Chapter 13

Computer Integrated On-Line Weather Station and Water Management For Typical Crops

Luis M.J. Carvalho and William James

School of Engineering
University of Guelph

13.1 Questionnaire

A computer tool for farm managers with on-line weather station will help to ameliorate two present day water management concerns: nonpoint source nitrate pollution and the availability of spatially appropriate weather data. Development and successful implementation of a widely acceptable and relevant computer system for farm management necessitates input from the farmers/users. This information includes basic physical farm data (such as farm area) and crop/water cultivation practices. It is also important to gauge the current level of computer technology on the farm and its acceptance. Farm manager's perceptions of the benefits of a computer system, and what components such a program should have, must also be identified. To collect this data a farm/computer survey was drafted by Jim Law and Brett Young. The results of this survey were used as a basis for the design of a widely-applicable computer-based management

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system.

A total of one hundred and forty eight surveys were mailed to farms in Southern Ontario. Forty eight were mailed back to the School of Engineering, representing a return rate of 32%. The average farm area was six hundred and thirty acres (Table 13.1), a significant size especially in terms of impact, on local streams, from agricultural runoff. The average number of years the farm operated under the same management was nineteen years. Managers or potential system users are therefore unlikely to change very rapidly so that the project can expect a measure of continuity. Also constant is the wide use of corn and its inclusion in most crop rotations. For these reasons, and the fact that most farm managers have grown the same crops for more than five years, corn is a focus of the computer management system.

Table 13.1: General

630 acres	Average farm area
19 years	Average time under same management
Corn	Most widely cultivated crop
83%	Farmers growing similar crops for over 5 years
92%	Farmers who practice crop rotation
83%	Farmers who will include corn in their crop rotation

Most farm managers have had computer experience (Table 13.2). A slightly smaller percent have access to computers. Most of these computers are IBMs or IBM compatible. The same number that have access to computers are also willing to upgrade their present system. Clearly any computer application geared towards these farm managers must be IBM compatible.

The most popular types of software on the farm were word processors, spread sheets and accounting packages (Table 13.3). Most of the present applications are relatively un-sophisticated

Table 13.2: Computers

63%	Farmers who have access to computers
	- 1 Apple
	- 18 IBM
	- 11 Others
63%	Farmers willing to upgrade computer
83%	Farmers who have computer experience

and deal mainly with financial data management and writing. However it was interesting to observe that farm managers used crop management computer programs in conjunction with their personal computers. Increased use of this software is expected as crop management software was the most popular program farm managers felt should be included in a farm management computer system. Weather was also mentioned in this section, as the second most popular feature. In general there was an overall willingness to acquire and use additional and more sophisticated software.

The environmental section in the survey was designed to identify environmentally-related farm concerns and how the farm managers felt a computer system could be used in this respect (Table 13.4). The features that farm managers thought should be included in a computer system are application rates and dates of farm chemicals and weather. The group most often responsible for the application of chemicals on the farm are the farmers and managers themselves. This strongly suggests that chemical-application software developed specifically for farm managers could be viable and perhaps necessary.

27% of farms have ponds, all of which, save one, have algae problems. This may be an indicator demanding more effective control of fertilizer application on the nearby fields. Further, this could be especially significant to potential water quality problems, as most farms have at least one well. Questions are therefore

Table 13.3: Software

Software presently being used	
68%	Word processing
68%	Spreadsheets
59%	Accounting
36%	Database
Desired features in a computer system	
73%	Crop Management
60%	Weather
56%	Accounting/Tax/Inventory
54%	Livestock/Management

raised as to quality of the well water, extent of possible contamination and well-water uses. Interestingly though, most farm managers reported no water quality problem on their property, an obvious contradiction which should be further investigated in order to assess more clearly present problems or simply gauge water quality perceptions in the farm community.

Animal management, although financially significant to most farms was too diversified (Table 13.5 & 13.6). It did not allow the development of a management system that could be used by a large segment of farm managers, as was the case with the corn crop. This section of the survey does serve to further emphasise the concern farm managers have with manure handling and the environment (Table 13.7).

The farm managers were questioned on the instruments they currently use and those they would like to use, as well as the type of weather data they would like to see included in a computer system. Rain data was cited most (Table 13.8). Almost all the farm managers have a rain gauge and hence few are willing to get another. However, these gauges are thought to be non-recording, totalizing gauges. Such an instrument would not be suitable for

Table 13.4: Environmental

Desired features in computer system	
77%	Fertilizer application rates/dates
75%	Pesticide application rates/dates
67%	Weather
Applicators of farm chemicals	
69%	Farm managers
4%	Contractors
Water and farms	
27%	Farms have ponds
25%	Farms have algae problems
83%	Farms have wells
2	Farms reporting water quality problems
36	Farm reporting no water quality problems

Table 13.5: Animal management.

Farms	Income %
6	Less than 25%
6	Between 25 %-50%
9	Between 50 %-75%
19	Greater than 75%
6	Did not respond

Table 13.6: Livestock distribution.

TYPE OF LIVESTOCK	FARMS	AVERAGE HEAD COUNT	MIN. HEAD COUNT	MAX. HEAD COUNT
HOGS	8	795	9	4000
DAIRY	18	126	55	300
POULTRY	11	11386	8	50000
MINK	1	1200	-	-
BEEF	15	143	2	600
HORSES	4	4.5	1	10
RABBIT	1	40	-	-
SHEEP	1	150	-	-

Table 13.7: Livestock computer system.

Desired features in computer system	
58%	Feed
58%	Cost
56%	Health
23%	Manure
15%	Environment

a computer system. Inexpensive recording rain gauges however are predicted to find acceptance as there is no manual labour involved with collecting the data. This improvement would also be welcomed by the farm managers if they had a better understanding of recording time steps and how these relate to their farm operation. A curious observation is the willingness of the farm managers to install humidity meters but humidity as a data type has a relatively small desirability in a computer system.

However, there is no doubt that farm managers would like temperature sensors and some measure of sunlight or radiation (heat units are calculated using temperature). The farm managers seem to know what weather parameters they would like to have but showed some doubt about recording time intervals. Almost 70% are willing to install some meteorological equipment and connect it to their computer.

Table 13.8: Meteorological

INSTRUMENTS	PRESENT	WILLING
Rain Gauge	39	3
Snow Depth Gauge	0	18
Air Temperature	14	19
Humidity Meter	6	26
Anemometer	2	20
Water Levels in Shallow Wells (depth < 15m)	0	16
Water Level in Deep Wells (depth > 15m)	0	13
Hours of Sunlight	0	26

Desired weather data for computer system	
38%	Rain
25%	Heat units
6%	Humidity

In general there was a great deal of interest in a computer-integrated management system for the farm. 81% of the respondents would like to be kept informed of progress while 67% would like to participate. A map displaying the locations of the interested farms was prepared to illustrate the dense spatial coverage a network of computerized weather stations could provide.

One of the most critical factors in this project is the cost that farm managers are willing to incur to purchase the system (Table 13.9). Implementation and development of this project is expected to be self-supporting. Therefore it is vital that the cost to the farm manager be within an acceptable range. Excluding computer upgrading costs, implementation of the computer system on the farm should be kept, if possible, below \$600.

Given that initial acceptance is successful, increasing numbers of farm managers are expected to show interest in the project. This prediction is based, among other things, on the increasing use of computers on farms. J.P. Loranger (1990), indicated that there were 42,000 farmers in Quebec and that a surprising 25% use computers, a high percentage in lieu of the September 1988 Canadian Census report entitled "A Profile Of Farmers With Computers." The report documented that in 1986, just under 2% of Quebec farmers used a computer principally in managing their farm business, while for the whole of Canada the average was 2.6% (Bollman, 1988). The Quebec survey indicates the rapid acceptance and application of computers on the farm. Grant G. Murray quotes a Cornell University Study where "by 1989, fully 15% of U.S. farmers were using Computers" (Murray, 1990), stating that "agriculture may be among the fastest-growing sectors for information technology applications" (Murray, 1990).

As it becomes an essential part of farm management, the computer will be expected to perform three main functions: cognition and communication, data and knowledge management, information processing (Gauthier, 1987). Implied in these functions is the need for sensors, data links to other systems and interfaces with the operators (Gauthier, 1987).

The benefits to farmers at the farm level could come as

Table 13.9: Expenses farmers are willing to incur to participate in project.

Computer upgrade		
19%	21%	23%
< \$2,000	\$2,000 - \$5,000	\$5,000 - \$8,000
Crop Management Software		
19%	44%	8%
< \$50	\$50 - \$200	> \$200
Livestock Management Software		
19%	40%	10%
< \$50	\$50 - \$200	> \$200
Weather Instruments		
27%	33%	8%
< \$50	\$50 - \$100	\$100 - \$200
Workshops		
42%	33%	2%
< \$50	\$50 - \$100	\$100 - \$200

improved ability to select variety, planting date, crop mix and to evaluate various management strategies (Mishoe, 1988). To meet such aims and better predict the development of a crop, there is a need to integrate, crop, soil, pest and fertility information (Mishoe, 1988). "There is a large demand for combining crop models with data bases on soils and weather to allow users to evaluate policies and strategies" (Jones, undated).

"Critical to the use of these models is the availability of weather data that are representative of the actual weather for the specific location or region for which these models are applied" (Mishoe, 1982). The implementation of an automatic

meteorological measuring and recording system is expected to maintain a higher level of integrity than one necessitating a human operator. A weather station connected to a home computer is expected to reduce or eliminate human error, an inherent problem in non-automatic meteorological stations. The integrity of data collection sensors may also be better assured by examining the data in a timely manner (Titlow, 1988). To do this, the inclusion of a modem for regular communication would be necessary. This feature could yield many additional benefits as it introduces the user to yet another very powerful tool.

The components of a computer integrated system should be designed such that it operates simply and in a user friendly manner. "... to facilitate the application of crop models for those who did not develop them, they must be integrated with data bases and utilities that provide the user access to functions needed for the analysis" (Jones, undated). The only operation the farm manager should be expected to perform is some data entry and analysis of modelling results.

The crop management system should then help evaluate corn management practices using yield prediction as an output. Modelling of this system should be locally relevant both in terms of farm field specifics, such as chemical applications, as well as weather. The system should shelter the user where possible from operational details such as program execution management, data acquisition, data management and data presentation. This system should therefore include: a computer, modem, weather instruments, weather data logging device, crop model, data base and a shell to manage the operation of all the components and provide a user interface.

13.2 Crop Model

The crop model must simulate crop growth and development through the various phenological stages and represent these quantitatively with respect to time. A principal concern in the

selection of a corn growth model was that it be complete, commercially available and supported. Such models are not suitable for the computer integrated system as the model must simulate the whole plant and life cycle as influenced by management and environmental factors. The desired full crop growth model could be very complex, so it must be accompanied by documentation and sample input and output files.

A search using farm software catalogues was conducted to find the best model. It was discovered that most of the programs available and relating to corn yield and corn management were not growth simulators but financial programs. The only complete program listed which modelled corn growth was Ceres-Maize.

Ceres-Maize uses weather, soil, management and cultivar parameters to predict among other things, local hydrologic cycle, nitrogen cycle, carbon cycle, phenological development and grain yield (Jones, 1986). These calculations are made with respect to time measured in days. Ceres-Maize organizes the input data in two files, the parameter input file and the weather input file. The weather file contains total radiation, maximum temperature, minimum temperature and total precipitation on a daily basis. The parameter input file contains information relating to soil type, soil water characteristics, soil chemistry, cultivar traits, irrigation and management decisions.

Ceres-Maize (Version 2.1 especially) is one of a number of crop models that use standardized input data sets (Hoogenboom, 1990). These crop models include wheat, rice, sorghum, millet, barley, potato, soybean, peanut and dry bean growth simulation (Hoogenboom, 1990). These models have been incorporated into the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project, part of Decision Support System for Agrotechnology Transfer (DSSAT) (Hoogenboom, 1990). This could lead to further system expansion as it facilitates future adoption of other crop models into the CICMS or integration with DSSAT. Selecting Ceres-Maize therefore forces the construction of a system basic to other crop models. This will facilitate future adoption of other crop models into CICMS or integration with

DSSAT.

13.3 Weather Station

The center-piece of an automatic weather station is the data logging system for collecting and storing weather data. The data logger works in conjunction with a PC and must feature easy transferability of weather data to the PC/XT/AT, '386 or '486. Moreover it should permit the farm computer to be used simultaneously for other operations. This means that the datalogger must also be able to operate in background mode, as XT computers are not able to perform multitasking functions.

The data logger must be able to collect the signals from the weather instruments (a) specified in the CIFM Survey and (b) required by the simulation crop model for corn growth. The most constraining factor for selecting the data logger is the cost. The CIFM farm survey indicated that only four farm managers were willing to spend between \$250 and \$500 on weather instruments. Most respondents would not pay more than \$250. Thus an overriding constraint of this study was that both the weather instrumentation (sensors) and the data logger were to be inexpensive, which severely restricted the choices.

Various data loggers were investigated from companies such as LI-COR, Geneq Inc and Solus Systems Inc. Keithley and Connect Tech Inc. carry data logging computer cards that satisfy the three main technical criteria: (1) support weather instruments, (2) operate in background mode and (3) easily transfer data to the PC. Unfortunately their cards and accompanying software all exceed \$1,000 in cost. Only Digital offered a data logging system for less than \$1,000. For \$398(US) Digital offered (in 1991) a weather station system with a data logging computer card that satisfied the criteria and included an anemometer, wind vane, two thermistors, a precipitation gauge, barometric pressure transducer and operating software.

13.4 PC Weather

The "PcWeather" (PcW) station with expanded software is a product of Digitar of Hayward, California. The PcW station has three main components: (a) the data logger, (b) software and (c) instruments. PcW uses a computer card for data collection and storage. The card has five accessible channels, one digital and four analog. As its power source, the card uses an 8 volt adapter that must always be connected. A power failure may result in data loss. Power loss to the card can result in some operating options being reset to factory values. To prevent this an optional power adapter and charger is available to prevent this type of data loss. The computer card downloads weather data to a hard drive or computer diskette every 30 minutes.

PcW software gives the user a large number of operational and data output options. The most important feature of PcW is its ability to run in either foreground or background mode. The PcW program can be executed either by typing PCWPRO at the DOS prompt or by using the "hot keys" when in background mode. The program can be invoked from within other programs such as Word Perfect by pressing the hot key sequence. The hot keys are a combination of keyboard keys that are pressed simultaneously. The PcW program contains a number of menus from which alarms may be set, paths chosen, instruments calibrated, settings initialized and data presented. The PcW data menu options summarize weather data graphically and numerically. Screens with greater degree of detail can also be displayed as well as graphs illustrating the changing weather in 30 minute intervals over a 24 four hour period.

Operation in background mode allows access to the computer to perform regular computer operations while continuing to collect weather data. The operation of PcW in the background has almost no effect on the normal operation of whatever program is being run in the foreground. The only difference that may be observed is a temporary but short pause when PcW downloads data from the data logging card to the hard drive or diskette once

every 30 minutes.

The PcW system will also allow the execution of user programs that access the weather card. In the course of temperature data investigations the BASIC program TEMP23.BAS was written by the author. It displays weather data on the screen in one-minute time-steps and at 2400 hours creates a file in which it stores the day's weather data in one minute intervals.

13.5 Weather Instruments

Some instrument alteration and development was attempted in order to better accommodate the desires of the farm managers and to provide weather data input for the crop model. The first modification was carried out on the precipitation gauge supplied with PcW which was not suitable. Second, an affordable radiation meter had to be designed.

13.5.1 Rain Gauge

Although there are a number of variations on the siphon principle, the common basic principle is a siphon working in combination with a float and a float chamber (Doorenbos, 1976). When a known amount of water is collected a siphon drains water, which causes a float to rise in the float chamber, which in turn causes a switch or lever to transmit a signal (Doorenbos, 1976). The signal then corresponds to a known volume of precipitation.

There are a number of possible sources of error associated with these types of gauges: 1. The rate at which the siphon drains is a limiting condition (Doorenbos, 1976) which, depending on rainfall intensity, could result in significant error. 2. The siphon does not completely drain the collecting container. 3. The amount of water that is at the bottom of the chamber changes with evaporation introducing an additional source of error (Doorenbos, 1976). 4. In general this type of gauge is very

delicate and easily affected by dust and insects (Doorenbos, 1976). 5. Gauge calibration is very important and its neglect may cause large errors (Doorenbos, 1976).

The precipitation gauge included in the PcW package (1990) was a small siphon gauge with a float. As the float rose it closed a reed switch. Each switch closure indicated 2.54 mm (0.1") rain. The PcW siphon gauge in addition to the measuring problems already discussed is also subject to error arising from its small size. The collecting funnel has a diameter of 7.1 cm and gauges with a diameter less than 10 cm can produce additional error in total rain collection (Doorenbos, 1976).

The tipping bucket on the other hand comprises a collecting funnel, tipping bucket and a switch. The funnel collects and directs the rain water into a wedge shaped bucket. When the bucket is full, the weight of the water causes the bucket to tip, emptying the water and positioning the second bucket under the funnel. Every time the bucket tips, a switch closes a circuit indicating that a known weight of rain has been collected. This type of gauge experiences some error at the beginning and end of a rain event: the bucket may contain an amount of water in the bucket from a previous event that was not sufficient to tip the bucket. This error causes the gauge to under-measure the total amount of rainfall for that period (thus rainfall intensity is also under-measured).

If this same rain water is present at the beginning of a subsequent rainfall event, then measured rainfall error is passed on to that event. The intensity of the event as well as the total rainfall amount at the beginning of the storm is over-estimated; when the bucket tips for the first time at the beginning of an event it is impossible to estimate the time that rainfall commenced and therefore the duration for calculating intensity. Further, as with siphon gauges, evaporation of the water in the bucket between events causes an under-measurement of total rainfall.

The gauge that requires the least amount of maintenance and attention of a skilled person is the tipping bucket. It will therefore be more likely to yield better and more consistent results than the other gauges given the same amount of care. The

tipping bucket gauge will also experience less data recording interruptions as maintenance and repairs will be less frequent. Erroneous data recorded while the gauge was uncalibrated or working improperly could be hard to identify and correct. These reasons make the tipping bucket gauge the most appropriate choice for a farm weather station.

A "Rainwise" tipping bucket rain gauge was purchased for under \$150 (Cdn) and can be purchased in the United States for well under \$100 (Cdn). The low cost of this instrument is also compatible with the low equipment cost criteria for the acceptability of this weather station. The plastic Rainwise gauge may use a 22.15 cm in diameter collecting funnel which directs water into the 10 cm³ tipping bucket. With this arrangement every tip of the bucket corresponds to 0.26 mm or 0.01 inches of rain.

As a preventive measure it was decided that the rain gauge should be equipped with a device to prevent freezing. A plastic tube was used to raise the gauge funnel from the base to provide space for an automotive light bulb to be installed. The funnel was extended internally to slightly above the tipping bucket to prevent errors due to splash. When air temperature drops below freezing the light is turned on, by the farm manager, using a 12 V DC power adapter. This arrangement also measures approximate frozen or crystallized precipitation. The error however is expected to be high because evaporation losses may be significant (the intensity of the light bulb is not adjustable). On the other hand, this technology is not being used at present at the local farm level; in fact, no winter precipitation of any kind is being measured on the farm. Estimates of frozen precipitation, and intensity, may offer other benefits, but further study is recommended to determine the measurement error.

An improvement to the light bulb arrangement was proposed by Greg Noakes (1991), an undergraduate at the School of Engineering, in a final design project. The basic approach was to use a controller to maintain a metal collecting funnel at just above freezing. This device is a definite improvement but incurs a relatively greater cost. It is also recommended that a comparative

study of these two systems be conducted to assess their costs and performance.

13.5.2 Solar Radiation Meters

The purchase of commercially available pyranometers for integration into the system was avoided due to their high cost. Therefore, a number of devices were constructed and tested in an effort to measure total daily short wave radiation affordably. An Eppley pyranometer was used as the reference instrument to calibrate and judge the performance of the experimental pyranometers. The experimental pyranometers can be divided in two groups: 1. those dependant on temperature difference between different surfaces, and 2. those with photoconductive properties. All these devices respond as variable resistors, so that their signal may be measured by one or both of the temperature ports on the PcW data logging card. This approach was adopted because of the greater need for radiation and temperature data than for two temperature readings. This approach will also avoid the need to alter the existing hardware configuration. A description and discussion of these instruments follows.

Temperature Sensors

Three devices were constructed on the principle that the temperature difference between two surfaces of different reflectance could yield a measure of solar radiation. A body at the earth's surface is subject to radiation gains and losses from and to various sources. The gains are: a. incident short wave radiation (direct and reflected) and b. absorbed long wave radiation. The losses are: a. reflected and transmitted shortwave radiation and b. emitted long wave radiation. The difference between the gains and losses is referred to as net radiation (Monteith, 1973).

If two identical bodies were subject to identical radiative conditions, the net radiation each would experience would be

identical. However, if one of these bodies has a white surface and the other a black surface, their net radiation will not be the same: one body absorbs radiation in the visible range while the other does not. As the two different bodies receive differing amounts of energy, their temperatures will differ, and different amounts of long wave radiation will be emitted by the bodies, as given by Equation 6.2 (De Jong, 1973).

$$R_B \uparrow = \epsilon \sigma T^4 \quad (13.1)$$

$R_B \uparrow$ = Long wave radiation emitted by a surface
(Cal.cm⁻².day⁻¹)

σ = Stefan-Boltzman Const. (Cal.cm⁻².day⁻¹.K⁻⁴)

ϵ = coefficient of deviation from black body
characteristics

T = Temperature (K)

The significance of the difference in long wave radiation emittance by the two bodies must be determined. In particular, their relative importance in comparison to short wave radiation must be resolved. However, since the difference in the long wave radiation emittance is a result of the different amount of short wave radiation received, the difference in net radiation should be directly proportional to the amount of visible radiation. In addition, the temperature difference between the two bodies should correlate with the amount of visible radiation for the same reason. Once these relationships are determined, the total short wave radiation can be calculated by multiplying the flux of visible radiation by 2. There will be some error in this procedure, as it assumes that visible radiation accounts for approximately half of the total short wave radiation at the surface of the bodies (Monteith, 1973). This is not always the case, especially on cloudy days, when the visible radiation fraction is greater, due to cloud moisture absorption of infra-red radiation (Monteith, 1973). The total short wave calculation also assumes that ultra-violet

radiation does not contribute appreciably to the energy balance.

The first instrument constructed consisted of a glass dome and ventilated shelter as shown in Figure 13.1. A black thermistor was placed under the glass dome shelter and a second in the vertical ventilated and shaded shelter. The initial observations were encouraging, as the temperature difference between the thermistor and the radiation measurements of the Eppley seemed to respond in a similar manner as shown in Figure 13.2. An attempt was made to correlate the area under these curves. If the temperature difference between the two thermistors could be used as a measure of solar radiation, the area relationship would be evident. The accumulated daily temperature differences between these two thermistors were compared to the total radiation values of the Eppley. Unfortunately, the results did not correlate well. On a second evaluation of this design it was concluded that the two thermistors were not equally exposed to long wave radiation. Although air was able to flow horizontally over the two thermistors the same was not true vertically. This fault was undoubtedly exaggerated by the device's placement on the roof of the engineering building which is covered by a black layer of tar and gravel, and itself acts as a heat emitter.

A second device was constructed which exposed the thermistor to long wave radiation equally, as shown in Figure 13.3. Again the resulting accumulated daily differences of temperature were compared to the short wave radiation measured by the Eppley pyranometer. As with the previous instrument, the results did not correlate well. There are two possible design faults responsible for the lack of a clear relationship: 1. The thermistor was influenced by radiation in the visible spectrum. All or most of the visible radiation should have been reflected but this was not achieved; the white coating on the thermistor is believed not to have been as effective as was necessary. 2. The wire leading to the thermistor, protected by a black rubber, may have conducted radiation absorbed from the visible spectrum to the thermistor.

A third radiation meter was designed to address all the above

Figure 13.1: Radiation meter 1.
RADIATION METER #1 VRS. EPPLEY
FOR MAY 13 1991

Figure 13.2: Radiation observations using meter 1.

Figure 13.3: Radiation meter 2.

deficiencies in addition to instrument dampening as shown in Figure 13.4. Meter 3 used:

1. two metal (steel) cylinders, one painted black the other white, as shown in Figure 13.4,
2. a white thermistor wire leading to the white disk. This design is expected to behave similarly to the two disks of the Eppley pyranometer, and
3. an increased mass of the sensor which will yield more reliable results as it will better integrate the temperature differences.

This is significant as the time between sampling could be longer, by reducing the number of samples. This design is still to be tested. An important detail in the design of the third meter is the necessity that, in the effort to measure radiation, ambient

temperature readings must not be sacrificed. Therefore, temperature as recorded by the white temperature sensor should be compared to temperature sensors in a thermometer shelter, such as described by Doorenbos (1976) or Hanan (1984).

Figure 13.4: Radiation meter 3.

Cadmium Sulphide Photoconductive Cells

The cadmium sulphide photoconductive cell is a light sensitive resistor. The resistance of this cell decreases with increasing incident illumination, and the spectral response peaks at approximately $.6 \mu\text{m}$ in the visible light range (Norton, 1989). The response of these instruments to visible light may allow them to be used as radiation meters. Their suitability depends on their sensitivity and ease of integration into the CICMS. Work is currently under way to determine just this. With a unit price of approximately \$3.91 (Cdn), if successful, this instrument could easily and affordably be distributed and installed throughout the farming community.

Figure 13.5: Shell's general architecture.

13.6 The Shell

The computer integrated system includes: 1. weather station, 2. data logger, 3. data logger software, 4. a DBMS, and 5. a crop model. To bring together these five components in a compatible and interactive manner, a number of R:Base and FORTRAN programs were written by the authors. It is precisely this integration effort that is the central achievement of this study; the new programs are part of a single overall management system operated by mouse-supported, pull-down menus. The general architecture of the shell and associated applications is illustrated in Figure 13.5.

The system's program manager is executed at the DOS prompt, displaying the main menu; the options are: PcWEATHER, CERES-MAIZE, MODEM and EXIT. Pressing the [F1] key displays a help screen explaining the menu

selections.

Selecting PcWEATHER from the pull-down Main Menu displays a second main menu headed CERES-MAIZE. This pop-up menu offers the user the choice of one of four methods of executing Ceres-Maize: 1. Standard-No Irrigation, 2. Standard-With Irrigation, 3. Nitrogen-No Irrigation and 4. Nitrogen-With Irrigation. Ceres-Maize was organized by the writers into four subsections for the computer integrated shell, to help differentiate the four main management choices and the data each version requires. This removes confusion and data entry errors caused by the different data requirements of the four versions. The execution of any of the pop-up menu selections generates nearly identical pull-down menus with the headings EDIT MAIZE, RUN MAIZE, VIEW RESULTS and EXIT. These menus also have help screens that are invoked by pressing the [F1] key, all written by the authors. These menu selection allow easy data input through the use of input forms, value checks, rule checks and perform calculation the user would otherwise have to perform. Weather files are automatically updated, parameter data files generated and the crop model executed without user assistance. The results of the run are subsequently imported into the shell for display.

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