

1) It tells the user how to operate it.

2) It is able to detect user errors and allow the user to correct the error easily.

Jenkins (1982) describes more fully how these features are implemented in the monitoring program.

DATA LOGGER FACILITIES

The system described uses the Commodore microcomputer as a means of sorting, labelling and displaying a basic set of information. In order that this standard program should be always available, and to avoid errors caused by users re-writing sections of BASIC coding, special measurements are normally accommodated using the built-in facilities of the IMP data logger. Examples of the type of measurement required are: mean daily light levels in a glasshouse, soil temperature measurements, and minute to minute measurements of control voltages when setting up chambers.

The data logger has a program area in which programs can be stored in a calculator-like language. Each input channel has a table in which the user can enter voltage range, scan speed, output device, and also the starting address of the program to be used on that channel's data. It is therefore relatively easy for users to set up a channel to log at given time intervals, and perform some kind of calculation on the measured value, outputting the result to an internal printer, or to a cassette tape. Commonly required routines for temperature linearising, relative humidity calculation and scaling of solarimeter readings are kept permanently available for users.

RELIABILITY & PERFORMANCE

Faults in the system can arise from several sources:

(a) Faulty sensors. The majority of errors in individual measurements are due to faulty sensors. It is difficult to ensure the reliability of wet bulb sensors even with careful maintenance of wicks and frequent calibrations. Some thermistor sensors are supplied with the sensing element embedded in a resin bead on the end of a stainless steel tube. This construction allows the thermistor to be very thin, and aspiration of the wet bulb is improved. However, it has been found that many of these thermistors fail due to the resin bead swelling and cracking when wetted, and this thermistor type has now been abandoned. Current thermistors have the sensing bead located in the end of a 3mm diameter stainless steel tube whose end has been sealed by welding.

Solarimeters are generally reliable, though in some cases, particularly when plugged into sockets in high humidity environments, both solarimeters and thermistors may give false readings due to poor plug contact.

(b) Data logger faults. The data logger suffered extensively from mains-borne transients when first delivered. Attempts to suppress the interference were unsuccessful, and the problem was eventually resolved by changing the mains supply to a different source, and fitting an improved power supply to the machine. There are one or two faults in the logger's own internal software, for example stack overflows occasionally arise when doing simple calculations which should only load the stack with one or two values, and there is a delay in updating the channel number when a scan of a new channel is requested via the serial input and output port, so that two requests are required to obtain the correct result.

(c) Computer faults. The computer has on occasions returned to the monitor routine for no apparent reason. Most other faults were traceable to early software offering inadequate protection against users, though there has been one hardware fault - in the video monitor. Input and output operations, including tape reading and writing, seem to have a very low error rate. Until recently, the computer was not protected against power supply interruptions, and an interruption of more than about 0.5 sec would result in loss of program and data. A sinewave inverter has now been obtained. This has a standby battery and will power the computer without interruption during power cuts.

ADVANTAGES & LIMITATIONS OF THE SYSTEM

The computer controlled system replaced an earlier logging facility in which the measurements were printed out every hour without formatting, labels or other identifying text. It proved difficult for users to find the information they wanted, and much paper was wasted printing redundant information.

The present system presents the information in a more understandable way and allows users to choose the information they require. Errors are identified and displayed, encouraging prompt rectification. Printing is in a compact format and archive printouts are generated at midnight, when the noise of the printer is unlikely to disturb anyone. The logger's own programmable scheduler and calculator makes it easy to set up short term measurements very quickly.

There are limitations to the present system, mainly because of the decision not to employ a magnetic disc store. The computer cannot reload itself after a malfunction and hence errors causing the program to fail need manual intervention. Tape storage and retrieval of information, though very reliable, is much slower than disc, for example, loading new sets of prototype values takes several minutes. The system has no software-independent calendar and hence is not able to reset the date after a program reload. The logger is still occasionally susceptible to electrical interference, the effect often being to corrupt the service routines so that the input ports are not inspected and hence no commands can be issued to it.

On balance however these limitations do not prevent the system serving its purpose, and there has been a noticeable improvement in the quality of environment control and the ease with which errors are detected.

ACKNOWLEDGEMENTS

The author wishes to thank Mr W Jenkins for the provision of the computer programs, and Mr C J Stent for his time spent testing the programs, and his invaluable suggestions for improvements.

REFERENCES

Institute of Electrical and Electronic engineers (1978) Digital Interface for programmable instrumentation. IEEE Standards Board. Standard No. 488-1978.

Jenkins, W. (1982) Annual report ARC Letcombe Laboratory 1982.

Simmons, R.C. (1978) Simple multiple thermistor thermometer for use with data loggers. Laboratory Practice. January 1978.

APPENDIX List of Equipment Suppliers

| | | |
|---|---|---|
| Data Logger | IMP | Micro Consultants Ltd.,<br>Kenley House, Kenley Lane,<br>Kenley, Surrey CR2 5YR. |
| Computer<br>Printer<br><br>IEEE/RS232<br>Interface | Commodore 8032 | Anaspec Ltd.,<br>PO Box 25<br>Newbury, Berks. RG14 5BS |
| Thermistor Psychrometers<br><br>Tube solarimeters | WVU<br><br>TSM | Delta-T devices Ltd.,<br>Low Road,<br>Burwell, Cambridge |
| Cable, connectors,<br>miscellaneous electronic<br>components | | RS Components,<br>PO Box 427<br>13-17 Epworth Street<br>London EC2P 2HA |

## ABBREVIATIONS

| | |
|---|---|
| ångström | Å |
| Abstract | Abs. |
| acid equivalent* | a.e. |
| acre | ac |
| active ingredient* | a.i. |
| approximately equal to* | $\simeq$ |
| aqueous concentrate | a.c. |
| bibliography | bibl. |
| boiling point | b.p. |
| bushel | bu |
| centigrade | C |
| centimetre* | cm |
| concentrated | concd |
| concentration | concn |
| concentration x time product | ct |
| concentration required to kill 50% test animals | LC50 |
| cubic centimetre* | $cm^3$ |
| cubic foot* | $ft^3$ |
| cubic inch* | $in^3$ |
| cubic metre* | $m^3$ |
| cubic yard* | $yd^3$ |
| cultivar(s) | cv. |
| curie* | Ci |
| degree Celsius* | $^oC$ |
| degree centigrade | $^oC$ |
| degree Fahrenheit* | $^oF$ |
| diameter | diam. |
| diameter at breast height | d.b.h. |
| divided by* | $\div$ or / |
| dry matter | d.m. |
| emulsifiable concentrate | e.c. |
| equal to* | = |
| fluid | fl. |
| foot | ft |

| | |
|---|---|
| freezing point | f.p. |
| from summary | F.s. |
| gallon | gal |
| gallons per hour | gal/h |
| gallons per acre | gal/ac |
| gas liquid chromatography | GLC |
| gramme | g |
| hectare | ha |
| hectokilogram | hkg |
| high volume | HV |
| horse power | hp |
| hour | h |
| hundredweight* | cwt |
| hydrogen ion concentration* | pH |
| inch | in. |
| infra red | i.r. |
| kilogramme | kg |
| kilo ($x10^3$) | k |
| less than | $<$ |
| litre | l. |
| low volume | LV |
| maximum | max. |
| median lethal dose | LD50 |
| medium volume | MV |
| melting point | m.p. |
| metre | m |
| micro ($x10^{-6}$) | µ |
| microgramme* | µg |
| micromicro (pico: $x10^{-12}$)* | µµ |
| micrometre (micron)* | µm (or µ) |
| micron (micrometre)*† | µm (or µ) |
| miles per hour* | mile/h |
| milli ($x10^{-3}$) | m |
| milliequivalent* | m.equiv. |
| milligramme | mg |
| millilitre | ml |

† The name micrometre is preferred to micron and µm is preferred to µ.

| | |
|---|---|
| millimetre* | mm |
| millimicro* (nano: $x10^{-9}$) | n or mμ |
| minimum | min. |
| minus | - |
| minute | min |
| molar concentration* | M (small cap) |
| molecule, molecular | mol. |
| more than | > |
| multiplied by* | x |
| normal concentration* | N (small cap) |
| not dated | n.d. |
| oil miscible concentrate | o.m.c. (tables only) |
| organic matter | o.m. |
| ounce | oz |
| ounces per gallon | oz/gal |
| page | p. |
| pages | pp. |
| parts per million | ppm |
| parts per million by volume | ppmv |
| parts per million by weight | ppmw |
| percent(age) | % |
| pico (micromicro: $x10^{-12}$) | p or μμ |
| pint | pint |
| pints per acre | pints/ac |
| plus or minus* | ± |
| post-emergence | post-em |
| pound | lb |
| pound per acre* | lb/ac |
| pounds per minute | lb/min |
| pound per square inch* | $lb/in^2$ |
| powder for dry application | p. (tables only) |
| power take off | p.t.o. |
| precipitate (noun) | ppt. |
| pre-emergence | pre-em. |
| quart | quart |
| relative humidity | r.h. |
| revolution per minute* | rev/min |
| second | s |
| soluble concentrate | s.c. |
| soluble powder | s.p. |
| solution | soln |
| species (singular) | sp. |
| species (plural) | spp. |
| specific gravity | sp. gr. |
| square foot* | $ft^2$ |
| square inch | $in^2$ |
| square metre* | $m^2$ |
| square root of* | $\sqrt{\ }$ |
| sub-species* | ssp. |
| summary | s. |
| temperature | temp. |
| ton | ton |
| tonne | t |
| ultra-low volume | ULV |
| ultra violet | u.v. |
| vapour density | v.d. |
| vapour pressure | v.p. |
| <u>varietas</u> | var. |
| volt | V |
| volume | vol. |
| volume per volume | v/v |
| water soluble powder | w.s.p. (tables only) |
| watt | W |
| weight | wt |
| weight per volume* | w/v |
| weight per weight* | w/w |
| wettable powder | w.p. |
| yard | yd |
| yards per minute | yd/min |

* Those marked * should normally be used in the text as well as in tables etc.

# WEED RESEARCH ORGANIZATION

TECHNICAL REPORTS
(Price includes surface mail; airmail £1.00 extra)
(* denotes Reports now out of print)

6. The botany, ecology, agronomy and control of Poa trivialis L. rough-stalked meadow-grass. November 1966. G P Allen. Price - £0.25

7. Flame cultivation experiments 1965. October, 1966. G W Ivens. Price - £0.25

8. The development of selective herbicides for kale in the United Kingdom. 2. The methylthiotriazines. Price - £0.25

10. The liverwort, Marchantia polymorpha L. as a weed problem in horticulture; its extent and control. July 1968. I E Henson. Price - £0.25

11. Raising plants for herbicide evaluation; a comparison of compost types. July 1968. I E Henson. Price - £0.25

*12. Studies on the regeneration of perennial weeds in the glasshouse; I. Temperate species. May 1969. I E Henson. Price - £0.25

13. Changes in the germination capacity of three Polygonum species following low temperature moist storage. June 1969. I E Henson. Price. - £0.25

14. Studies on the regeneration of perennial weeds in the glasshouse. II. Tropical species. May 1970. I E Henson. Price - £0.25

15. Methods of Analysis for herbicide residues. February 1977. (second edition) - price £5.75

16. Report on a joint survey of the presence of wild oat seeds in cereal seed drills in the United Kingdom during Spring 1970. November 1970. J G Elliott and P J Attwood. Price - £0.25

17. The pre-emergence selectivity of some newly developed herbicides, Orga 3045 (in comparison with dalapon), haloxydine (PP 493), HZ 52.112, pronamide (RH 315) and R 12001. January 1971. W G Richardson, C Parker and K Holly. Price - £0.25

18. A survey from the roadside of the state of post-harvest operations in Oxfordshire in 1971. November 1971. A Phillipson. Price - £0.12

*19. The pre-emergence selectivity of some recently developed herbicides in jute, kenaf and sesamum, and their activity against Oxalis latifolia. December 1971. M L Dean and C Parker. Price - £0.25.

* 20. A survey of cereal husbandry and weed control in three regions of England. July 1972. A Phillipson, T W Cox and J G Elliott. Price - £0.35

21. An automatic punching counter. November 1972. R C Simmons. Price - £0.30

22. The pre-emergence selectivity of some newly developed herbicides: bentazon, BAS 3730H, metflurazone, SAN 9789, HER 52.123, U 27,267. December 1972. W G Richardson and M L Dean. Price - £0.25

23. A survey of the presence of wild oats and blackgrass in parts of the United Kingdom during summer 1972. A Phillipson. Price - £0.25

24. The conduct of field experiments at the Weed Research Organization. February 1973. J G Elliott, J Holroyd and T O Robson. Price - £1.25

25. The pre-emergence selectivity of some recently developed herbicides: lenacil, RU 12068, metribuzin, cyprazine, EMD-IT 5914 and benthiocarb. August 1973. W G Richardson and M L Dean. Price - £1.75.

26. The post-emergence selectivity of some recently developed herbicides: bentazon, EMD-IT 6412, cyprazine, metribuzin, chlornitrofen, glyphosate, MC 4379, chlorfenprop-methyl. October 1973. W G Richardson and M L Dean. Price - £3.31

27. Selectivity of benzene sulphonyl carbamate herbicides between various pasture grasses and clover. October 1973. A M Blair. Price - £1.05

28. The post-emergence selectivity of eight herbicides between pasture grasses: RP 17623, HOE 701, BAS 3790, metoxuron, RU 12068, cyprazine, MC 4379, metribuzin. October 1973. A M Blair. Price - £1.00

* 29. The pre-emergence selectivity between pasture grasses of twelve herbicides: haloxydine, pronamide, NC 8438, Orga 3045, chlortoluron, metoxuron, dicamba, isopropalin, carbetamide, MC 4379, MBR 8251 and EMD-IT 5914. November 1973. A M Blair. Price - £1.30

30. Herbicides for the control of the broad-leaved dock (Rumex obtusifolius L.). November 1973. A M Blair and J Holroyd. Price - £1.06

31. Factors affecting the selectivity of six soil acting herbicides against Cyperus rotundus. February 1974. M L Dean and C Parker. Price - £1.10

32. The activity and post-emergence selectivity of some recently developed herbicides: oxadiazon, U-29,722, U-27,658, metflurazone, norflurazone, AC 50-191, AC 84,777 and iprymidam. June 1974. W G Richardson and M L Dean. Price - £3.62

33. A permanent automatic weather station using digital integrators. September 1974. R C Simmons. Price £0.63.

34. The activity and pre-emergence selectivity of some recently developed herbicides: trifluralin, isopropalin, oryzalin, dinitramine, bifenox and perfluidone. November 1974. W G Richardson and M L Dean. Price - £2.50

35. A survey of aquatic weed control methods used by Internal Drainage Boards, 1973. January 1975. T O Robson. Price - £1.39

36. The activity and pre-emergence selectivity of some recently developed herbicides: Bayer 94871, tebuthiuron, AC 92553. March 1975. W G Richardson and M L Dean. Price - £1.54

37. Studies on Imperata cylindrica (L.) Beauv. and Eupatorium odoratum L. October 1975. G W Ivens. Price - £1.75

38. The activity and pre-emergence selectivity of some recently developed herbicides: metamitron, HOE 22870, HOE 23408, RH 2915, RP 20630. March 1976. W G Richardson, M L Dean and C Parker. Price - £3.25

39. The activity and post-emergence selectivity of some recently developed herbicides: HOE 22870, HOE 23408, flamprop-methyl, metamitron and cyperquat. May 1976. W G Richardson and C Parker. Price - £3.20

40. The activity and pre-emergence selectivity of some recently developed herbicides: RP 20810, oxadiazon, chlornitrofen, nitrofen, flamprop--isopropyl. August 1976. W G Richardson, M L Dean and C Parker. Price - £2.75.

41. The activity and pre-emergence selectivity of some recently developed herbicides: K 1441, mefluidide, WL 29226, epronaz, Dowco 290 and triclopyr. November 1976. W G Richardson and C Parker. Price - £3.40.

42. The activity and post-emergence selectivity of some recently developed herbicides: KUE 2079A, HOE 29152, RH 2915, Triclopyr and Dowco 290. March 1977. W G Richardson and C Parker. Price - £3.50

43. The activity and pre-emergence selectivity of some recently developed herbicides: dimefuron, hexazinone, trifop-methyl, fluothiuron, buthidazole and butam. November 1977. W G Richardson and C Parker. Price - £3.75.

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62. The activity and pre-emergence selectivity of some recently developed herbicides: UBI S-734, SSH-43, ARD 34/02 (= NP 55), PP 009 and DPX 4189. February 1981. W G Richardson, T M West and C Parker. Price - £3.50

63. The activity and post-emergence selectivity of some recently developed herbicides: SSH-41, MB 30755, AC 213087, AC 222293 and Dowco 433. May 1981. W G Richardson, T M West and C Parker. Price - £3.50

64. The activity and pre-emergence selectivity of some recently developed herbicides: chlomethoxynil, NC 20484 and MBR 18337. March 1982. W G Richardson, T M West and C Parker. Price - £3.00

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