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AGROMETEOROLOGICAL DATA MANAGEMENT

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PREFACE

The Commission for Agricultural Meteorology (CAgM), recognizing the importance of agrometeorological data requirement in the planning and operational activities in agriculture, decided at its tenth session (Florence 1991) to establish a working group on agrometeorological data management with the following terms of reference.

(A) To survey and summarize existing knowledge and information from published literature and from reports/guidance material used by Members and proven methodologies where applicable on the subject of responsibility of the rapporteurs.

(B) To provide examples wherever feasible of the operational use of the information in member countries.

(C) To provide such information in a form suitable for publication as guidance material.

(D) To identify potential contributions to CARS-Food and CARS-Desertification.

(E) To identify any problems relating to the subject of the rapporteurship and to make recommendations on actions to be taken by the Commission.

(F) To submit annually, information on progress of activities and a final report to the Chairman of the working group.

The Commission invited the following members to serve on the working group:

Dr R. Motha, Chairman, (USA) as rapporteur on computer-based management systems;

Dr A.N. Hayhoe (Canada) as rapporteur on New Techniques for Data Analysis and Information Formulation;

Dr A.D. Kleschenko (USSR) as rapporteur on Processing, Analysis and Applications of Remote Sensing Data;

Ing. I. Adebissi Isaac (Benin) as rapporteur on New Methods of Agrometeorological Observations and the Development of New Instruments;

Ing. C.E. Gray (Argentina) as rapporteur on the Preparation of a Manual on Coding of Phenological and Agricultural Observations.

Mr R. Gommes (FAO) was also invited to serve on the working group.

A meeting of the working group held in Geneva, from 18 to 22 April 1994, reviewed the draft contributions of the various rapporteurs and assigned responsibilities for additions and proposed improvements to the final draft report.

The Chairman reviewed, compiled and edited the contributions into a final report which was submitted to the president of the Commission.

The eleventh session of CAgM (Havana, Cuba) which reviewed the final report recommended that the report be published in the CAgM report series.
ACKNOWLEDGEMENTS

This report brings together a range of expert knowledge in the field of agrometeorology. It focuses on trends in rapidly changing technology that can be directed toward agricultural applications. This technology is currently being utilized in some geographic areas. Our goal is to provide guidance for effective utilization throughout the world. We are grateful to the WMO and the Commission on Agricultural Meteorology for giving us the opportunity to prepare this report. Specifically, recognition must be given to Professor G.O.P. Obasi, Secretary-General of WMO, Professor C.J. Stigter, President of CAgM, and Dr. V.G. Boldirev, Director of WCP for their support. Special thanks also go to Mr. N. Gbeckor-Kove, Chief of Agricultural Meteorology Division, WCP and Mr. V. Krishnamurthy, WCP for their invaluable assistance.

Special recognition must be given to my colleagues viz Dr. H.N. Hayhoe (Canada), Professor A.D. Kleschenko (Russian Federation), Mr. I. Igue (Benin), Mr. C.E. Gay (Argentina) and Mr. R. Gommes (FAO) who dedicated their valuable time and expertise for the preparation of this report. The contents of each chapter reflect both the diversity and complexity of our work. I am extremely grateful to them for their support, knowledge and expertise which were brought together in order to realize the objective of the Working Group on Agrometeorological Data Management.

R.P. Motha
CHAPTER 1
EXTENDED SUMMARY

1.1 This technical report on agrometeorological data management, presented at the eleventh session of the Commission on Agricultural Meteorology (February 1995), is intended to focus attention on the modern developments in data acquisition, processing, archival, analysis, and dissemination. The quality of data cannot be overemphasized for, without accurate measurements, coding and reporting, any improved management techniques or implementation of computer-based systems will fail to achieve their desired objectives. These objectives are to provide the greatest functionality of computer-based management systems and to expedite the flow of information to the user for problem-solving and decision-making applications. It must also be clear that any recommended approach for the use of such systems is oriented to requirements and constraints of the end-users. The advances in microcomputer (PC) technology, software development and the rapidly expanding informational networks offer new opportunities for global access to computer management systems. A cost-effective means to get these systems and products to farmers and decision-makers is the ultimate goal. In this report, Chapter 2 focuses on the development of computer-based management systems which are incorporating new technological innovations (Motha/Gommes). Chapter 3 deals with techniques for data analysis and formulation of information relevant to the user (Hayhoe). Chapter 4 directs attention to remote sensing techniques which complement ground-based meteorological data (Kleschencho). Chapter 5 reviews new observation techniques and new instrumentation for agricultural meteorology (Quine). Chapter 6 highlights the very important aspect of coding phenological and agricultural observations (Gay). Finally, Chapter 7 presents the conclusions and recommendations of the Working Group.

1.2 The objective is to standardize a data collection-information delivery system for farmers, agronomists, foresters, plant pathologists, entomologists, and animal scientists. Some uses of the information include optimum conditions for planting and harvesting, disease and insect pest management, physiological and phenological crop models, cooling and heating requirements, moisture usage and wetting period logistics, rainfall effectiveness and soil moisture models, and their effects and durations on crops and livestock.

1.3 The final judgement of agrometeorological data management technology rests with those who need timely and accurate information for tactical or strategic decisions. Questions that must be addressed include the following. What information is needed for specific applications? Who are the users of this information? When is this information required? How is the information going to be delivered? The answers vary considerably depending upon the specific area, crop, and climate regime. There are also two categories of planning crop and livestock management decisions. Strategic decisions are made for long-term planning, which is influenced by marketing factors as well as an agronomic and environmental considerations. Short-term planning, such as daily field activity, require tactical management decisions. Both types of agricultural planning categories can effectively use technological advances in data management and information dissemination.

1.4 All aspects of agrometeorological data management require one essential prerequisite for success, and that is training. The researcher must be trained to understand the needs of the person who will apply the results. The user must be trained to access and acquire the specific information needed for the application. In other words, any potential user of this system, whether they are farmers, planners or decision-makers, must be educated to understand the capability and expectations of the system. As with any endeavor, there must also be the opportunity to have a feedback mechanism to allow refinement or improvement.
in the system. The agrometeorological data base is rapidly expanding. With data quality assurance, the components including weather and climate data, remote sensing data, agronomic and phenological data, and hydrological data can be formulated into relevant information for crop and livestock management decisions. This information system must focus on unique and specific regional problems, but guidelines for the framework of the system should be universally accepted. The following chapters deal with some important aspects of this framework.

1.5 This extended summary serves not only as an introductory statement but also as a synopsis of three essential components of the report. They include data acquisition, analysis, and products or applications. Individual contributions of the rapporteurs follow this summary, addressing various elements in the field of agrometeorological data management in more detail.

1.6 Logically, the first problem to address is data acquisition. Advances in technology to collect data from surface stations, remotely-sensed platforms and radar, increase the capability to monitor and assess weather's impact on agriculture. The ability to move these data from a technical center to field applications, and more specifically to a farm operator or planner, is still a major obstacle in many areas of the world. Moreover, how weather information can be utilized effectively by farmers in making production and marketing decisions in a timely manner is also an extremely important attribute. Agrometeorological data also implies more than weather data. Historical climate data, soils data describing type and water-holding characteristics, remotely-sensed products indicating vegetative surface conditions, crop phenological data, and crop statistics all combine to form a comprehensive, multidisciplinary set of agrometeorological data.

1.7 Automatic Weather Stations (AWS) have been introduced and expanded to provide a viable alternative to the manual observation system in some areas. The electronic sensors, data loggers, and communication links to a host computer to automatically record agrometeorological data can be employed on a regional scale for specific applications. While the AWS systems can improve the timeliness and quantity of data, caution must be advised on the feasibility of such systems in areas subjected to rapidly changing environmental conditions. For example, in semi-arid to arid regions vulnerable to sand storms and frequent blowing dust, manual inspection of the equipment must be a frequent requirement to ensure no degradation in data reporting and data quality. With proper maintenance, data logging from AWS to a host computer and data retrieval from the host computer to the user are most commonly transmitted through telephone communication.

1.8 Remotely-sensed data are also gathered at regional processing centers and techniques are evolving to incorporate these data into the agrometeorological data base. Estimation of rainfall, soil moisture, vegetation conditions, and water supplies, as well as land use analysis can be obtained and disseminated. Remote sensing data refers to satellite and aerial data, primarily. New technology has increased the use of microcomputer-based hand-held data loggers which measure infrared crop canopy temperature, humidity and solar radiation. The sensor automatically transmits data to the computer for crop, irrigation and soil analyses. Thus, a variety of remote sensing techniques continue to complement ground-based data systems.

1.9 Missing and erroneous data problems are routinely encountered in operational applications, requiring quality control checks. Precipitation data are the most difficult to identify and correct. The frequency of erroneous or missing reports (as indicated by frequent large differences compared to surrounding stations or long durations of no reports) at each site must be evaluated. Options for correcting erroneous values must be consistent with standard guidelines. Extreme value thresholds should be determined based on climatological
expectations. These values falling outside the determined thresholds may be suspect. After appropriate quality checks, the format of data for archival is extremely important. Namely, what level of aggregation is feasible for practical application as well as for data management purposes. Daily, weekly, dekadal, monthly, seasonal and annual values can be derived from basic raw observations. Since historical data provide very important background guidance, merging of current and historical data files must be considered in this process. Moreover, an important flag must be raised regarding the introduction of new technologies for data acquisition and processing. Careful consideration must be given to proper documentation of changes in instrumentation, reporting procedures, and data processing techniques to account for any biases in the complete (current plus historical) data base.

1.10 The development of a standard coding format for exchange of meteorological, phenological, and agricultural observations, which comprise the agrometeorological data base, is necessary for regional applications. While data types can often vary by region, an internationally recognized standard should be adopted, including a Latin crop naming convention, to establish a suitable code for specific crop types in all countries. Special consideration must be given to areas where a false start of the wet season forces replanting. This situation will alter the reporting of phenological stages, and a standard coding format must be recognized to account for the adjustment in the growth cycle.

1.11 The agrometeorological data base provides a wide variety of information available for special uses. The ultimate goal is to offer technical solutions, but the applications range in complexity from making quality controlled raw data available for specific analytical use to providing advisory information based on model results and interpretations. New electronic technology in the form of "bulletin boards" offers the user a menu spectrum ranging from data products and analytical results to decision-making recommendations. The concept of "meta-data bases" for data sources, tools and procedures reviewed at a recent FAO meeting, and models should be available on such electronic bulletin boards.

1.12 A major component of the agrometeorological data management system focuses on data analysis. Objective analysis programs allow calculation of regional or "gridded" estimates which are derived from station or site observations within the region. If historical data are available, then such an objective analysis program can generate historical data sets for assessment guidance of current conditions. An advantage of the gridded data set compared to station data is that it inherently has no missing estimates. It allows a spatial analysis of anomalous conditions for a specified time period. Temperature, solar radiation, potential evapotranspiration and soil moisture estimates are interpolated from station or site observations. Precipitation presents a far more challenging problem given its convective nature, but rainfall can be gridded over longer time intervals (i.e., 5-10 days or more). Automatic Weather Stations (AWS) provide the opportunity for better spatial distribution and more timely information. Radar derived rainfall estimates also offer a new horizon to improve the spatial distribution and timeliness of reports. Remote sensing techniques are also available for spatial interpolation, especially when combined with ground site observations.

1.13 The integration of data sources from ground stations to remote sensing platforms has also become more feasible in practical applications employing computer-based systems. From a large-scale perspective, satellites collect high resolution data for qualitative estimation of the condition of vegetation at the surface. These products in map graphic form can be made available on microcomputers in a network configuration. Further, remote sensing techniques can be employed for crop area estimation, frost advisories, rainfall estimation, desert locust population and land-use applications. Aircraft can also collect these high resolution data over specific areas. A relatively new technology is employing hand-held remote sensing devices which log data directly into a microcomputer for analysis of crop canopy temperatures,
irrigation requirements and soil conditions at the field level. All of these remotely sensed data provide complementary information which can be used together with ground-base observations in agrometeorological data management systems. However, these data need to remain independent within the data system. In addition to observational problems discussed earlier, remotely-sensed data are subject to calibration errors, new instrumentation and sensing techniques, and rigorous data processing procedures. Proper documentation is essential.

1.14 There has been extensive reporting of agrometeorological models for operational applications, including statistical weather crop yield relationships, physiologically based crop growth estimates, integrated pest management, irrigation scheduling, leaf wetness calculations, and stochastic weather generators. Families of models have been incorporated into networks such as the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT). The advantage of this concept is to provide standardized documentation in a user-friendly format available in microcomputer versions.

1.15 These process-oriented models are based on objective analysis of simulation or regression techniques, and produce specific responses to weather, soil or management conditions. Current developments in decision support systems exemplify the progress toward providing more useful interpretations and guidance. The expert system technology broadens the knowledge base to include relevant considerations of alternative decisions. An expert system builds on the interactive processes and goes beyond process-oriented results. In an advisory role, this system offers merits and risks associated with each course of action in the decision-making process. Keeping in mind that an expert decision may be unreliable if insufficient data or limited information are available for analytical reasoning, the scope must be focussed on specific problems with strategies established to provide concise decisions. A key element in the new technological approach is to arrive at a decision of expected variability associated with observations and knowledge rather than a decision of average expectation. The latter is typically derived from simulation or process-oriented needs. Moving beyond the average expectations requires the knowledge and skills of an expert to sift through the data to formulate the best management decision. The expert system approach, discussed in more detail in both chapters 2 and 3 moves toward this goal, keeping in mind that human resources should not be excluded. The artificial intelligence serves merely as an efficient tool for the best utilization of resources for agricultural decisions.

1.16 Numerous examples of modeling efforts and decision support systems are reviewed in this report. It is not the intent to recommend these specific examples for any or all situations. They serve merely as case studies for reference or guidance in the development of relevant applications to specific situations. These are standardized procedures, such as IBSNAT which was referenced earlier, which offer guidance in research development and testing so that the ultimate goal can be achieved; namely, getting the right information to the end user at the right time for management decisions. The use of artificial intelligence, involving well-documented and user-friendly hardware and software to recommend the most appropriate decision, is becoming more feasible at remote locations with advances in telecommunication. Sophisticated development of expert systems can make better use of agrometeorological data in decision-making. The recommended decisions can be disseminated to the farm-community center via dedicated telephone line to personal computers through an agricultural network. This process is interactive, allowing better access to new techniques with limited computer resources.

1.17 The agrometeorological database is also used for advisories as well as for planning decisions. High-quality data observations can be used to monitor crop moisture conditions, crop canopy temperatures, and the qualitative state of vegetation in a given area. Furthermore, advisories can be issued rapidly throughout a network on frost and freeze potential, high wind
conditions or heat stress on crop and livestock. Remote sensing techniques play a key role in weather and crop monitoring, and the development of geographic information systems (GIS) allows graphic product displays which are easily discernible. Warnings of severe storms, such as tropical cyclones, or bitter cold air outbreaks which place severe stress on livestock, can be rapidly transmitted to concerned areas, if a technological network and public awareness is developed or expanded.
CHAPTER 2

COMPUTER-BASED MANAGEMENT SYSTEMS

2.1 Introduction

2.1.1 The limits placed on agricultural productivity in any given area are directly related to weather variability, the influence of latitudinal and climatic zones, topographical features and soil types, and anthropogenic impacts such as irrigation, farm management practices, land use management and deforestation. While crop adaptation has long been practiced based on any or all of the constraints mentioned above, the availability of computerized decision-making tools is a relatively recent innovation and continues to expand rapidly. Computers are being used more extensively in various ways ranging from accessing basic data directly from instrumentation networks to producing advisory scenarios for management and planning. A management system in this context includes basic data processing as well as decision-making tools. This point will be emphasized throughout the report because techniques for proper management can be successful only if the basic data and derived variables needed for solutions are consistent and accurate. Analytical results depend upon the quality as well as quantity of data. Finally, there are widely ranging applications of agrometeorological data to assist agricultural operations. These include water balance computations, crop and range management, yield forecasting, integrated pest management, phenological stage assessment, climatic and forest fire risk assessment, and farm and local use planning to name only some of the applications which have been identified and listed in FAO (1994). Artificial intelligence refers to the development of computer technology capable of solving problems generally thought to require human intelligence. Expert systems in this regard are computer programs written specifically to address well-defined problems and attempt to represent knowledge and skills of a human expert.

2.2 Definition of Concepts: Simulation Models and Expert System

2.2.1 An expert has knowledge and skills that are applied to a practical problem, resulting in advice on a scenario analysis or a decision based on judgement from relevant information. Shanteau (1989) noted that expert decisions may be inaccurate, unreliable and biased if influenced by irrelevant or too little information. However, a set of factual relationships can be established for specific problems if the skills of an expert are tailored to a specific task. This concept has been applied to computer technology, building an interactive process which contains compiled knowledge that emulates an expert. The flood of information, which is produced in simulation models for example, is synthesized into concise packets which are yet converted into alternative, but relevant courses of action. In an advisory role, relative merits and risks associated with each course of action are outlined for the decision-making process. This computerized expert system must have the capacity to deviate from standard decision patterns and follow special-case strategies, a trait which distinguishes an expert from a novice. Thus, an automated procedure which incorporates some of the “behavioral characteristics” of an expert is the ultimate goal. During the past decade, the emphasis has clearly shifted toward utilizing computer science technology for the development of expert systems applications for agricultural decisions. This is an evolutionary technology which has great worldwide potential.

2.2.2 A distinction must be made between the expert systems concept and simulation models. Whereas plant-process models are more descriptive of crop growth and yield responses to weather, soil, and management for example, expert systems are oriented toward problem solving and decision making in a user friendly format. Models focus on biological, physical or economic components, or combine all three, to predict the response to weather, soil or management conditions. Considerable progress has been made in developing
process-oriented models for crops, soils, and pests. The ultimate goal is to transfer the specific results of these models to operational applications. These applications must be oriented toward making decision at the right time for a particular course of action. Data requirements, assumptions and model limitations must be fully understood to utilize models as a tool in the decision making process. Rigorous simulation models become part of the knowledge base. The expert systems concept attempts to organize the knowledge base into a logic format easily accessible to aid decisions. This systematic methodology would then serve as a practical guide for various realistic crop management decisions regarding planting, fertilizer, pest and disease control, irrigation, and harvesting.

2.2.3 A good example of the useful integration of this methodology would be for irrigation scheduling. While the expert systems approach is structured to present a dialogue between the user and the computer, simulation models may be needed to provide objective results for a specific set of input conditions. Thus, the separate components of expert system and simulation can be connected through an interface to achieve the desired results. In this irrigation example, an expert system is developed for the decision to irrigate or not using information on daily available soil water generated from a soil moisture simulation model.

2.2.4 In essence, the expert system attempts to move beyond the objective analysis of simulation and broaden the knowledge base to include relevant considerations for alternative decisions. In the above example, simulation models may estimate available soil water and present objective results useful to the decision. However, while this model may suggest the application of irrigation, other factors such as insect or disease potential or economic assessment of irrigation must be considered as part of the expert systems strategy. The net return in yield response if irrigation is applied at some growth phase may not be worth the cost even though the results of the simulation model indicate low soil water. Thus, the merits and risks are provided along with a specific decision recommendation in the expert system model. More discussion of data analysis techniques and the formulation of relevant information will be presented in Chapter 3.

2.3 Data Requirements

2.3.1 Before proceeding with a discussion of the rapid changes in computer technology which can be employed for solving problems and making decisions, it is imperative to review data requirements. The quality and quantity of data available on an operational basis as well as historical records for background guidance form the essential building block. Techniques to quantify both ground-based and remotely-sensed estimates must be evaluated for both accuracy and reliability measures. Quality control procedures must be documented. The ability to utilize these data for research and development of computer-based applications, to rigorously test the results for operational use, and to ensure that both physical and fiscal requirements can be met to implement the application for the specified users must be attainable for success. More detailed discussion of data requirements for computer processing follows based on the Food and Agriculture Organization (FAO) in crop and weather monitoring for food early warning systems. The FAO also organized a meeting in late 1993 (FAO 1994) to focus attention on the coordination and harmonization of databases and software used in agroclimate applications. Weaknesses of the data management system were noted, especially the availability of tools for operational applications of the farm level. A significant recommendation of the meeting was that "meta-databases" be established for data sources, for standard tools or procedures, and for models. A strong, interactive partnership should be developed at all levels to establish meta-databases, standard data exchange formats, and agrometeorological procedures to get the right information to the user. Training and training material, including appropriate software and learning tools, were also emphasized by this expert committee.
2.4 GIS and the Integration of Data Sources

2.4.1 The discussion below concentrates on the integration of different data sources and data types used for agroclimatic analysis. In practice, agrometeorological analyses incorporate data from many different sources ranging from station weather data to agricultural statistics by administrative units to derived vegetation indices and other satellite data by pixels of varying sizes. In addition, areas with homogeneous soils and crop distribution data are usually included in polygons which do not coincide with any of above. This explains why Geographic Information Systems (GIS) are now gaining wider acceptance in many fields of operational agrometeorology. The common "geographic denominator" now becomes a "pixel" or a grid-element of a size depending on the resolution of the study.

2.4.2 FAO national food security systems in Africa mostly standardize the data to METEOSAT resolution, i.e. 7x7 km pixels (Gommes, 1991) while the MARS project of the EEC on crop forecasting in Europe has adopted 50x50 km units (Vossen, 1993). Although the resolution is apparently lower in the MARS project, it is in fact significantly more complex than the FAO approach.

2.4.3 FAO food security projects conduct all agrometeorological analyses with station data, and convert these to a grid and administrative units in later steps, using terrain characteristics or NDVI (Normalized Difference Vegetation Indices) in the interpolation process. In the EEC-MARS methodology, all parameters are first interpolated, and only in a second step are the agrometeorological analyses performed on the interpolated data. The amount of calculations involved is significantly greater in the second option. Potentially, however, the accuracy can be high as such factors as soil characteristics can be taken into consideration. There remains, however, the fact that "pixel" sizes should be very small if averages of environmental factors are to be realistic.

2.4.4 Realistic averages of soils data (water holding capacity), some crop factors (planting dates) and a number of meteorological parameters can be difficult to obtain. What is the significance of average pixel rainfall, or average pixel temperature in hilly terrain? The same obviously applies to the well known difficulty to interpret and to reconcile canopy resistances at the scale of a plant, a field or a region. The accuracy of analyses done in a GIS context largely depends on the quality of the interpolation algorithms. While for some elements (like sunshine and temperature), the technical problems are not too difficult, their complexity increases very significantly for rainfall, wind, etc., particularly at the short time intervals. In fact, the above may be one of the reasons why, for many agrometeorological analyses at the regional scale, it is not desirable to use time intervals shorter that the dekad or the pentad.

2.4.5 It is also clear that sturdy and reliable interpolation (gridding) routines for most common weather elements are badly needed. Interpolation is one of the current serious bottlenecks in operational agrometeorology. References on interpolation include: Myers, 1988; Porch and Rodriguez, 1987; Booth et al, 1989; Guenni and Hutchinson, 1990; Beek, 1991a and b; Laughlin, Hutchinson and Mackey, 1993, Gobel 1989, Jones and Thornton (1990).

2.5 Qualitative and Quantitative Data

2.5.1 The operational agrometeorologist frequently deals with qualitative or subjective data on such parameters as crop condition reported by field observers, or a soil description ("fertile soil"). Another category regards the comparison with other years or other areas (this year is "better" than last year, district A produces "more maize" than district B, farmers this year have planted more maize than sorghum...). Such information can be very important in agrometeorological practice and, by multiplying the number of sources, its consistency can be
verified. For instance, by plotting on a map subjective crop condition estimates according to an arbitrary scale, outliers are immediately spotted.

2.5.2 Many "objective and quantitative" data are affected by large errors; for instance, rainfall estimates obtained from satellites or global radiation as computed from the percent of cloud cover. Qualitative data are not necessarily subjective. For instance, most phenological observations ("maize is tasselling") are qualitative, but not subjective. The date of the beginning of a phenological stage tends to be subjective. Yield estimates by extension staff are quantitative ("12 bags per hectare") but subjective. There is an element of subjectivity in most data used in agrometeorology and, in fact, example can be found for the whole spectrum from objective-quantitative to subjective-qualitative.

2.5.3 Another problem to be addressed is rainfall observations. The density of raingauges is never sufficient. The difficulty arises from the fact that rainfall is spatially variable and, depending on the location, correlations between neighbouring raingauges tend to decrease rapidly with increasing distances. This applies particularly to the shorter time periods. For months and longer time periods, if topography, slope and aspect or other physiographic factors do not interfere, the correlations can remain significant over hundreds of km. The difficulty stems from the need to use short intervals for operational work (dekads or less), a constraint which reduces the representativeness of raingauges. A raingauge provides a correct estimate only at its very location, based on a time-continuous record of a small surface (usually less than 200 sq. cm).

2.6 Remotely Sensed Data

2.6.1 Particularly in GIS environments, the space-continuous coverage provided by remote sensing data sources potentially constitutes an improvement over point data (Gommes, 1993). While the following discussion focuses on techniques for rainfall estimates, the best ultimate solution is to utilize both data sources in a complementary role. Several cloud indexing techniques have been developed which statistically relate a cloud index and rainfall. FAO routinely operates the ARTEMIS programme which provides, on a ten-day basis, data on Cold Cloud Duration (CCD) and NDVI (Hielkema et al., 1987; Hielkema, 1988).

When assessing the respective advantages of CCD based rainfall and the standard raingauge reading, the following must be taken into account (the same considerations also apply to most other satellite indicators).

(i) CCD corresponds to an areal average (pixel of about 50 sq. km),

(ii) it is affected by specific errors (collocation, parallax, threshold adopted to consider a cloud to be "cold", sub-pixel cloud contamination),

(iii) it is based on a time-discontinuous sample and,

(iv) it has to calibrated against raingauge readings which are, as indicated, basically different in nature (point data and time-continuous).

Considering in addition to point (iv) above, that areal averages tend to smooth extreme values, it is obvious that the statistical correlation between a raingauge and the corresponding pixel cannot possibly be perfect, even under the unrealistic assumption that most sources of error have been corrected. In other words, the reason why the direct correlation between raingauge readings and CCD is usually low is theoretical as much as practical. Values achieved in practice are close to 0.7, accounting for 49% of the variance in rainfall.
2.6.2 The ARTEMIS programme also provides regular information on NDVI, the temporal variation of which can be used to determine the start of the growing season and infer planting dates of crops (Henrickson and Durkin, 1986).

2.6.3 In practice, NDVI requires a careful calibration if it is to be used for assessing the beginning of the actual cropping season. In fact, under African conditions, NDVI mostly does not "see" crops but rather the natural vegetation. Under subsistence farming, fields tend to be small, dispersed in the natural vegetation and irregularly shaped. In addition mixed cropping is often the rule, and mostly "local" varieties are very inhomogeneous in their phenology. It is, therefore, necessary to "calibrate" NDVI against crops or, in other words, to calibrate crops against the local vegetation! This is found to be very location-specific and has so far prevented the systematic use of several potentially useful satellite indices for assessing crop phenology over large areas.

2.7 Computer Data Processing and Analysis

2.7.1 Let us turn our attention to computerization of data. The "operational agrometeorologist" performs a number of calculations, both explicitly or implicitly. A sample of common operations is given in annex 1. A set of standard computer procedures ("routines") would be very useful. as recommended by the above-mentioned FAO Expert Meeting (FAO, 1994). They should be written in the common languages used for scientific computing (C, FORTRAN, PASCAL? ). The sources should be available both in printed form and on floppy disk, or remotely retrievable from a central on-line service. If such routines were available, the development of applications could be greatly simplified, to some extent even reduced to assembling building blocks. Such an exercise should be a collaborative effort among the organizations which have been active in this field.

2.7.2 Many useful routines are readily available. For instance, the source code of CERES has been published starting with the early versions of the programme (Jones and Kiniry, 1986). Also, many public agencies are rather liberal in the distribution of the programme listings (a good example being EPIC, the USDA/ARS Erosion-Productivity Impact Calculator; Taylor, 1991). There are, of course, many more examples. For a systematic approach, the first step should be an inventory of agrometeorological software. There are several partial lists, some of which originated in the UN system (e.g. WMO 1986 and Chidley et. al., 1993). CAgM could play an active role in the collection of the information.

2.7.3 The standardization of routines implies the standardization of variable names and units. In this context, CLICOM can be seen as a starting point, as it provides, for most meteorological variables, variable codes which could be readily adopted for broader use (WCDP, 1991). Standardization of computer routines can be envisaged at several levels of aggregation:

- At the lowest level, there appears to be virtually no room for "interpretation." The calculations involved are standard procedures like the rounding of data, conversion of units or the computation of such variables as "saturation vapour pressure in the pure phase over plane surfaces of pure water".

- At the intermediate level, several techniques can be used and are actually used according to circumstances or to national tradition/preference. Examples are potential evapotranspiration (PET) according to one of the Penman, Priestley-Taylor, Makkink or Thornthwaite variants; and, day-length (with or without a correction for atmospheric effects). Routines at this level usually incorporate one or more routines of the lowest level. This is the reason why standardization is more difficult whenever several options are available, as is the case with the
wind function in Penman's equation.

At the highest level one could include soil water balance calculations, a number of indices such as fire risk, for example, the definition of growing season types and characteristics (date of start and length of growing season...), interpolation and estimation of missing records, and effective rainfall. Each routine is characterized by a set of input parameters (type, time interval) and one or several outputs.

2.8 Data Storage

2.8.1 The storage of data in files is also very important. There are two basic and extreme options:

- Either the files are readable only by the specialized programme that created them (e.g. CLICOM), in which case their number is limited but their structure can be very complex and their sizes tend to be in the multi-megabyte range. Applications are relatively difficult to build if they are to access the data directly;

- The second option adopts a fixed and conventional file structure. Files typically hold only one, or a limited number or variable types. This results in large file numbers, but greatly simplifies the development of application software. In general, the files are not application-specific.

The two options above are not mutually exclusive. The second allows a greater flexibility in the development of applications. It provides an easy way to exchange data and can be imported (exported), with minor editing, into (from) the large specialized climatic data management systems. It is worth noting that storage efficiency, i.e. basically the amount of disk space required to store the data, is comparable in the two options.

2.8.2 The next point of consideration is a review of the desirable features for agro-climatic data files. It is largely inspired from the approach adopted by the FAO agrometeorology group for food security applications. Files should be self-describing, i.e. the name should be sufficient to allow the nature of the data contained in the file to be determined. In addition, the files may contain a "header" with additional information about the data.

- Files also need a standard naming convention. Many agrometeorological data users follow no well-defined system when giving names to their data files. In the DOS world, there are 8 characters for the name proper, and 3 for the extension. Standardization of file names has several advantages:

  - The name clearly indicates the style of the file (this is defined below. The "style" includes (i) file structure, (ii) format, (iii) contents and (iv) auxiliary information). File names can be cryptic as they can be decoded by a programme; for instance, by "knowing" the naming conventions, a programme will understand that file KEWXRD84.WK1 has 1984 rainfall data in Kenyan weather stations, 36 dekads per line, in LOTUS format. Alternatively, if several conventional naming systems coexist, the name, or the header, could provide all the details. An important implication is that file names and headers are managed by a programme. This is frequently done with headers, more rarely in the case of file names.
- File names are no longer user-specific; they can be distributed and read by any programme that "knows" the conventions. It is clear that both input and output data must follow the same conventions. This permits applications to be chained, i.e. outputs from one programme can be immediately read by another programme;

- The convention simplifies programme use: it suffices to specify a country name, type of data (e.g., rainfall) and a year, and the name will be composed automatically by the software. It thus constitutes a good basis for a retrieval system;

- File and data management, and analysis (processing) can be treated separately. This, again, is a advantage in the development of applications.

2.8.3 The wording "file styles" is used here as a very general term, as files have a certain number of attributes which, together or in combination, depict their form and the type of data they contain. There is a wide variety of commercial and application software used in agrometeorological operations. Most of them make use of "proprietary formats" (Mostly binary, sometimes ASCII) but offer the possibility to convert from, and more rarely to, LOTUS (WKS, WK1) or DBASE formats. The "format" is just one of the features that describe data files. In general, files can be characterized by:

- Their structure, i.e. the way in which the information is arranged. For instance, 100 data items can be on one line, or one item per line, or ten items on 10 lines. The data can be preceded by the names of the variables or station names, which are all defined by the structure. The data are usually arranged in groups or records which can be of fixed length (36 dekad rainfall data for 150 stations: each station corresponds to one record) or variable length. For instance, in arid areas, it is more economical to store the date of each rainy day next to the amount recorded. If, on average, it rains only two days per month, then only 4 data items are needed (two day numbers and two amounts), as opposed to 28, 30, or 31 numbers, most of which will be 0 (nil).

- Their format, i.e. the way in which the information is coded to be readable by a specific application. The LOTUS and DBASE formats were mentioned above. ASCII, i.e. plain text is the most straightforward format which can be read by editors, word-processors, imported into spread-sheets and data bases.

- Their contents, i.e. the type of information contained in the file, for instance geographic coordinates, monthly rainfall or crop stages.

- Auxiliary information which pertains either to format (e.g. column width or "right justification" or "number of decimals") or to contents (a standard code for missing data, for instance "n.a." or "-9999" for missing information). The borderline between auxiliary information (auxiliary data) and contents is not always clear cut. For instance, many programs use "flags" (for instance CLICOM) to identify missing or estimated data. As indicated, structure, format, contents and auxiliary information are not strictly independent attributes. In general, however, they are sufficient to describe an agrometeorological data file.

2.9 Agrometeorological Software

2.9.1 There are also certain desirable features in the software used in agrometeorology.
Agrometeorological software should be multilingual. This facilitates the adoption of the software and the development of both manuals and training material. In practice, multilingual software can be developed easily if all screen outputs are taken from a file, in which case it suffices to translate the file. This approach has been adopted by FAO. Next to spreadsheets and word-processors, several statistical packages are in relatively common use. In FAO, we found that statistical clustering of stations based on actual weather data (for instance, rainfall from the beginning of the season) is a very useful tool for the preparation of agrometeorological summaries. Such programmes identify stations/regions with similar behaviours and facilitate the description of the development of the season.

2.9.2 A comprehensive review of data analysis and information formulation techniques will be presented in Chapter 3. Several points will be briefly mentioned here relating the characteristics of data, problems of scale and data sources discussed in sections 2.3 and 2.4 with model applications at the operational levels. First, data requirements for microscale analysis can differ considerably from macroscale analysis. Models developed on the microscale (field level) are usually derived from a large set of variables, often measured under experimental conditions. Thus, soil profile characteristics, radiation, evapotranspiration, wind velocity and any number of other weather and agronomic variables may be obtained from field experiments. However, for macroscale (regional) applications, these models developed at field level would likely be inappropriate because of the voluminous data requirements not available on an operational basis. The key factor is to then identify and select the most important independent variables for model development which can be obtained operationally and clearly define the assumptions necessary for large-scale applications. It is essential that models developed in the research environment have as the ultimate goal, the utility for operational applications of the end-user.

2.9.3 To review, some of the specific utilities of agrometeorological data applications include computation of potential evapotranspiration, irrigation scheduling, phenological estimates and crop yield modeling. Agricultural planning also has great potential for crop diversification, land use management and agroclimatological trends. Advisories and warnings of conditions conducive to pest and disease incidence, bush fires, frost and freeze potential, severe storm warnings and sandstorms are based on these data. Cloud cover, normalized vegetation indices, crop canopy temperatures and reservoir levels can be obtained from image processing. The introduction of software to produce multiple layers of graphics, data points and text onto a map to project contours, pattern, and trends from the data base offers new potential applications.

2.10 Operational Applications of Agrometeorological Data

2.10.1 An example of an operational application of agrometeorological data, utilizing computer resources for large-scale data management and analysis, is illustrated by the Joint Agricultural Weather Facility (JAWF). JAWF is operated cooperatively by the United States Departments of Commerce and Agriculture providing assessments of world-wide crop growing season conditions. Within the Department of Commerce, the National Meteorological Center routinely received and processes global surface and upper-air meteorological data via the Global Telecommunication System. The large volume of global data from the GTS enters communication computers, which in turn relay these reports to mainframe computers for processing.

2.10.2 These data are extracted by the Climate Analysis Center (CAC) for analysis, diagnosis, and prediction. Such products as El Nino/Southern Oscillation advisories and long-range weather outlooks are made by CAC. A Climate Assessment Data Base (CADB) was created by CAC to provide a flexible automated data management data program for a variety of users (Finger, 1985). The system allowed interactive accessibility of data over any time
frame and location, and was compatible with most software. The CADB data extraction process is based on a few generalized subroutines for easy access. Automated data quality control procedures were implemented at each step. Automated procedures deal with systematic errors, independent data source comparisons and estimates of missing parameters such as temperature and precipitation. Estimated values are flagged for documentation.

2.10.3 One of the major applications for this data flow is agricultural weather monitoring and assessment at the JAWF. A staff of meteorologists and agricultural meteorologists provide a focal point for monitoring anomalous weather and assessing its impact on the growing season. The primary task is to assess the impact of drought, flooding, heat and cold stress, and severe storm activity on agriculture. The meteorologists not only monitor current weather conditions but also manage an historical data base obtained from the CAC/CADB system. Annex 2 lists products available from CAC's original request/reply microcomputer system.

2.10.4 The weather data are extracted from the mainframe computer on a daily basis and stored in regional files on the USDA PC-based computer system. While station data are less than optimal in most crop areas, agriculturally-useful information can be obtained as discussed earlier by the integration of different data sources. Recognizing the limitations imposed on the analytical process, other information can be utilized for assessment purposes, especially when required data files are established to allow a GIS concept discussed in section 2.4 to supplement the primary data base. For example, surface and upper-level synoptic reports provide a broad overview of atmospheric conditions which may be conducive for random convective rainfall within a given region. Rain-producing convective cells can develop, reach maturity, and dissipate without being detected at station sites regardless of the density of the reporting network. Rigorous monitoring of synoptic reports can provide some guidance on rainfall potential by scrutinizing dew points, vapor pressure deficits, wind conditions, etc. Satellite imagery provides qualitative techniques for identifying cloud coverage and the potential distribution of precipitation over a given area. Satellite imagery can also provide estimates of snow cover and reservoir levels which are important moisture supplies. Utilizing these various data sources also provides a final quality control mechanism for the user. For example if a station frequently reports precipitation, or the lack of precipitation, and both synoptic observations and satellite imagery suggest otherwise, the quality of station reports or data transmission becomes suspect.

2.11 Applications and Access By End-Users

2.11.1 These meteorological data are used in empirical methods to compute potential evapotranspiration, growing degree days, and crop moisture indices for the weather crop yield analysis. Crop phenology, soil profile data (especially water holding capacity), and historical yield trends by region are all in an automated format. The data files are merged by region as required for analysis. Each meteorological and agronomic data base is updated independently and stored in PC format for accessibility.

2.11.2 While written summaries of agricultural weather conditions have been issued by the U.S. government for public release since 1872, the electronic age now allows rapid dissemination with computer technology. Thus, weather data, agricultural weather summaries and agricultural information have become available through computer networks and automated bulletin boards. Annex 3 presents an example of an electronic bulletin board established by the University of Idaho to get agricultural information to the public as quickly as possible. Reports from the USDA are included on this network.

2.11.3 The information age has been ushered in by new and powerful methods of
communication. The capability for two computers at remote locations to communicate with each other is based on the requirement of using the same protocol, or standards for communications, at the same time. With that simple feature and a network connection via telephone line, three major applications have been introduced: electronic mail, remote login, and file transfer. Electronic mail, or Email, is the most frequently used service, which allows a text to be sent electronically across the network. Remote login is an interactive tool allowing access to programs and applications available on another computer. File transfer allows files to be transferred from one computer to another. These files can be a document, graphics, software, or spreadsheets which can then be utilized for application on a different computer one room away or thousands of kilometers away.

2.11.4 Electronic bulletin boards offer a new means of transferring relevant data and information, compiled at a technical computer center and transmitted rapidly, for making decisions at a distant location. This technology continues to expand and offer potential guidance to farmers with access to a computer or even a telephone network to a electronic bulletin board. The key factors to any network are standardization of equipment and timely interpretation of data. The design of an automated data management system can be structured to collect data from remote sites, to simulate biological processes requiring weather data, and to disseminate results electronically via relatively inexpensive systems. Putting these components together requires expertise from not only meteorologists, but also agronomists, plant pathologists, entomologists, animal scientists, and of course, computer systems analysts. The development of a knowledge-based expert system must account for initial collection of data, including the reliability of the data and sensor performance, data processing and analytical techniques, and transfer of the right information to the decision-maker in a timely manner.

2.11.5 This automated data management system does not imply that implementation would eliminate human resources. It does offer a real potential to maximize the efficient use of human resources by focusing the major effort on interpretation or translation of results for specific end-users. Training personnel to maintain automated remote stations, to ensure data quality control checks, to implement analytical procedures for objective and scenario analyses, and to avoid disruption in electronic transfer of the results are an integral part of this process to bring computer technology into an agricultural weather system.

2.11.6 The information system concept can be built from computer-based technology into an efficient process that captures, stores, manipulates, analyzes, models, displays, and disseminates user-oriented attributes. This technology provides users with a tool to solve problems and make decisions. There are four integral components, including hardware, software, data, and people. Each application must be user-specific and, of course, cost-effective. Consequently, the final point must be to emphasize that coordination between the developers and users of such a system is essential for success.
REFERENCES


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Annex 2.1

A partial list of typical computer applications used in agrometeorology

a. General
   - rounding the "climatological way", i.e. .5 to nearest odd number
   - coordinate conversions (DD.dd <---> DD.mm)
   - unit conversions (W/sqm <---> Cal/day/sqcm, moisture, sunshine)
   - Calendar (DD.mm.yy to "Julian", date to pontad number and back)
   - Interpolation (X-Y interpolation of crop-coefficients)
   - Smoothing
   - Simplex

b. Statistical
   - rainfall probabilities (incomplete gamma)
   - classification (clustering)
   - regression
   - histograms

c. Climatological and GIS
   - Saturation vapour pressure from temperature, psychrometric "constant", vapour
     pressure from dry-bulb and wet-bulb reading...
   - estimating missing climatic data
   - interpolation in time and space of various parameters, including contouring, gridding and
     area averaging
   - verification and cross-verification of data

d. Agrometeorological
   - soil water balance
   - crop coefficients
   - Potential Evapotranspiration
   - indices (Palmer index, fire risk...)
   - irrigation scheduling
   - pest and crop development

e. Astronomical
   - Global radiation
   - Position of the sun
   - Day-length

f. If we agree on standards...
   - file management routines, with standard variable names...
Annex 2.2

Near Real-Time Agricultural Weather Products Available on a Request/Reply Microcomputer System

The Climate Analysis Center (CAC) implemented a microcomputer dial-up communications system, which enables users to acquire various products for agriculture applications (Finger et al., 1985). Some of the most frequently requested files are those containing the weekly Palmer drought and crop moisture data for 350 U.S. climate divisions. The Palmer Drought Index (PDI) is a measure of prolonged and abnormal soil moisture deficiencies or excesses and can be used to help delineate potential disaster areas as well as indicate the availability of irrigation water supplies, reservoir levels, range conditions, amount of stock water, and the forest fire potential (Palmer, 1965). The Crop Moisture Index (CMI) gives the short-term status of agricultural drought or moisture surplus and can be used to measure the status of dryness or wetness affecting warm season crop and field activities and conditions for forest fire ignition (Palmer, 1968). Additional parameters obtained from the computations and listed on the files are soil moisture in the upper and lower layers, moisture in the soil at the end of the week as a percentage of total field capacity, potential evapotranspiration (Thornthwaite, 1948), runoff, and the additional precipitation needed to end a drought according to Palmer’s formulation. Related files include monthly percentage probability projections of the PDI for seven basic drought/wet categories three months in advance. These projections are based on current conditions and on historical weather scenarios (temperature and precipitation).

A weekly summary file of daily potential evapotranspiration using the modified Penman’s method (Penman, 1949) for given stations in the crop growing regions of the world was also added. This method is considered to give the most realistic results on an operational basis and uses the meteorological inputs of temperature, humidity, sunshine, and wind (Doorenbos and Pruitt, 1977). The difference between the precipitation and potential evapotranspiration provides an indicator of crop water availability. Other products include cumulative weekly growing degree days for corn for 445 stations in the U.S., weekly international weather and crop summaries, and weekly international agricultural weather highlights. Options for accessing these products include acquiring data for the three preceding weeks/months and selecting data by states.
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<td>FORECAST</td>
<td>Five-day, six-to-ten-day, seven-day maximum and minimum, and monthly and seasonal outlooks for temperatures and precipitation. Weekly heating and cooling degree-day forecasts.</td>
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<td>GLOBAL</td>
<td>Weekly and monthly summaries of temperature and precipitation data for more than 6000 locations throughout the world.</td>
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Annex 2.3  
IDAHO AGRI-NET: Idaho’s Remote Bulletin Board System  
by  
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University of Idaho

Background

Financial management and marketing decisions play an increasingly important role in determining the success or failure of farm and ranch operations. Being a “good” producer is a necessary but not a sufficient conditions for success. Today’s successful farmer and rancher must also master financial management and marketing techniques.

The personal computer plays an important role in many businesses today and that includes agriculture. While the number of farm businesses using computers may not compare to the number on main street, the number is growing.

Producers site accounting and record keeping as the primary reason for purchasing a computer. Accumulating data is only the first step in making full use of the computer as a management tool. Analyzing the data and using it to make management and marketing decisions is the ultimate goal.

Electronic bulletin boards, both private and public, have been around for many years. Many of the early bulletin boards were used primarily by computer programmers. AG-NET was one of the first publicity supported efforts designed specifically for agriculture on a regional basis. Large scale multi-state efforts seem to inevitably lose momentum and support. Several private sources have operated successfully for years. A March 1990 list of agricultural/Extension related electronic bulletin boards and on-line services lists 20 free on-line services and 33 pay on-line services.

Getting Started

Extension agricultural economists at the University of Idaho have been offering workshops to producers on microcomputers since 1983 under the umbrella program “Using Computers In Farm Management.” These workshops have covered a variety of topics and have concentrated on demonstrating computer programs and templates. The number of Idaho producers with computers continues to grow, although no precise numbers or percentages are available. The sophistication of the users is also increasing. Topics covered at workshops over the past year have included: DOS commands, hard disk management, telecommunications, and file compression.

Which came first, the chicken or the egg? Let me restate that in another way, which came first, farmers with modems or electronic bulletin boards for farmer? The demise of some early agricultural electronic bulletin boards stemmed in part from too few farmers with computers and modems. That is changing and is one reason that Idaho got into the electronic bulletin board business.

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The establishment of Idaho Agri-Net (IA-N) was partially funded by the Special Project Farm Financial Management Funds’ USDA. Idaho Agri-Net has been on line for over 2 1/2 years, beginning operation on January 30, 1989. The original system ran on an old IBM PC-XT with 640 K memory, a graphics card and monitor, serial and parallel ports, a 40-meg hard card in addition to the original 10-meg hard disk and an Epson MX-80 dot matrix printer. The communications link is provided by a Hayes (C) 2400 Smartmodem, capable of communication at 300, 1200 or 2400 baud. The original computer system has been replaced by a 386SX Zeos with 1 Megabyte of RAM,a 130 Megabyte hard disk, and a tape backup system.

The system is located in the District IV Extension Office in Idaho Falls and is accessible through a single user line, no parity, 8 data bits and 1 stop bit. The system has been in continuous operation with the exception of two weeks in October of 1989 and five days in November of 1990. Both disruptions were the result of hard card failures.

Reports

The operating software provides a very flexible system for classifying and organizing files available as downloads. The nine basic categories for programs and reports found on Idaho Agri-Net are listed below. The primary emphasis to date has been on the weekly market reports, USDA reports and to a lesser degree, comments from the Agricultural Economics Department faculty. More recently, crop management information and historical data for crops and livestock has been added.

1) Weekly Commodity Market Reports
2) USDA Acreage, Production, Stocks and Prices
3) USDA Commodity Market Situation and Outlook:
   Economic Research Service (ERS)
   World Agricultural Outlook Board
4) Commodity Comments from University of Idaho
5) Crop management Information:
   Water Use Tables, Pest Surveys, Weather Summaries
6) Agricultural and Business Management Programs
7) General Utility Programs
8) Personal, Home Management and Miscellaneous
9) Historical Data for Crops and Livestock

There are twelve crop or livestock weekly market reports that are presently found on Idaho Agri-Net.

National Grain Market Report
Portland Grain Market Report
Utah, Washington, and Oregon Hay Reports
Idaho and National Dry Bean, Pea & Lentil Summary
Idaho Potato and Onion Prices
Feed Stuff Market Summary
Lamb and Wool Markets
Idaho, Washington & Oregon Direct Cattle Summary
Hog Market Summary
National Feeder Cattle Market Report Summary
National Weather Service 6-Day Summary
National Dairy Market Reports
The Western Livestock Roundup, a monthly livestock and feed grains report from the Western Livestock Market Information Project, is also made available on Idaho Agri-Net.

Articles and comments written by members of the Department of Agricultural Economics and Rural Sociology, University of Idaho, for trade publications or in-house publications are also uploaded to Idaho Agri-Net unless they contain a substantial number of graphs that are essential to article. A regular comment section on key commodities following release of USDA reports has been planned, but not yet implemented.

Users

As of September 1, 1993, there were 144 active users. Every six months the users list is purged of anyone who has not been on the system in the last six months. Of the current users, 12 are University of Idaho extension faculty or faculty from other States.

Non-UI/Extension users have downloaded over 4,000 files from May 1990 to September 1993. This included 2,277 weekly market reports, water tables and a phid reports which are stored as ASCII files and require no special procedures for the user to read, and 1,790 compressed files which require the user to uncompress them before they are readable.

A user file is created which shows the users name, city/state (optional), security level, password, the last day on the system, the number of uploads to the system and the number of downloads from the system. In addition, the system creates a user log which shows who logged in, when and what files they uploaded and downloaded. This information is useful in analyzing what information users are accessing and how frequently.

File Compression

One issue that both operators and users face is file compression formats. The reason is two-fold. First, compressed files take less space to store, and second, compressed files can be transmitted faster so it reduces connect time for the user. If the user is calling long distance, this can be a significant cost savings. File archiving is another common feature of programs that compress files. Archiving allows multiple files to be stored intact but compressed in a single file. This allows a single computer program, most composed of multiple files, to be stored in a single compressed file. Archive files are also referred to as Library files.

Problems

The most serious problem encountered has been the failure of hard cards. This has occurred twice, October 22, 1989 and November 8, 1990. Both situations involved a power failure. The system was connected to a surge suppressor in both situations. The second time the system was also "protected" by a $160 line stabilizer which supposedly offers increased protection. While the hard card was knocked out but in both situations, the hard disk was not affected. Based on a limited number of observations, we've concluded that hard cards are more sensitive to power fluctuations. The new computer system has been on line since April 1993 with no down time.

Recommendations

If you are seriously considering developing a bulletin board for producers in your area we would offer a number of recommendations.

First, determine who is going to run the system. While the bulletin board will for the most part
run itself, system maintenance is, if not a daily chore, something that must be done consistently. It is best if you can share the Sysop responsibilities with someone else. That reduces the chance of having no one to mind the store. The Sysop should also be available for user to contact if they are having a problem.

Much of the routine system maintenance and data acquisition procedures can be handled by a secretary or technician. Downloading files from other systems can be automated which greatly simplifies the task. The person who handles these routine chores should be willing, not just capable.

Second, inventory the resources you have available to work with. I'm talking primarily about hardware, software and office space. You're not going to be able to stick the bulletin board in your filing cabinets. The computer will need a clean, dry environment.

Do you have access to an old PC or will you have to purchase one? How much do you have to spend? Remember, you'll need a modem and serial cable and the computer must have a serial port. Do you have a good backup utility? Don't rely on DOS Backup unless the person responsible is a masochist.

Also, what kind of telephone lines do you have? Will they handle a dedicated line? What about multi-user lines? How much does a single-user line cost per month?

Third, become familiar with electronic data transmission and file compression protocols. This can best be accomplished by accessing other bulletin boards and downloading files. Trial and error is a wonderful teacher. File compression is necessary not only to help conserve space on your system, but to reduce the download time of users. It does present an additional educational opportunity as well, explaining to users what file compression is and how to uncompressed a file. Fourth, determine what type of information you are going to provide, how frequently you will provide it and where you are going to access it. How much will it cost? How much do you have to spend?

Fifth, acquire someone else's bulletin board. We don't mean committing larceny. But, it is much easier to take an operating system and modify it than it is to start from scratch. Why not profit by the hard work of others?

Sixth, develop a nomenclature for the files you will place on the system on a regular basis. This will greatly simplify the jobs of the Sysop in removing old files and the file descriptions contained in the FMS directory (assuming you use RBBS-PC). CROPPROD may seem like an appropriate file name for the crop production report. But these are monthly reports, and if you want more than one months reports on the systems, you will need different names as they will all have the same file extension. CRDN may work a lot better, where is an abbreviation for the month.
CHAPTER 3
New Techniques For Data Analysis And Information Formulation

3.1 Introduction

3.1.1 This chapter will focus on advances which are related to the availability of powerful, reliable and economical microprocessors which are the central component of modern data loggers and personal computers (PC). New technology has provided efficient and reliable means of transmitting and storing data in electronic form (Grace and McGinn, 1990; Mott et al., 1992). Automatic weather stations have developed to the point that in some situations they provide a viable alternative to manual observation systems provided guidelines and standards for their operation and maintenance are followed (Meyer and Hubbard, 1992). This has opened a whole range of new possibilities. Weather stations can be located in more remote areas (Yee, 1987) or in a farmer’s field (Mott et al., 1992; Carlson et al. 1994). Observations can be recorded more frequently and can be made available in real-time in electronic form (Mott et al., 1992). New low cost electronic sensors have been developed for a range of important agrometeorological parameters (Edew and Hayhoe, 1987; Atmospheric Environment Service, 1992).

3.1.2 Previously, data was manually observed, entered on a form, and mailed to the meteorological service, where it was manually checked and printed in tables or displayed on maps. Indices and simple empirical models were used to provide added value to the data (Hayhoe, 1975). With the advent of computers, data were often punched on cards or typed into a computer data file. CLICOM, which was developed by the WMO (superscript refers to the appendix), is an example of a climatological program for PCs which incorporates facilities for data entry, quality control, data management as well as statistical and graphical outputs. Examples of agrometeorological applications based on these data include: land use planning and agrometeorological zoning; protection against adverse weather factors; weather information for plant protection; application of meteorological information to the use of fertilizers; and agrometeorological assistance in irrigation, crop storage and transportation, forestry management, animal husbandry and estimation of yields (Dommermuth, 1990). There is a need for a current agrometeorological advisory service as well as climatological advice (Dommermuth, 1990; WMO, 1988). Given the importance of near real-time climate information for a current agrometeorological advisory, there has been an effort to develop systems to make the data available (Ansaheto et al., 1985; Changnon et al., 1987; Barrie, 1989; Carlson et al., 1994).

3.1.3 Recent developments have focused on AWS networks with automated data retrieval, and analysis (Hubbard and Rosenberg, 1983; Meyer and Hubbard, 1992). Data and information are accessed with PCs using computer links (Brown, 1987; Mott et al., 1992). Advances in user friendly software for PCs has contributed to advances in data management, interpretation and in information formulation. New relational data base management systems have made it easy to store large amounts of data efficiently in an accessible format (Calixte et al., 1992; Combe, 1993). Advances in Geographical Information Systems (GIS) have contributed to the analysis of layers of spatial information and facilitated in its interpretation and mapping (Lai et al., 1992; Liang et al., 1992; Jacucci et al., 1994). Expert Systems software has advanced to the point where it can provide useful advice for farm management decisions (Plant, 1989a&b; Travis et al., 1992; Parsons and Randle, 1993). There are an increasing number of simulation models available for use on PCs which contribute to decision support (Boisvert et al., 1990; Lightner and Steiner, 1992; Hoogenboom et al., 1992). Multiprocess models which combine many individual processes to address agricultural production systems are now available for PCs (Benson et al., 1992; IBSNAT, 1989).
3.1.4 An objective of this chapter is to highlight some of the most promising new techniques which are in use or being developed for agrometeorological data management and information formulation. Data handling, spatial analysis, model development and decision support systems will be highlighted.

3.2 Data Handling

3.2.1 The first step is collecting and checking data. Systems have been developed which incorporate new sensors, data loggers and communication links to a host computer to automatically record agrometeorological data (Hubbard et al., 1983; Grace and McGinn, 1990). The Oklahoma Mesonet uses a radio link to retrieve AWS data from 111 sites (Carlson et al., 1994). Meyer and Hubbard (1992) found that the most common method of retrieving data from AWS was via transmission through telephone communication. Once the data has been retrieved, the first critical step is to check the integrity of the data. The change from a manual to an AWS can introduce biases which may significantly affect the value of derived agrometeorological indices. This problem can be reduced by developing and implementing AWS guidelines (King and Trivers, 1992; Atmospheric Environment Service, 1992) and by collecting the data required to compare output from new electronic sensors with manual observations (Shewchuchuk et al., 1990). The guidelines developed by the Atmospheric Environment Service (1992) include a maintenance and calibration schedule. It is strongly recommended the sites be inspected weekly and immediately after severe weather events. As well, it is important to develop and apply quality control algorithms (Atmospheric Environment Service, 1992; Combe, 1993).

3.2.2 Quality assurance tests that can be made automatically using computer software include range checks, rate of change checks and consistency checks (Atmospheric Environment Service, 1992). Simple range checks could be to determine if the data lies within the response range of the sensor or within the range of values previously observed at a site. If climate normals are available this information can be used to establish a more site specific range check for a variable. Often problems with an AWS can be identified by monitoring the rate of change of parameters. For example, if the same wind speed (other than calm) is read for 12 or more hours the data could be assumed questionable. There are a number of consistency tests that can be implemented. If there are nearby climate stations or replicate observations at a site, then large discrepancies can suggest data quality problems. Other tests of consistency could include a check to see if the 60-minute maximum rate of precipitation in a 24-hour period is less than that for 30 minutes. These calculations can be often be made by the data logger located in the field (Balchin et al., 1991). Another consistency check would be to determine if the solar radiation is greater than the net radiation. These as well as many more extensive quality assurance tests are documented for a range of parameters by Atmospheric Environment Service (1992). CLICOM provides for extensive quality control including extreme value checks, rate of change checks, internal consistency checks and area value checks. Mott et al. (1992) also provide a summary of error checks for climate data. Another useful approach is to visually quality check the data using graphical presentations (Combe, 1993).

3.2.3 Mainframe computers have frequently been used to store data (Barrie, 1989; McGinn et al., 1994). The rapidly growing PC disk capacity has made it possible to maintain large PC data bases. PC data base software provides a user friendly system to efficiently store weather information in tables which facilitate data access, analysis and preparation of reports. A useful feature of many data bases is that they support flags for individual data points. A system of error codes can be developed to flag data points that have failed quality assurance tests. Estimated data can also be flagged to caution users. WeatherBase is a PC software package to manage and maintain data collected from an individual AWS or up to 99 networks totalling 1000 stations. It is commercially available from Omnidata International, Inc. and is
described in a recent article by Combe (1993). It provides automated quality control. It flags data that fall outside of user-specified ranges, out-of-sequence data and missing data. It has a graphical analysis capability and generates daily and monthly summaries.

3.2.4 Dissemination of accurate weather and climate data in a timely manner is essential if producers are to make the best possible decisions. Dávila-Zurita et al. (1993) have presented a comprehensive review of systems for transmitting agrometeorological information to the final user. A promising new PC technique is the use of computer bulletin boards (Brown, 1987; Mott et al., 1992). Mott et al. (1992) describe Bulletin Board Software (BBS) running on an IBM PC equipped with a 40MB hard disk and 2400 Bd modem. This system makes it possible for other modem-equipped computers to access the data base or programs and information. The Oklahoma Mesonet² data and value-added products are updated every 15 minutes and are available via modem connection to a bulletin board service (Carlson et al., 1994). The data is suitable for input into management decision models. Meyer and Hubbard (1992) review some of the applications of AWSs. They include crop water-use estimates (Meyer et al., 1989), irrigation scheduling (Heermann, 1981), livestock management (Hahn, 1981), crop canopy temperature estimates (Sagar et al., 1988), forestry management (Running, 1981), crop and soil moisture modelling (Robinson and Hubbard, 1990), frost and freeze warnings and forecasts (Martsof, 1981), crop growth monitoring (Ark in and Dugas, 1981), and drainage design and management (Curry et al., 1988). Mishoe et al. (1984) apply an AWS network for decision models for pest control and irrigation scheduling.

3.3 Spatial And Temporal Analysis

3.3.1 In order for agrometeorological information to be useful, it must be valid for the region, field or site of interest. AWS provide the opportunity for a better spatial distribution and more timely information (Meyer and Hubbard, 1992). The AWS network in Oklahoma² has at least one site in every county and an average spacing of 31 km. Manual stations are usually located so that they are easily accessible for the observer. The conventional way of acquiring data is observations from the network of the national meteorological service. This network may have been designed for aviation or economic requirements and may not be satisfactory for agrometeorological applications (Dommernuth, 1990). AWS can be located in a farmers field and the data can be retrieved automatically in real or near-real-time (Hayhoo and Balchin, 1987; Plant et al., 1992). In this way, individual producers can benefit by having site specific weather information while contributing data to an AWS network (Mott et al., 1992; Carlson et al., 1994). In England and Wales, radar derived rainfall data on a 5 km grid and the conversion of climatological stations to AWS is contributing to the availability of real-time data (Barrie, 1989).

3.3.2 Remote sensing can be a powerful tool for spatial interpolation when combined with weather site data. Seguin (1992) has recently provided a review of current applications of remote sensing techniques for spatial interpolation of radiation, surface temperature and precipitation. Martsof (1989) describes the application these techniques to frost advisories. Estimates of insolation provide input into large area yield estimates (Botner and Sakamoto, 1989). Kanemasu and Fitchcroft (1992) describe the application of remote sensing for estimates of rainfall in Africa. Remote sensing may contribute to pinpointing areas which could support the explosive growth of desert locusts populations (Kanemasu and Fitchcroft, 1992). Feddes et al. (1993) estimated regional latent and sensible heat fluxes using remotely sensed measurements. They demonstrated the estimation of regional soil hydraulic properties using these flux estimates with SWATRE, a soil-water-vegetation model.

3.3.3 Many integrated pest management models require weather data which corresponds to conditions experienced by the pest. These applications suffer from the fact that data may
be used from a weather site which does not account for mesoscale climate effects. Kelley et al. (1988) presented a mesoscale forecasting technique called Model Output Enhancement to provide screen-level forecasts of temperature and other weather variables. The product of the technique are forecasts at a temporal resolution of one day and a spatial resolution of about 1 km. The forecast domain included the northeastern U.S. The technique has been demonstrated on the predictions of the development of the alfalfa weevil (Kelley et al., 1989) and for plant disease prediction (Royer et al., 1989).

3.3.4 Leaf wetness is an example of an agrometeorological parameter which is known to be important for plant diseases but is difficult to measure (Sutton et al., 1984) and has a large spatial and temporal variability (Huber and Gillespie, 1992). Some empirical methods of combining weather station data and air temperature in the crop are proving useful for estimating leaf wetness duration (Huber and Gillespie, 1992). Srivastava et al. (1989) found that useful estimates of a disease severity value (DSV) for tomatoes could be derived from a combination of local maximum and minimum temperatures and regional dewpoints. Local dewpoints were estimated using linear regression from regional dewpoints. Hourly local temperatures were estimated from maximum and minimum temperatures following Parton and Logan (1981). The DSV's computed from leaf wetness measurements were not found to be significantly different from DVS's calculated with dew point depressions and maximum and minimum temperature data (Srivastava et al., 1989).

3.3.5 If the climatological station network is sufficiently dense, useful area average values can be calculated using a spatial weighing procedure such as the Thiessen polygon (Mather, 1975; Hayhoe and Williams, 1982). This approach combined with the concept of uniform regions has been recently used to determine stress indices for spring wheat on the Canadian prairies. Agroecological Resource Areas (ARAs) were defined for the prairie region. ARAs are natural landscape areas that are more or less uniform in terms of climate, landforms, soils and crop production potential (Bootsma et al., 1992). Climatological variables for each ARA were determined using a computer implementation of the Thiessen polygon technique and with station data (Williams and Hayhoe, 1982; Kirkwood et al., 1993). Some empirical adjustments to the weighing were made to account for topographic effects. The Thiessen polygon technique is less appropriate for hilly or mountainous terrain. Extrapolation techniques which account for topography are required to provide a climatological map for sites in mountainous terrain (Running, 1981). Bootsma (1976) developed empirical equations to estimate minimum temperature and climatological freeze risk in hilly terrain. Other researchers have used geostatistical approaches to study spatial variability (Davidoff and Selim, 1988).

3.4 Model Developments And Information Formulation

3.4.1 There has been extensive reporting of agrometeorological models and indices for operations management in the form of workshop proceedings (Weiss, 1981; Hatfield and Thomason, 1982) and WMO reports. A comprehensive review of the effects of meteorological factors on plant diseases, insects and weed pests has been completed (WMO, 1988). Recent work has summarized the effect of agrometeorological and climatic factors on pests and diseases attacking citrus crops (Ramón, 1992) and on viticulture (Turmanidze, 1992). Khambete (1992) summarized developments in Agrometeorological applications in developing countries and Strogenova (1990) and Dommermuth (1990) reviewed new applications and requirements in countries with highly developed industries. Agrometeorological applications are frequently provided from a central processing office (Blackburn et al., 1986; Barrie et al., 1989). This section will include examples of operations management models which are designed for use on a producer's PC. This approach contributes to timely, and site specific analyses and recommendations as well as providing training for the producer when models are run in a simulation mode (Mishoe et al., 1984).
3.4.2 Irrigation scheduling is a widely recognized requirement for agrometeorological applications. The WMO\(^1\) together with FAO have contributed to the development a system for the application of climatic data for effective irrigation planning and management. Training manuals\(^1\) are available and roving seminars for agrometeorologists have been arranged to facilitate the application of the system. A similar system is also being evaluated in Ontario for selected local crops\(^6\). IRRGATE\(^8\) (Boisvert et al., 1990) is an example of a model designed for use on a producer’s PC. It is written in a PC version of BASIC and is primarily designed for the daily management of water in irrigation. Daily maximum and minimum air temperature and precipitation are required inputs. It incorporates a soil moisture budgeting procedure and provides an estimate of the number of days before an irrigation is required. It can provide estimates for a number of fields with different crops and soils. The software has been tested by potato growers\(^6\).

3.4.3 MARYBLYT\(^{TM}\) (Lightner and Steiner, 1992) is a computer model for predicting fire blight disease. It is compiled in Pascal and operates on IBM-compatible PCs. The computer program features data input screens for daily maximum and minimum air temperature, precipitation and trauma events. Infection risk assessment and predictions are generated in both real and simulated time, providing an interactive basis for decision-making. This system has proved useful in field evaluations in Ontario\(^6\). PLASMO (Rosa et al., 1993) is a computer simulation model for grapevine downy mildew development forecasting which is written in Pascal and operates on a PC. It is designed for use with an electronic data acquisition system to provide timely information to farmers to identify the time of fungicide applications.

3.4.4 AWSs have changed the meteorological variables which can easily and economically be measured. Solar radiation can now be monitored with more economical silicon pyranometers (Atmosphere Environment Service, 1992). Weiss (1983) noted that the application of the Penman equation for irrigation scheduling could often not be realized until the advent of AWSs. AWSs have the capacity to integrate daily solar radiation and day and night wind runs as well as 24 hour averages of air temperature and humidity. These measurements can be made near the area of interest and daily observations can be made to begin at midnight rather than 8 AM. This more detailed information can contribute to model estimates of drying of grasses (Atzema, 1992) and the moisture content of cereal at harvesting (Atzema, 1993). Often more empirical methods have been used in the past because of a lack of data (Hayhoe and Jackson, 1974). Electronic sensors for leaf wetness\(^{10}\) (Sutton et al., 1984; Huber, 1992) can contribute to validation of models for leaf wetness (Weiss and Norman, 1987) as well as to plant disease forecasts (WMO, 1988; Huber and Gillespie, 1992). Hourly soil temperature measurements from AWSs can provide useful input to pest models (Schafsm, et al., 1991).

3.4.5 Normals and levels of risk for a range of agroclimatological parameters provide useful information for many management decisions. There is a growing recognition of the importance of accounting for risk in the planning process. Meyer (1993) described a commercial package for PCs called CLIMPROM\(^3\) which can be used to calculate probabilities of agroclimatic events. Mukerji and Hayhoe (1988) used a Markov chain probability model to quantify seasonal risk of grasshopper outbreaks on the Canadian prairies. Similar analyses have been used to quantify the probability of field workdays (Hayhoe and Baier, 1974) and hay drying weather (Hayhoe et al., 1986). There is a continuing interest in deriving and mapping agroclimatic indices and risk levels to assist in crop selection and management. A stress index has been defined and mapped for the Canadian prairies. The risk of stress in spring wheat between the jointing and soft dough stage is designed to help with planning crop rotations and evaluating the need for soil moisture conservation (Bootsma et al., 1992). Bootsma and Brown (1989) mapped the spring and autumn freeze risk in Ontario. They developed rules-of-thumb to estimate freeze dates for various risk levels and critical temperatures.

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3.4.6 Spatial and temporal weather models are also being applied to planning and decision-making. They provide the opportunity to simulate the effects of weather variability on management decisions. The advantage of using stochastic weather models is that they can supplement limited historical records and reduce data storage requirements. A model for generating daily weather variables (WGEN) (Richardson 1981; Richardson and Wright, 1984) is being used in EPIC to model the relationship between erosion and soil productivity (Williams et al., 1984; Sharpley and Williams, 1990a&amp;b). A weather generator based on WGEN is an important component of the USDA - Water Erosion Prediction Project (WEPP) (Lane and Nearing, 1989). Liang et al. (1992) used a temporal and spatial weather model for stochastic simulation of daily temperature, solar radiation and humidity for Hawaii. Their method was based on the hypothesis that the annual distribution of many climatic variables remains nearly constant for large land areas while the absolute value may vary greatly from point to point. Statistical clustering was used to group weather stations of similar distribution. The approach was applied using a GIS to analyze greenhouse energy needs.

3.4.7 Crop weather analyses and simulation models remain a very important component of agrometeorological information formulation. Historically, statistical approaches (Williams et al., 1975) or combination approaches (Baier, 1973; Stewart and Dwyer, 1990) have contributed to yield forecasting. Crop growth simulation models have taken longer than expected to be widely adopted. They required more detailed data than traditionally were available; they were difficult to use and needed substantial computer resources. Simulation models of crop growth are becoming useful tools in part because of the availability of data from AWSs and the advances in computer technology that make it possible to run complex simulation models on PCs (Lui et al., 1989). Whisler et al. (1986) identified 30 simulation models for a range of crops. Van Kuenlen and Seligman (1987) identified nine for wheat. Model developers have made a major effort in programming, documentation and education to make the models useful to a wider audience (Hoogenboom et al., 1992). There has been a coordinated effort on field research to test the models. Porter et al. (1993) demonstrated the testing of three wheat simulation models and Asare et al. (1992) provide an evaluation of three cotton simulation models. Yang et al. (1989) have made an assessment of models for rice. The pattern of model development, testing, improvement, and implementation for easy use by researchers has led to the evolution of highly useful tools (Hoogenboom et al., 1992).

3.4.8 These features are exemplified in families of models which have been incorporated in the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT). They illustrate characteristics which have contributed to making simulation models of growth, development and yield useful tools. Features of these models include: standardized input for multiple crops, PC versions with a user-friendly interface and complete easy to follow documentation. Hoogenboom et al. (1992) describe a family of models for grain legumes which include SOYGRO, PNMUGRO and BEANGRO. Other models include CERES-Wheat (Ritchie and Otter, 1985), and CERES-Maize (Ritchie et al., 1989). The concepts of CERES are being extended as CERES-CEREAL to include models for wheat, maize, sorghum, barley, and pearl millet (Singh et al., 1991). CERES-Rice has been developed for upland and lowland rice (Jinrathawet et al., 1991). Other simulation models which are incorporated in IBSNAT include SUBSTOR V2.0 for potato growth and development (Griffin et al., 1991), and a model for aroids (Prasad et al., 1989). All these models require IBSNAT standard Minimum Data Set (MDS) (Hoogenboom et al., 1992; IBSNAT, 1990a). This allows for the exchange of data between models. Weather and soil description files can be exchanged between various crop models. Procedures have been defined for data collection (IBSNAT, 1990b). In addition there is a computer program available to enter all data into the data base (Hoogenboom et al., 1992). The crop models are written in FORTRAN for PCs. A daily time step is used. The output includes IBSNAT standard files and graphs. The documentation and structure facilitates testing, development and applications (Carberry et al., 1989; Robertson et al., 1993). CERES-Maize has been adopted for large area yield estimation in the U.S. (Hodges et
al., 1987; Botner and Sakamoto, 1989).

3.5 Decision Support

3.5.1 The objective is to formulate information in the form a farm manager or a planner can readily use. There is a need to identify the information that the farmer wants and can efficiently use. Climate-related information may be more useful to a farmer than climate information by itself. Weiss (1989) suggested that there is an important difference between climate information and climate-related information. Climate information would include for example the average last day of frost (0°C). Climate-related information for instance could provide information on the effect of pests on crop yield and income for different climate, management and economic scenarios (Weiss, 1989). Weiss (1989) concluded that a systems approach could provide a framework to supply climate-related information. Current developments in decision support systems exemplify the progress towards providing more useful climate related information.

3.5.2 Numerous examples of decision-support applications will be presented and referenced in this section. The goal is not to have the most complex management system that is available, but rather to have the most practical system to enhance strategic or tactical decisions. Risk management is an extremely important aspect in farming. Weather data combined with sampling information or agronomic estimations form the basis for farm management decisions. Integrated Pest Management (IPM) is one of the early successes of this multi-disciplinary approach. The temperature pattern over the winter and spring seasons is a key factor for the developmental threshold of an insect life stage and population. Scientific information from meteorologists, entomologists, and crop physiologists has been drawn together to formulate strategies for pest management, including the optimum timing of control measures based on pest population and the most cost-effective timing of application based on current weather conditions.

3.5.3 Rapid collection of accurate weather data is also critical to the success of any disease forecast system. The combination of high humidity and specific temperature thresholds affect the rate of pathogen development, and can lead to complete defoliation or significant yield loss if the crop is left untreated.

3.5.4 Proper irrigation scheduling is important to help ensure environmental resource conservation as well as to maximize the efficiency of water use. Proper scheduling conserves ground and surface water supplies, and the energy required to pump them. The primary approach to irrigation scheduling is to evaluate the degree of soil water depletion within a crop's root zone and recommend initiation of irrigation when a certain percentage of soil water has been removed. The estimate of evapotranspiration, derived from air temperature, wind speed, humidity, net radiation and soil heat flux, is a critical factor in modeling efforts leading to the most efficient use of irrigation scheduling.

3.5.5 Range management is another application of decision-support systems utilizing agrometeorological data. Accurate weather information allows livestock producers to make more informed decisions regarding prescribed burning, proper stock density, and grazing duration. The diversification of knowledge based decision-support systems for agriculture will become more evident in the following discussion.

3.5.6 Benson et al. (1992) note that most production oriented software has traditionally addressed particular crops or management practices rather than simulating the joint impact of many processes. The Erosion Productivity Impact Calculator (EPIC) is an example of a widely used model which simulates the impact of many processes. The model includes a physical
components for simulating erosion, plant growth and related processes and an economic component for assessing the cost of erosion and for determining optimal management strategies (Sharpley and Williams, 1990a). A single crop growth model is used for simulating all crops where each crop has unique values for the model parameters. EPIC has recently been applied on Agroecological Resource Areas (Kirkwood et al., 1993) on the Canadian prairies to assess the environmental impact of agricultural policy and resulting crop rotations. As PCs have become more powerful, EPIC, as well as other multiprocess models have been transferred to PCs which make them accessible for use by farm consultants and farmers.

3.5.7 There is a lot of interest and effort going into the development of decision support systems (Kuhlmann, 1990; Lal et al., 1993). Parsons and Randle (1993) describe a decision support system for dairy farms which includes a herd records data base, a weather and field events data base, a ration formulation program and a grassland utilization planning program. Mishoe et al., (1984) suggest that farm manager decisions can be classified as within-season and pre-season. They illustrate a framework using the example of soybeans to structure models to provide decision support. An automated weather collection system is used for timely collection of the necessary information. Their system included component models for yield (SOYGRO), soil water including irrigation, insects, foliar pathogens and economics. The system provided a long-term strategy evaluation model, and a soybean game component designed as a teaching tool (Mishoe et al., 1984). More recently Fortson et al. (1989) have used SOYGRO for managing irrigation. Smedra et al. (1990) have incorporated economic analysis with crop models to estimate risks in crop management systems. Asare et al. (1992) evaluate three cotton models under different irrigation regimes. These models are used to help make decisions that maximize the use of available resources by quantifying the effect of irrigation on yield.

3.5.8 Expert systems are increasingly being developed for decision support. Their objective is to simulate the response of an expert for management decisions (Rafea et al., 1993). The systems involve computer software to enter and store information and they use concepts based on artificial intelligence (AI) to recommend the most appropriate decision. CALEX is an expert system shell which provides for efficient data entry and management and permits the integration of information from a variety of sources to develop crop management guidelines (Plant, 1989a&b). CALEX/Cotton is the first large-scale implementation of a CALEX-based crop management decision support system. It was developed for cotton production management in the San Joaquin Valley, California (Plant et al., 1992). It is designed for use on a PC to perform tasks such as generating irrigation schedules in a manner similar to a human expert.

3.5.9 A range of other environments and crops have been considered in expert system developments. Heinemann et al. (1992) describe an expert system to assist growers with planning and management of frost protection systems. The program is based on the experience of personnel involved in frost protection and combines heuristics, models, and data bases to provide growers with recommendations. The program includes support for planning and design of a frost protection system, as well as day-to-day operations management, and risk forecasting. Instrumentation to monitor frost events is part of the system. It is designed for use with other expert systems for managing fruit crops including PSAOC for apple orchards, VITIS for viticulture, and PeachES for peach orchards (Crassweller et al., 1989; Heinemann et al., 1994). Rafea et al. (1993) report on the development of expert systems to enhance the services of extension workers provided for farmers in crop management of cucumbers grown under protected cultivation and citrus fruit in open field cultivation. Edward-Jones et al. (1992) present an expert system for weed control in sugar beet. Many expert systems do not use a crop simulation model. SMARTSOY, an expert simulation system for soybean insect pest management, includes a crop simulation model (Batchelor et al., 1989a; Batchelor et al., 1989b). GOSSYM-COMAX is a cotton simulation model and expert system (Boone et al., 1993)
3.5.10 Montas and Madramootoo (1992) describe a decision support system for soil conservation planning. It incorporates a GIS, an Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS) and an expert system. The system was used to select erosive hot spots and choose appropriate soil conservation practices for a watershed in southwestern Quebec, Canada.

3.5.11 Decision support systems provide the tools to examine the production system and may incorporate data base management systems, a family of crop simulation models, weather generators, expert systems and GIS. The IBSNAT Decision Support System for Agrotechnology Transfer (DSSAT) is an example of a comprehensive system. DSSAT version 2.1 computer software for PCs and documentation can be purchased from IBSNAT. The package includes 10 crop models with complete user instructions. It can be used with site specific soil and weather parameters to identify the most promising crop and management practices (IBSNAT, 1989). It is a PC based shell which includes a Data Base Management System (DBMS) (IBSNAT, 1991), the IBSNAT family of crop models and application programs (IBSNAT, 1989). Recently a regional Agricultural and Environmental Geographic Information System (AEGIS) has been developed (Calixte et al., 1992). AEGIS uses the DSSAT capabilities within a GIS for regional planning and productivity analysis. The GIS is a PC-based system which links digital map features to a data base of attributes describing these features. A simple expert system is used to provide optimum ranges of soil and weather requirements for crop production (Calixte et al., 1992). The system has been successfully applied for regional productivity analyses in western Puerto Rico using BEANGRO to identify optimum crop management practices such as cultivar selection, planting date and irrigation strategy (Lal et al., 1993).

3.5.12 A multiprocess decision support system (HYDRA-DSS) is being developed in a European Community project designed to provide farmers and water authorities in European Mediterranean agriculture with the information to improve irrigation practices (Jacucci et al., 1994). The system includes a set of crop growth simulation models, an agro-meteorological information system, a soil information system, a GIS, an expert system and a graphical user interface. The agro-meteorological information system is able to analyze time series of historical observations and generate the input parameters for the built-in weather generator. It will also use a blend of observed and short-term forecasted data. The soil-water-balance and crop-growth simulation module consists of a set of mechanistic models and simpler empirical models. The most appropriate model is selected based on the available input data and the objective of the simulation exercise.

3.5.13 The LANDS (Land Analysis and Decision Support) system (Moon and Jeck, 1993) was developed through a cooperative project between Agriculture Canada and Malaysia. It is a fully integrated PC or work station based package for land information and data management which was developed to emulate a group of experts in land use planning. The LANDS shell includes a data base management system with forms and menus for data entry, an expert system, a linear optimizer, a GIS, a climate analysis module and a land allocation model (LAM). The LAM is a versatile and robust decision model which can be used to maximize net farm income within user definable environmental, resource, social, policy and production constraints or to analyze all possible land use options and the constraints or limitations to their implementation. The system was applied in the Padang Terap district of northern Malaysia. The objective was to schedule land use options to land area over 5 years so as to maximize income and respect seasonal growth patterns and prices, seasonal resource constraints, policy and social constraints, account for land improvements and conversion costs from current land use, accommodate different rotation ages and recognize productivity differences. The solution was provided as a five year plan identifying land conversion activities, resource requirements and discounted cashflow for each year of the five year plan. The information was presented in maps, graphs and reports.
3.6 Conclusions

3.6.1 The current trends suggest that agricultural decision makers can anticipate easier access to more data and useful information. AWSs and database management systems have the potential to make weather and climate data readily available in usable formats. The development of standards is an important part of this process. Crop simulation and management models are becoming more reliable and user-friendly. Combined with the required input data they provide useful tools for training and decision support. GIS which provide the analytical capability to combine layers of spatial information are ideally suited to assessing land resources including climate to support planning and management operations decisions. Recent developments with expert systems indicate the potential to make better use of agrometeorological data in decision-making. Many of the developments we have discussed are taking place on PCs or are compatible with PCs. This means that even with limited computer resources these powerful new techniques are accessible.

3.6.2 One of the biggest limitations in decision support systems is still the availability of quality data. Projects such as IBSNAT have the potential to develop the expertise and methodology to expand the data base and facilitate its analysis.
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Appendix 3.1

The following is a list of experts on selected topics. The numbers refer to the superscripts in the text and are arranged in the order the topics are discussed.

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CHAPTER 4

OPERATIONAL APPLICATION OF REMOTE SENSING DATA TO AGRICULTURE

4.1 The agrometeorological requirements for creation of observational systems using remotely sensed data will be discussed in this chapter. Prior to the development and utilization of meteorological satellites for resolving agrometeorological problems, certain systems functioned (and still are functioning) for collection, processing and provision of information to the user. For example, the USSR had such a system base on a rather dense observational network including the ground and aerial (aerovisual) observations [2,8]. In such countries as the USA and Canada, much of the information was collected on the basis of farm questionnaires [11,12]. In the EEC member states, this system was largely supported by statistical services [14]. Quite often such systems were able to function successfully enough, particularly in the years with normal weather. That is why the first attempts to use remote sensing systems as a substitute for the existing ones or to contribute to the latter without an in-depth study did not always prove successful. This may be primarily related to the specific features of satellite data (inadequate speed of data collection from the first satellites, cloud effects, lack of data series, qualitatively new information, etc.) Thus when experience was gained in managing remotely sensed data, requirements could be established for the information systems to use space data in operational systems derived from generalization of the available literature in the field [1, 3, 4, 11, 12, 14]. These requirements are presented as system components: the sources of remotely sensed data, initial data processing and sorting, data provision, data analysis, and regional system configuration.

4.2 The sources of remotely sensed data are primarily from satellites and aircraft. Currently, satellites are in operation which enable the collection of data in several spectral ranges with different spatial and time resolution. Specifically, there is an inverse relationship between the latter characteristics. The geostationary satellites (Meteosat type) have a wider image coverage (in principle, whole continents may be covered), a high sensing frequency (1-2 times in an hour) for the covered area, although the resolution is slow (several kilometers). For the meteorological and earth resources satellites, as a rule, a sun-synchronous orbit is selected. Moving along this orbit the satellite passes a given latitude at the same local time which thus minimizes the daily deviations resulting from the solar lighting. The choice of local time for one particular latitude means that the same local time will be selected for all other latitudes. Multispectral scanning systems of the meteorological satellites (Meteor type for Russia, NOAA type for the USA) also have a wide coverage (ca. 1.5-2.5 thousand km), a high enough image taking frequency (1-2 times in a day) and the spatial resolution from several hundred meters (Meteor) to 1.1 km (NOAA).

4.3 The multispectral scanning systems of the earth resources satellites (Landsat and Landsat-D for the USA, Spot - France, Kosmos 1939 - the USSR, and others) have a very high spectral resolution (100 to 10 nm) and a high spatial resolution (10 to 100 m), which enables them to be more efficiently used for resolving different problems in agriculture. However, a low scanning width (100-200 km) and a low image taking frequency of particular areas (1 time every 15-18 days) makes the information collected less applicable. An optimal solution for the future data collection system would be a combination of low and high resolution would provide imagery [10, 13]. In this case the low resolution would enable a global view identifying anomalous regions, whereas the high resolution would provide a detailed survey of the conditions and an understanding of the reasons which resulted in the anomalies.

4.4 Currently in many studies aimed at assessing the land resources, the data from the visible and infrared spectral ranges are used. The applicability of this data is significantly limited by cloud cover, fog, and heavy atmospheric pollution. For the provinces of western
Canada, the probability of obtaining the Landsat imagery with the cloud cover of less than 50 percent is, for example, as low as 53 percent [12]. For the NOAA satellites this probability is higher since the observation frequency is higher, however, the problem still remains. There is a way to overcome this predicament, introducing the prospective use of microwave sensors.

4.5 Aircraft, as a source of remotely sensed data, may play an important role in creating operation agrometeorological systems for the collection, processing and use of data for selected regions. An airborne sensor can enable the output of data with a higher resolution than a similar sensor fixed on a satellite. Besides, aircraft can carry special purpose sensors which cannot be mounted on satellites (e.g., sensors which measure the natural gamma-radiation - earth background radiation used to estimate soil moisture).

4.6 Aircraft may be used to collect the basic data over vast areas if multispectral sensors with a relatively high resolution are used. However, such an application may not be made frequently. On the other hand, which makes it different from the use of satellites, if an emergency arises, the aircraft flight assignment may be quickly corrected on the basis of the spatial and time requirements. It stands to reason that there are definite problems in the use of aircraft too, with the flight costs playing an important role. This problem can be partially resolved if aircraft can be used for the collection of data for several users simultaneously. In such a case, although the flight tasks may vary in terms of time and space, an optimum flight schedule may be derived to satisfy all the users.

4.7 In the process of initial processing and sorting of data, the basic "raw" satellite and aerial data are reshaped into spatially located parameters. On the satellites, the process includes the basic data correction with the help of calibration signals generated by the satellite equipment as well as the calibration data obtained during the tests prior to the launch. As soon as the radiometric calibration is over, the data are processed and transformed into a geophysical form with the use of specific algorithms and special procedures aimed at creating images. At the same time, correction is made to account for atmospheric phenomena, and earth’s revolution, as well as, for transformation into the conventional map projection. Initial processing of the aerial data also includes nearly all of the above stages.

4.8 Satellite and aerial remotely sensed data may be provided by the space telecommunications networks, ground telecommunications networks, using post facilities and messengers, or a combination of the above ways of data provision. The structure of data provision is determined by the amount and forms of the data transmitted, the experience of provision and the relative costs. The technical facilities for the satellite data relaying within the framework of the Landsat program described in [11] enabled the four-spectral image acquired by the Landsat to be transmitted in 8 minutes from the Italian town of Frascati to Farnborough (UK) practically without mistakes. Whenever expediency in data acquisition in required and costs of data relaying are not taken into account, satellite communications channels may be used. Currently, the most extensively used ways of data transmission are rather slow (postal services, messengers), since the costs of these services are relatively low and, for most purposes, this way of data transmission is justified. For example, in Canada [11] from the time the satellite data is received at the ground to the time it is delivered to the user is 3 hours for emergency (ice monitoring) and 24 hours for vegetation monitoring.

4.9 The study of potential users of remotely sensed data [1, 5, 11, 12] shows that only a few users have the resources for independent analysis of this information. These "independent" organizations deal with a sufficient number of problems but can provide adequate funding. Thus, these users may be assumed to have adequate analyzing systems and the personnel capable of data processing (decoding), assessment, and interpretation. As stated in [11], for example, the organizations acting as "direct" users of remotely sensed agricultural
information in Canada comprise only five percent of the total number of potential users.

4.10 To enable the effective use of remotely sensed data, a highly coordinated distribution mechanism is required. To this end, a distribution network may be used including a high capacity personal computer connected to a large number of remotely located terminals. Each of the terminals must have a limited capacity to manage and analyze the data [5, 11]. Thus the problems involving processing of a limited amount of data may be resolved “locally”, i.e., using the terminals. However, operations involving large volumes of data and extensive computations can be performed at the mainframe computer. Taking into account stringent requirements on the analytical tools it seems reasonable that a public access system can be developed for image analysis and data integration [5].

4.11 In [4, 11] information systems are discussed which are used for the acquisition of earth resources information at the regional level, aimed primarily for the solution of agricultural problems. Practically, these systems provide a basis for an extensive use of remotely sensed data in operational practices. As for the former USSR, selected parts of the system are practically used in operational activities of the Federal Service on Hydrometeorology and Environment Monitoring. According to [4, 11], the main elements of the system are: the satellite facilities for data collection, aerial facilities for data collection, standard data sources (for Russia these include, for example, a relatively wide network of observational stations and, additionally, statistical services, etc.), data analysis and output equipment, and the users of the earth resources information.

4.12 The satellite and aerial facilities receive requests for specific tasks, including the type, format, and quality, as well as the requests for preliminary data processing and sorting. There must be a close relationship between the process of task control and the subjects performing the data requests, to ensure the recording and processing of the data selected in accordance with the assignment of specifications, as well as the delivery of satellite and aerial data to the subject who issued the request at the specified time.

4.13 The component which is responsible for the analysis of measurements also analyzes the data received from other sources (the data of topographic maps, soil data, data of agrometeorological and meteorological observations and measurements, etc.). Although this kind of data may be quite easily obtained from generally accessible sources, users are not always satisfied with the format of presentation. Thus the system must accommodate data acquired at different times and at different scales. Geographic information systems (GIS) [5, 8, 12, 15] play an important role in analyzing and comparing all the types of data. These data contain additional information which has been structured in a definite order. This establishes a connection between all incoming data and the available agrometeorological models for the generation of estimates of crop state and production (dynamic and dynamic statistical models of the “CROP-WEATHER” type) [4, 15].

4.14 To enable a full-scale use of the remotely sensed data in the operational applications, sufficient progress should be achieved in three aspects of future data systems: data accessibility and availability; availability of procedures; and, technological support for both analytical use and user training.

4.15 The accessibility and availability of satellite and aerial data should be undoubtedly guaranteed at reasonable prices. The cost of data acquisition must be known prior to the time when data users get fully involved in the process of using the data. Further, the data should be available in a corresponding form and within the time limits which would enable the useful application of the resulting information.
4.16 Depending on the nature of changes in the general data system, the subsystems and analysis procedures may vary from very simple ones (such as a fast visual analysis of the limits of a forest fire) to very complex types of the digital imagery analysis and integration of different data types stored in the data base (for example, the digital land-use data maps). The costs involved will respectively differ considerably.

4.17 The personnel of a resource management agency should have adequate knowledge and skills to effectively utilize remotely sensed data and the staff should have an access to relevant training facilities. The above skills should include the ability to analyze data, learn the potentialities and limitations of the analysis methods, and develop the potential to make the most effective use of the results obtained.

4.18 An example of an aerial system for crop monitoring is presented in this section. Since the 1970’s the former USSR State Committee of Hydrometeorology has regularly conducted the aerial spectrozonal surveys of crops in different areas of the country [4, 7, application 3]. As a vegetation index (β) a simple ratio of the value of spectral brightness coefficient (SBC) for the infra-red spectral range to the SBC value for red range is used. As a result of numerous investigations a rather close relationship was derived between the β value and the plant cover parameters (above-ground biomass, leaf area, etc.). A simple two-channel photometer is used as a sensor. Its characteristics are as follows: the spectral sensitivity range is from 740 nm to 1100 nm for the infra-red channel and from 610 nm to 690 nm for the red one; the viewing angle is 35° ± 2°; the total relative error in estimating the SBC ratio at a confidence level of 0.9 is not greater than 10 percent. The equipment has to be modernized to increase the spectral channel number, to narrow the spectral sensitivity range and to provide real-time processing. Before the observations the instrument has to be calibrated, viz simultaneous measurements of β for crops and soil and the canopy parameters are to be made on the same sites (the area is usually equal to 1 m²). The number of sites must be in the range from 20 to 30. Then the calibration curve is calculated to define the relationship between β and a canopy parameter. The calibrations curve must be defined for all crops of interest.

4.19 After the calibration the device is mounted aboard the plane and the β observations for crops in the study area begin. The altitude of flight is about 2000 m for desert pasture vegetation estimation and 150-300 m for cropped areas. The usual velocity of an aircraft is near 200 km per hour. At these conditions an operator could perform a crop visual recognition on the basis of a number of features [4]. The only operator action is to turn on the equipment at the beginning of a field and to turn it off at the end. The equipment performs all the other procedures automatically and enables a data output in a suitable format for operational processing [4]. As soon as a working day is over the survey results are cabled to the operational departments of the Federal Service on Hydrometeorology and Environment Monitoring. Within the former USSR State Committee of Hydrometeorology eight aerometric teams have been established to carry out the surveys of crops and pasture vegetation on a regular basis (usually two times in a season). Those surveys cover large regions in the European Russia, West Siberia, Central Asia, and Kazakhstan. The teams are located in Obninsk, St. Petersburg, Rostov-na-Donu, Novosibirsk, Krasnoyarsk (Russia), Kiev (Ukraine), Tashkent (Uzbekistan), Alma-Ata (Kazakhstan). The methodology has been defined in Obninsk (Institute of Agricultural Meteorology). According to the survey results the chart of the desert grassland vegetation productivity is made and the value of the above biomass of some crops according to routes or averaged over the territory is calculated. The obtained values of plant biomass are used by operational departments as a predictor in yield forecasting. The forecast procedures are based on statistical relationships or on simulation models “Weather - yield.” The last ones, especially from recent studies could utilize some remote sensing data to increase the forecasts quality [4]. The following crops are surveyed: winter wheat and rye, spring
wheat, barley, maize, and cotton.

4.20 In addition to the vegetation observations the aerometric teams fulfill the aerial gamma survey procedures. The method of water storage estimation in the upper soil layers and on the soil surface based on the gamma radiation attenuation effort of natural soil radioactive elements was invented in the USSR in 1982 [6]. Radioactive soil elements of uranium-238 and thorium-232 families and potassium-40 isotope are the sources of soil gamma radiation. These elements are widespread everywhere. Fall-out from nuclear explosion products, cosmic rays, etc., contribute to the radiation. The above mentioned elements create a gamma field in the near surface atmosphere. The field intensity I at the height h above soil surface unequivocally depends on relative soil moisture w and water storage of the soil surface, for example, in the snow cover p. The relationship could be approximated by the expression [6]:

\[ I = \frac{l_p \exp (-\gamma_p -\gamma_s / l_1)}{1 + Kw} \]  

(1)

where \( I = I_p \) at \( p = 0, h = 0, w = 0 \) is the value determined by the radioactive element concentration in soil. The coefficients \( K_p \) and \( K \) express the variety of soil, water and air absorbing properties. The coefficient \( \gamma \) depends on the spectral and angular characteristics of the field in question. The expression (1) is quite valid if the distance from the sensor and soil surface in less than 200 m (aerial gamma survey). For this case \( K_p = K = 1.1 \). The relation (1) could be used as the calibration curve for water storage in snow determined at constant soil moisture. If \( p = 0 \), the (1) equation is used for soil moisture calculations.

4.21 For more than 10 years, the Institute of Agricultural Meteorology has been conducting some research projects to develop systems for processing and interpreting remote sensing data with different spatial resolution (small, medium, and high) for solving diverse agrometeorological problems. The above systems work with space digital images, spectrometric data from aircraft, ground truth data as routine and special observations from meteorological stations (the former USSR Meteorologic Service Network), and dynamic-statistical models "Weather-Yield" to evaluate crop state and productivity. Remote sensing data were obtained from "LANDSAT", NOAA (USA), "FRAGMENT", "KOSMOS 1939", and "METEOR" (Russia). Procedures were developed to process and analyze the mentioned data were worked out.

4.22 The system EXTEC was developed to evaluate the state of winter crops in southern regions of the European USSR through remote sensing data from AVHRR ("NOAA") or MSU-S ("METEOR") [5, application 2.] The essence of the algorithm is as follows:

to calculate the Normalized Difference Vegetation Index (NDVI)

\[ NDVI = \frac{(S_i - S_d)}{(S_i + S_d)} \]

where \( S_i \) is the reflectance in the near infrared band (0.7 - 1.1 mkm), \( S_d \) is the reflectance in the red spectral band (0.7 - 1.1 mkm);

- to divide pixels into three classes - winter crops, soils, and the rest; the success might be achieved only early in the spring of late on the autumn when the green fields with a winter crop are the only ones in the region;

- to divide the "GREEN" class into the three sub-classes with good, bad, and satisfactory states using the plant density data for the calibration.
4.23 The geographical coordinate calculation accuracy on the base of the satellite orbit prediction is 3 to 5 pixels. If there are some specific points on the image (a coastline, river, etc.) the accuracy might be increased to 1 pixel. The K-mean procedure is used for clusterization. Out of the break down, NDVI selects the vegetation cluster (usually it is the one with maximum NDVI in the center). It represents the winter crops, mainly winter wheat. The NDVI distribution map is of great important for qualitative estimation of crop growth conditions. With such a map, the user could compare the crop growth conditions in different regions (see the next page). The set of maps provides the possibility to evaluate changes in crop state. These maps are very promising for detecting regions with an abnormal state of vegetation. For quantity estimations of NDVI calibration procedure on the basis of plant density was developed. The empirical plant density thresholds for different states of crops were gathered [6]. The ground observation data are combined with NDVI imagery to transform the plant density thresholds into the NDVI values. Then, crop areas with different states could be easy calculated. Errors in the total area estimations are less than 10 percent. With the help of EXTEC, NOAA and METEOR images are processed on a regular basis during the autumn and spring growing periods with the results sent to the Hydrometeorological Center (HMC) of Russia. The results are used in the HMC to derive recommendations on the state of winter crops (staple cereal crops in the late USSR) after wintering, and to evaluate the areas where resowing is required.

4.24 Now the State Committee for Hydrometeorology (Institute of Agricultural Meteorology) has the first version of the early warning system to monitor the state of cereal crops [5]. The system includes the above described subsystem for processing digital images from meteorological satellites, the subsystem to create the land use maps on the basis of high-resolution images, and the subsystem for ground truth data (observations of precipitation, air temperature, soil moisture, phenology, etc.) analysis. Such a system gives the users the possibility not only to detect the crop state in the region of interest but also to look for the causes of the state changes, to explain them and to chose the means for improving the crop state.

4.25 In brief, the following requirements may be formulated for the functions of operational systems which use remotely sensed data:

- reliability of work;
- continuous flow of incoming data,
- timely acquisition of data;
- stable timing of data acquisition;
- potential to adapt to a change (system flexibility);
- succession (capability for agreement with the existing systems of acquiring additional information);
- availability and accessibility of the analysis systems and procedures.
- stability of products in time and space

4.26 Additionally, the system development should be performed specifically for obtaining a solution of particular operational problems (for specific users). In this regard, the spatial resolution of pixel data ranges from 1 sq. km. to 49 sq. km. Each specific application will determined the cost-effective requirements.

Finally, consideration must be given to the coordination of data and information obtained through remote sensing techniques and from ground site observations. Both methodologies and complementary and should be integrated into the "system" approach. How these results are made available through the information network for the user-commonly is also of utmost importance.
4.27 The development and level of application of remote sensing data to agrometeorology and agriculture in the two last years could be characterized in the following:

- there are only a few operational systems utilizing remote sensing data for working out real agricultural problems;
- there are some quasi-operational systems with remote sensing data as an additional information source;
- there are a lot of projects to develop methods for application of remote sensing data to agrometeorology and agriculture.

4.28 A special working group should be established to take into account the great perspectives of remote sensing data to agrometeorology and agriculture, utilizing country experience to establishing guidelines for the future.

The group should:

- select algorithms for general procedures of remote sensing data processing;
- define the data formats;
- select all the input data (remote sensing ground truth, etc.), including an international experiment;
- validate and test the selected algorithm on the same technology to be developed;
- establish and support an international base of tested algorithms and support the base;
- compile a guide on application of remote sensing data to agrometeorology and agriculture.

4.29 The continued participation of the CAgM representative in charge of the processing and utilization of satellite data in agrometeorology and agriculture in the work of the CBS Working Group on Satellite is highly useful and expedient. Such participation means that the results of work in this field can be presented to the working group and experience in satellite data reception, processing and application in hydrometeorology and agrometeorology can be put into practice.

Theses include:

- Reviewing the status of satellite data, products and service requirements;
- Assessing the status of the operational use of satellite data;
- Circulating a questionnaire to WMO members on the use of satellite data and products in the various areas of hydrometeorology;
- Developing a project plan for low cost satellite receiving stations for use in countries which at present do not have satellite reception facilities;
- Developing requirements and setting up standard satellite groundstations.

- Preparing a trial project for Specialized Satellite Training Centre and establishing such Centres in various WMO region;

- Developing WMO requirements on archiving and retrieval systems.
References


CHAPTER 5
NEW AGROMETEOROLOGICAL OBSERVATION TECHNIQUES AND DEVELOPMENT OF NEW INSTRUMENTS

5.1 The science of agrometeorology is concerned with the practical application of knowledge in meteorology and agriculture. The term "agriculture," taken in its widest sense, covers crop-growing, forestry and livestock-farming activities. The practice of agrometeorology as an applied science is relatively new science. This relatively young discipline studies interactions between the natural environment (soil and atmosphere), biological growth (of crops, parasites and livestock) and farming techniques. Like all sciences, it is based on observations. Wherever possible, these observations should be quantitative in nature, i.e. expressed in figures.

5.2 Below, we discuss the kind of observations that are involved in agrometeorology and the techniques that are used for making these observations. In particular, we focus on recent developments in resources, instruments and methods for agrometeorology. Since agrometeorology is derived from both meteorology and agriculture, it requires data from these two sources. Meteorological data includes the following:

- Current and extreme values of air temperature and humidity at different levels in the lower atmospheric layer (i.e. from ground level to about ten metras above the top of the predominant vegetation).
- Soil temperatures at depths of 5, 10, 20, 50, and 100 cm. Readings may be needed at greater depths in forest areas, or for special purposes.
- Soil moisture content at different depths.
- Air mixing and turbulence in low atmospheric levels, including wind-speed readings at 0.5 m, 2 m and 10 m above the ground level.
- Hydrometers and other water-balance factors (in particular rain, hail, snow, dew, ground-surface evaporation, plant transpiration, ground-surface run-off).
- Sunlight and solar radiation.

5.2 Agricultural data includes several types. Pedological data, for integration in agrometeorological models, is usually obtained from the authorities that are directly concerned with soil studies. Biological data for agrometeorological purposes includes the following:

- Phenological data, obtained by observing periodic phenomena in plant and animal life (dates marking different growth stages, for example). These data are used for determining bioclimatic relationships, which describe the way the climate affects plant and livestock development.
- Qualitative and quantitative observations on plant and livestock yields.
- Observations on direct climate-related damage to crops and livestock (frost, hail, floods, and drought, etc.)
- Observations on other types of damage to crops and livestock (disease, parasites, etc.). Data on farming techniques concerns the dates and the
methods used for performing various farming-operations (soil preparation methods, sowing dates, sowing density, weeding methods, crop treatments, irrigation, etc.).

5.4 Observation networks must be considered. Meteorological and agricultural data are obtained from the following sources:

- Synoptic stations (often specially selected) performing additional agriculture-related observations.

- Climatological stations.

- Agricultural meteorology stations, specially equipped for carrying out general meteorological and biological observations.

Observations on biological parameters and farming techniques are carried out on specially-marked-out sample plots within existing farms. Sample plots are about a hectare in area and located at a distance of 3 to 5 kilometers from the station responsible for taking meteorological readings.

5.5 When operated by the same organization, all these types of stations go together to make up an observation network. Countries will often have a number of different agrometeorological observation networks run by different authorities, such as the national meteorology service, the agriculture department, the agricultural research department, etc. Usually, the densest network will be that run by the national meteorology service, and this will act as a reference for instruments and observation techniques.

5.6 For all these varying types of stations, observations are carried out manually, which means that human operators use instruments to take readings on the required climatic and biological factors, then record these readings in logbooks or on special forms. The observation schedule will depend on the parameter in question, and may be daily, five-day, weekly or ten-day periods. Readings are transmitted to a central office responsible for processing the collected data and distributing elaborated information. In most West-African countries, phenological observations are ten-daily; phenological record sheets have five columns, as follows:

- crop name
- phenological stage
- weather damage
- parasite or pest damage
- work on field (sowing weeding, treatment, irrigation, etc.)

These data are coded and sent by radio or post to the central office. Here, it is entered into an agricultural database which has the two following purposes:

- Since data in the database have a standardized format, comparative studies can be performed between different locations, different crops and different periods. Data in the database can also be processed to yield information for use in compiling agrometeorological forecasts for farmers (yield forecasts, for
example).

- A comprehensive storage to data from various sources helps increase the efficiency and scope of studies aimed at developing our understanding in agrometeorology.

5.7 Concerning the usual instruments and techniques employed for measuring meteorological factors at ground stations (rainfall, temperature, soil humidity, etc.), no major developments have emerged in recent years. Full information on conventional instruments is given in [8] and [14]. For research purposes, microclimatic readings are required. Conventional meteorological instruments are not really suitable for this type of readings, because of their sensor size and readout systems. However, many suitable types of instruments do exist; a non-exhaustive list can be found in the appendix to [2].

5.8 If atmospheric monitoring is to be effective, it must be performed continuously. Moreover, rapid concentration is often required since certain types of data need to be used in real-time or near-real-time conditions. For this reason, a number of countries have started setting networks of automatic stations. This type of system also solves problems concerning the regular flow of data from manual observation stations, a serious setback in some regions. The big advantage of automatic stations is that relevant data are sent rapidly to each organization responsible for processing data and issuing information to users.

5.9 Another important development for agricultural meteorology concerns the use of remote-sensing techniques, which afford global evaluation of certain biological and climatic factors over large geographical areas. Satellite remote-sensing data complements the agrometeorological data obtained from the surface network and provides a valuable aid to organizations responsible for issuing forecasts and warnings to farmers.

5.10 Both of these new resources, automatic stations and satellites, further the tendency toward tighter integration between the observation, transmission, data processing and information distribution stages. This is true for meteorology in general and agrometeorology in particular.

5.11 Many countries are extending their surface networks to include automatic stations that are capable of taking meteorological readings, pre-processing these basic data, and transmitting then to the central office. Many types of automatic weather stations are available on the market. These are usually reliable and offer a number of advantages over manual stations: hourly or three-hourly readings, automatic data processing, and, ability to take readings at remote sites. Present-day automatic stations are fully discussed in [1], [7], [8], and [14].

5.12 Remote sensing for acquisition of agrometeorological data must considered some basic principles. The sun's rays are reflected in varying degrees by the atmosphere, clouds and the surface of the earth. Thus, each of these surfaces will radiate energy in varying amounts, depending on its temperature. Each surface will absorb solar radiation at certain wavelengths in the electromagnetic spectrum while behaving transparently to radiation at other wavelengths.

5.13 Satellite-source instruments measure the energy radiated at different wavelengths (visible region, infrared region) by the earth's surface, the cloud cover and the earth's atmosphere. After processing, these data yield valuable information on the behavior of each of these entities.
5.14 For agrometeorological purposes, we use data from the following types of remote-sensing satellites:

- Geostationary weather satellites. This type of satellite permanently monitors the weather over given coverage areas, supplying images in the visible and infrared regions. Images are taken at a frequency that ranges from every 30 minutes to every two hours. They have a spatial resolution of 1 to 2.5 km for visible-region images and 5 to 8 km for infrared-region images.

- Earth-orbiting weather satellites: This type of satellite performs vertical-profile sounding (depth-profiles for temperature and humidity, for example) and supplies visible and infrared images having spatial resolution of around 1 km.

5.15 Both geostationary and earth-orbiting weather satellites also provide communications functions (distribution of data to users, collection and relay of data from platforms).

- Earth observation satellites. Earth observation satellites are orbiting satellites without specific weather monitoring functions. They provide very-high-resolution images (20 to 30 m) in the visible and near-infrared regions, allowing us to accurately determine the surface areas taken up by different types of plant growth. While these images have a very high spectral and spatial resolution, their frequency is very low (about every 18 days for SPOT), which makes it difficult to monitor plant growth dynamics in detail. High-frequency monitoring is provided by wide-field sensors such as the NOAA/AVHRR, which gives daily world-wide coverage, but at a relatively low spatial resolution (for crop monitoring purposes at least). At short wavelengths (visible and near-infrared regions), vegetation and bare soil have different spectral responses; this allows us to exploit earth-observation images in order to establish simple indices (such as the normalized vegetation index, NDVI) to express photosynthetic activity in vegetation cover.

5.16 Thus, by combining the very-high-resolution data from earth observation satellites with the high-frequency data from weather satellites (notably NOAA-AVHRR and METEOSAT), we have a reliable means for agrometeorological crop monitoring. Satellites currently provide data on many agrometeorological parameters:

- global solar radiation and radiation balance
- rainfall
- minimum and maximum air temperatures
- surface temperature
- evapotranspiration and soil moisture content

All these parameters are inputs for agrometeorological models, developed for forecasting purposes. Details on the estimation of agrometeorological parameters from satellite instrument readings are given in [3], [6], [9], [10], [11], and [18].

5.17 Satellite instruments are characterized by a number of factors, the most important of which are as follows:
- spectral bands within which measurements are taken
- width of sensor observation field
- spatial resolution

Full lists and technical details on the instruments flown on board present-day satellites can be found in [6], [15], and [16].

5.18 In conclusion, agrometeorology requires data from meteorological and agricultural phenomena. These data are obtained by observations carried out using standardized procedures at synoptic, climatological and agrometeorological stations. Over the last few years, no major developments have emerged concerning the types of instruments used at these stations. However, many countries are now beginning to implement automatic stations, which offer many advantages over conventional manually-operated stations. In addition, satellites are providing valuable new remotely-sensed forms of agrometeorological data. Through these new developments, data transmission and processing operators have been greatly accelerated and it is now possible to perform continuous global monitoring of crop growth and atmospheric conditions.
References


12. Instructions a l'usage des observateurs agrometeorologistes - Programme Agrhymet dans les pays CILSS.


CHAPTER 6

CODING OF AGRICULTURAL METEOROLOGICAL INFORMATION - METAG

6.1 When properly used, meteorological information can help to increase agricultural production, improve the marketing and quality of produce, reduce crop losses and damage, improve planning, and facilitate decisionmaking. In order for agriculture to be able to benefit from the best possible application of meteorology, it is indispensable for meteorologists and agronomists to collaborate very closely.

6.2 The METAG code form highlights the main parameters for agriculture: precipitation and temperature. It enables the density of rainfall reports to be increased by introducing secondary and auxiliary stations, while the amount and type of precipitation can be indicated more precisely, to permit correct evaluation. It also enables evaporation and insolation data to be reported for use in developing and running models for estimating food production, soil moisture balance, and the occurrence of pests and diseases, as well as for solving other problems.

6.3 Two optional groups, which may be repeated, concern the relationships between weather conditions and agriculture: they constitute a key element of the code form and will, hopefully, be widely used. It is recommended that these groups should not be used without prior consultation with the local agricultural authorities. The first of these groups (C, B, P, G) is used for reporting the various crops, biological phases and state of crops. The second group (A, C, E, W, d) is used to report loss and damage (extent and severity) caused by the weather conditions to crops and livestock.

6.4 The indicators (222) in Section 2 and (333) in Section 3 are used to identify (for telecommunication and data-processing purposes) the optional groups which may be repeated, and they refer to the relationships between weather conditions and agriculture. For example, (222) is only to be used when (C, B, P, G) is transmitted, and only once, preceding the first group (C, B, P, G); and (333) is only to be used when (A, C, E, W, d) is reported and only once before the first group (A, C, E, W, d).

6.5 The organization of national inputs is a task for the national meteorological services and agricultural authorities, these being the only bodies that are fully aware of the available national resources and the particular requirements to which priority should be given. In order to help these bodies determine the input, a set of guidelines for the Members is given below:

(a) Identify the meteorological stations where agricultural meteorological observations are made regularly and reliably;

(b) Determine, with the help of agronomic specialists, the major areas of agricultural production;

(c) Select the stations which will, together, give an adequate description of the country's predominant weather conditions of importance to agriculture (precipitation being the most important parameter);

(d) As regards telecommunications, it could be useful to study the possibility of using synoptic stations as regional centers for collection precipitation data from climatological, agrometeorological and rainfall stations in various parts of the country (see the group (S, R, R, R, n) in the METAG code form). When this method is used for supplementary rainfall data collection, the figures (0 to 9)
should be assigned to the secondary stations associated with each synoptic station;

(e) Before taking a final decision about the national input, there must be consultation between meteorologists and agricultural specialists about station selection, contribution of the agricultural means to ten-day regional reports, and the subsequent dispatch of ten-day summaries to agricultural users;

(f) It would be very beneficial if ten-day meetings were held between representatives of the national meteorological service and the Ministry of Agriculture to examine the agrometeorological summaries.
METAG CODE FORM

FM METAG — Report of agricultural meteorological observation from an agricultural meteorological station and secondary rainfall stations or from a meteorological station, an agricultural station and rainfall stations

CODE FORM:

SECTION 0  \[ M,M,M_i M_j \quad Y, M M Y, Y \, \text{III} \]


SECTION 2  \[ C, C, B, P G_i \]

SECTION 3  \[ 333 \quad A, C, C, E, W_i \]

SECTION 4  \[ 444 \quad \text{Groups to be developed regionally} \]

SECTION 5  \[ 555 \quad \text{Groups to be developed nationally} \]

NOTES:

(1) METAG is the name of the code for reporting agrometeorological observations from an agrometeorological station and secondary rainfall stations or from a meteorological station, an agricultural station and secondary rainfall stations.

(2) A METAG report is identified by the symbolic letters \[ M, M_i M_j = --XX \].

(3) The code form is made up of figure groups arranged by sections in ascending order of their numerical indicators, as follows:

<table>
<thead>
<tr>
<th>Section number</th>
<th>Symbolic figure group</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-</td>
<td>Data for reporting identification (type, date, time, location)</td>
</tr>
<tr>
<td>1</td>
<td>-</td>
<td>Meteorological data for global exchange</td>
</tr>
</tbody>
</table>
Agronomic data concerning various crops, biological phases and the state of crops

Data on loss and damage (extent and severity) caused weather conditions to crops and livestock

Data for regional exchange

Data for national exchange

REGULATIONS:

--.1

General

--.1.1

The code name METAG shall not be included in the report.

--.1.2

In a bulletin of METAG reports, the groups M,M,M,M, and Y,M,M,Y,Y shall be included only as the first line of the text, provided all the reports of the bulletin were taken at the same time, in the same Region and in the same country.

--.1.3

In each report, whether separate or included in a bulletin, the location of the meteorological station shall be always indicated by means of the group IIIii, which shall be included at the beginning of the second line, preceding Section 1.

--.1.4

When no data are reported in a given section, the section indicator shall be omitted.

--.2

Section 0

--.2.1

Group M,M,M,M,
--2.1.1

\[ MM, M, M_j = \text{--XX is the identifier of a METAG report} \]

--2.2

Group \( Y_4, M, Y, Y_4 \)

--2.2.1

\[ Y_4 = \text{Ten-day period to which the report refers (1 = first ten-day period (1-10); 2 = second ten-day period (11-20); 3 = third ten-day period (21 to the end of the month))} \]

--2.2.2

\[ MM = \text{Month of the year (01 = January, 02 = February, ..., 12 = December)} \]

--2.2.3

\[ Y_4, Y_4 = \text{Tens and units of the year (93 = 1993; 94 = 1994; 00 = 2000; 05 = 2005)} \]

--2.3

Group \( \text{Ilili} \)

--2.3.1

\[ \text{Ilili = International station indicator (II = regional indicator; iii = station index number)} \]

--2.3.2

The regional indicator defines the area in which the reporting station is located. It is assigned to a country, part of a country, or to two or more countries in the same Region (see Volume A of publication WMO-No. 9).

--2.3.3

The station index numbers are three-digit numbers allocated by each Meteorological Service to reporting stations from the series of three-digit numbers forming its respective block number (see publication WMO-No. 9).

--2.3.4

The combination of regional indicator and station index number shall constitute the international
station indicator IIIii.

---.3

Section 1

---.3.1

Group RR,RR,RR,rr

---.3.1.1

RR,rr = Amount of precipitation which has fallen during the ten-day period, expressed in whole millimetres

---.3.1.2

rr = Maximum 24-hour amount of precipitation during the ten-day period (see Code table 01)

---.3.1.3

rr = Number of days during the ten-day period with precipitation equal to or more than 1 mm (9 = 9 or more days)

---.3.2

Group RR,RR,RR,rr,Wr

---.3.2.1

RR,rr,rr,rr,rr = Amount of precipitation which has fallen since the beginning of the season, in whole millimetres

---.3.2.2

Wr = Weather conditions which have caused damage (see Code table 02)

NOTE: If more than one weather event has occurred, the most important one shall be selected, or described briefly in plain language, and the next most important one shall be added at the end of the report.

---.3.3

Group T,T,T,T,T,T

---.3.3.1

T,T,T,T,T,T = Mean maximum temperature during the ten-day period, in tenths of a degree Celsius
(to indicate negative temperatures, add 500)

--- 3.3.2

$T_{\text{m}}T_{\text{m}} = \text{Highest temperature of the ten-day period, rounded off to the nearest degree Celsius (to indicate negative temperatures, add 50)}$

--- 3.4

Group $T_{\text{m}}T_{\text{m}}T_{\text{m}}T_{\text{m}}$

--- 3.4.1

$T,T,T_{\text{m}} = \text{Mean minimum temperature during the ten-day period, in tenths of a degree Celsius (to indicate negative temperatures, add 500)}$

--- 3.4.2

$T_{\text{m}}T_{\text{m}} = \text{Lowest temperature of the ten-day period, rounded off to the nearest degree Celsius (to indicate negative temperatures, add 50)}$

--- 3.5

Group $E,E,E,E,S,S$

--- 3.5.1

$E,E,E = \text{Amount of evaporation during the ten-day period, in millimetres}$

--- 3.5.2

$S,S = \text{Percentage of insolation during the ten-day period}$

--- 3.6

Group $H,H,M,S$

--- 3.6.1

$H,H = \text{Average soil moisture at 20 centimetres for the ten-day period, expressed as a percentage. If this measurement is not made, } H,H, \text{ shall be encoded as } //.$

--- 3.6.2

$M = \text{Method used for making the measurement at 20 centimetres, according to Code table 03}$
3.6.3

$S_n = \text{Surface moisture according to Code table 04}$

3.7

Group $(S,R,R,R,n_n)$

3.7.1

$S_n = \text{Number of secondary stations (n = 0, 1, 2, 3, ..., 9)}$

3.7.2

$R_{RRR} = \text{Amount of precipitation which has fallen during the ten-day period, in whole millimetres}$

3.7.3

$n_n = \text{Number of days during the ten-day period with precipitation equal to, or more than 1 mm (9 = 9 days or more)}$

\text{NOTE: This group is optional. Up to 10 groups may be included (one for each secondary station).}

3.4

Section 2

3.4.1

Group $C_6C_BPG$

3.4.1.1

$C_6C_B = \text{Crop observed (see Code table 05)}$

\text{NOTE: Countries which produce other crops and/or livestock not covered in the code table may request CAgM to include them under unused code figures.}

3.4.1.2

$B_i = \text{Biological phase (the most significant phase shall be selected from Code table 06)}$

3.4.1.3

$P = \text{Percentage of the crop observed to have reached the phase given as B, (according to Code table 07)}$
-4.1.4

\( G_i \) = State of the crop (see Code table 08)

**NOTE:** This group shall be repeated in this section as many times as is necessary to describe the phase and state of the main crops.

-5

**Section 3**

-5.1

Group \( A_cC_cE_cW_c \)

-5.1.1

\( A_c \) = Agricultural loss or damage (see Code table 09)

-5.1.2

\( C_c \) = Crop and animals affected (see Code table 05)

-5.1.3

\( E_c \) = Extent and severity of loss and damage (see Code table 10)

-5.1.4

\( W_c \) = Weather conditions which have caused agricultural loss or damage (see Code table 11)

**NOTE:** This group shall be repeated in this section as many times as is necessary to describe the loss or damage caused to the main crops.

-6

**Section 4 — Regional groups**

Inclusion of groups of Section 4 shall be determined by regional decision.

-7

**Section 5 — National groups**

Inclusion of groups of Section 5 shall be determined by national decision.
### CODE TABLES

#### 01

<table>
<thead>
<tr>
<th>Code figure</th>
<th>Precipitation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>&lt;10 mm</td>
</tr>
<tr>
<td>1</td>
<td>10-19 mm</td>
</tr>
<tr>
<td>2</td>
<td>20-29 mm</td>
</tr>
<tr>
<td>3</td>
<td>30-39 mm</td>
</tr>
<tr>
<td>4</td>
<td>40-49 mm</td>
</tr>
<tr>
<td>5</td>
<td>50-99 mm</td>
</tr>
<tr>
<td>6</td>
<td>100-149 mm</td>
</tr>
<tr>
<td>7</td>
<td>150-199 mm</td>
</tr>
<tr>
<td>8</td>
<td>200-249 mm</td>
</tr>
<tr>
<td>9</td>
<td>&gt;249 mm</td>
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#### 02

<table>
<thead>
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<th>Code figure</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>None</td>
</tr>
<tr>
<td>1</td>
<td>Strong wind, storm, hurricane (Beaufort scale 7)</td>
</tr>
<tr>
<td>2</td>
<td>Heavy snowfall or freezing precipitation</td>
</tr>
<tr>
<td>3</td>
<td>Heavy rainfall</td>
</tr>
<tr>
<td>4</td>
<td>Moderate or severe hail</td>
</tr>
<tr>
<td>5</td>
<td>Frost (air temperature &lt;0.0°C)</td>
</tr>
<tr>
<td>6</td>
<td>High temperature (air temperature &gt;35.0°C)</td>
</tr>
<tr>
<td>7</td>
<td>Dry period (precipitation &lt;0.1 mm)</td>
</tr>
<tr>
<td>8</td>
<td>Fire observed (grass, cereals, scrub, forest)</td>
</tr>
<tr>
<td>9</td>
<td>Drying wind (zonda, siroco, harmatan, sandstorm)</td>
</tr>
</tbody>
</table>

#### 03

<table>
<thead>
<tr>
<th>Code figure</th>
<th>Method used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Electrical resistance</td>
</tr>
<tr>
<td>2</td>
<td>Neutron-scattering</td>
</tr>
<tr>
<td>3</td>
<td>Tensiometer</td>
</tr>
<tr>
<td>4</td>
<td>Gravimetric</td>
</tr>
</tbody>
</table>

78
<table>
<thead>
<tr>
<th>Code</th>
<th>State of the soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Excessive soil moisture</td>
</tr>
<tr>
<td>2</td>
<td>Very moist soil</td>
</tr>
<tr>
<td>3</td>
<td>Moist soil</td>
</tr>
<tr>
<td>4</td>
<td>Slightly moist soil</td>
</tr>
<tr>
<td>5</td>
<td>Dry soil</td>
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<table>
<thead>
<tr>
<th>Code</th>
<th>Crop</th>
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<tbody>
<tr>
<td>00</td>
<td>Cereals, in general</td>
</tr>
<tr>
<td>01</td>
<td>Barley</td>
</tr>
<tr>
<td>02</td>
<td>Maize</td>
</tr>
<tr>
<td>03</td>
<td>Millet</td>
</tr>
<tr>
<td>04</td>
<td>Oats</td>
</tr>
<tr>
<td>05</td>
<td>Rice</td>
</tr>
<tr>
<td>06</td>
<td>Wheat</td>
</tr>
<tr>
<td>07</td>
<td>Sorghum</td>
</tr>
<tr>
<td>08</td>
<td>Rye</td>
</tr>
<tr>
<td>09</td>
<td>Oil-producing plants, in general</td>
</tr>
<tr>
<td>10</td>
<td>Castor-oil plant</td>
</tr>
<tr>
<td>11</td>
<td>Palm, oil palm</td>
</tr>
<tr>
<td>12</td>
<td>Rape</td>
</tr>
<tr>
<td>13</td>
<td>Sesame</td>
</tr>
<tr>
<td>14</td>
<td>Soy</td>
</tr>
<tr>
<td>15</td>
<td>Sunflower</td>
</tr>
<tr>
<td>16</td>
<td>Groundnut</td>
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<td></td>
</tr>
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<td></td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>20</td>
<td>Fruit, in general</td>
</tr>
<tr>
<td>21</td>
<td>Avocado pear</td>
</tr>
<tr>
<td>22</td>
<td>Banana</td>
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<tr>
<td>23</td>
<td>Berries</td>
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<tr>
<td>24</td>
<td>Citric fruit</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>Crop</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>Fresh vegetables, in general</td>
</tr>
<tr>
<td>51</td>
<td>Green pea and bean</td>
</tr>
<tr>
<td>52</td>
<td>Various varieties of cabbage</td>
</tr>
<tr>
<td>53</td>
<td>Gourd family</td>
</tr>
<tr>
<td>54</td>
<td>Leaf vegetables (lettuce, etc.)</td>
</tr>
<tr>
<td>55</td>
<td>Root vegetables (carrot, radish, beetroot)</td>
</tr>
<tr>
<td>56</td>
<td>Manioc</td>
</tr>
<tr>
<td>57</td>
<td>Onion</td>
</tr>
<tr>
<td>58</td>
<td>Potato</td>
</tr>
<tr>
<td>59</td>
<td>Sweet potato</td>
</tr>
<tr>
<td>60</td>
<td>Tomato</td>
</tr>
<tr>
<td>61</td>
<td>Pimento</td>
</tr>
<tr>
<td>62</td>
<td>Aubergine</td>
</tr>
<tr>
<td>63</td>
<td></td>
</tr>
<tr>
<td>64</td>
<td></td>
</tr>
<tr>
<td>65</td>
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<tr>
<td>66</td>
<td></td>
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<tr>
<td>67</td>
<td></td>
</tr>
<tr>
<td>68</td>
<td></td>
</tr>
<tr>
<td>69</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>Various, in general</td>
</tr>
<tr>
<td>71</td>
<td>Dry kidney bean</td>
</tr>
<tr>
<td>72</td>
<td>Lentil</td>
</tr>
<tr>
<td>73</td>
<td>Cocoa</td>
</tr>
<tr>
<td>74</td>
<td>Coffee</td>
</tr>
</tbody>
</table>
25 Date
26 Fig
27 Grape, raisin
28 Guava
29 Mango
30 Papaya
31 Pineapple
32 Apple and pear
33 Stone fruit
34 Coconut
35 Dry fruit, in general
36 Almond
37 Cashew nut
38 Hazelnut
39 Pecan
40 Pistachio nut
41 Walnut
42 Forage crops, in general
43 Improved fodder
44 Ordinary fodder
45 Pasture (semi-arid land)
46 Livestock and farmyard poultry, in general
47 Beef cattle
48 Dairy cattle
49 Pigs
50 Sheep
51 Goats
52 Farmyard poultry
53 Rest
54 Preparation of the soil
55 Sowing, transplanting
56 Growth, leaf formation
57 Cluster formation (formation of shoots)
58 Joint formation, development
59 Ear formation, flowering
60 Beginning of ripening
61 Maturity
62 Harvesting
P —

Code figure Percentage of the crop which has reached biological phase "B."
0 0-9
1 10-19
2 20-29
3 30-39
4 40-49
5 50-59
6 60-69
7 70-79
8 80-89
9 90-100

G, —

<table>
<thead>
<tr>
<th></th>
<th>Early</th>
<th>Normal</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Average</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Poor</td>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

A, —

Code figure Agricultural loss or damage
0 Stress for the crop and animals
1 Deterioration of the crop
2 Limitation of pollination, fertilization, germination, etc.
3 Flattening (stem crops)
4 Damage to products (in the field, in transit or during storage)
5 Fall or removal from stems (fruit, nuts, capsules, leaves, seeds, etc.)
6 Reduction in yield (milk, eggs, crop)
7 Damage to plants and trees (buds, flowers, leaves, etc.)
8 Damage caused by pests or disease
9 Death (extreme cold, rigorous conditions, suffocation, drowning, fire,
dessication, hail, heavy rain)

G. —

<table>
<thead>
<tr>
<th>Extent</th>
<th>Local</th>
<th>General</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slight</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Moderate</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Severe</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

W. —

<table>
<thead>
<tr>
<th>Code figure</th>
<th>Weather conditions which have caused agricultural loss or damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Rain (or excessive humidity)</td>
</tr>
<tr>
<td>1</td>
<td>Wind</td>
</tr>
<tr>
<td>2</td>
<td>Snow, ice</td>
</tr>
<tr>
<td>3</td>
<td>Flooding</td>
</tr>
<tr>
<td>4</td>
<td>Hail</td>
</tr>
<tr>
<td>5</td>
<td>Low temperatures</td>
</tr>
<tr>
<td>6</td>
<td>High temperatures</td>
</tr>
<tr>
<td>7</td>
<td>Drought</td>
</tr>
<tr>
<td>8</td>
<td>Fire</td>
</tr>
<tr>
<td>9</td>
<td>Drying wind or dry weather (low humidity)</td>
</tr>
</tbody>
</table>
CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Major strides in agrometeorological data management are being achieved as new technology becomes available for instrumentation, data processing, analytical procedures, and information packaging.

7.2 Computer technology has advanced rapidly, replacing cumbersome and expensive mainframe computer hardware with desktop microcomputers. A wide variety of software packages is available and the capability to adapt or develop unique software features for specific applications is more functional than ever. The rapid expansion of computer networks makes information, designed for decision support, more readily accessible throughout the world.

7.3 The progress in computer technology enhances the need for high quality data, standard procedures or guidelines to exchange data and information, and full documentation or inventory of data bases (meta data bases).

7.4 While automated weather stations and artificial intelligence offer great potential to agricultural applications, the importance of maintenance of instrumentation with periodic inspection and human oversight in data quality control cannot be overstated.

7.5 The ultimate goal of decision support applications is not to have the most complex management tools or systems available, but rather to provide the most practical systems for both strategic and tactical planning, utilizing interdisciplinary actions to formulate farm management alternatives.

7.6 Remotely-sensed data should form an integral part of an information system. User requirements and needs are the prime criteria for the data products. Training and cost are recognized as principal factors hindering the use of remotely sensed data. There still are significant limitations to be overcome in the utilization of satellite-derived information in agricultural applications, but future prospects are bright.

7.7 The list of variables relevant to agriculture go beyond instrumentation measuring air temperature and precipitation to further include horizontal wind velocity, leaf wetness duration and soil moisture measurements. Crop canopy temperatures as well as crop characteristics can be measured with remote sensing devices on satellites, aircraft and hand held equipment. These observations are extremely useful in agrometric studies. It is noted, however, that severe storms as well as instrument malfunction disrupt data observations, necessitating routine scrutiny to reduce "suspect" data.

7.8 There should be a standard format for coding not only meteorological data, but also agronomic and phenological observations. The code should make provisions for pest and disease observations. Moreover, crops should be noted by their Latin names. A valid concern to be addressed is how to deal with "false starts" to the growing season where replanting may occur more than one time.

7.9 Based on the conclusions of the working group reports, the following recommendations are made:

- There is a need to re-establish this Working Group to focus specific attention on the utilization of computer management systems for data analysis and information
formulation. The increased functionality of interactive computer networks at regional levels supports the need for this effort. National weather services are modernizing instrumentation, data processing techniques and product dissemination by electronic means. It is recommended that the Working Group focuses on advantages and limitations of this new technology, and provides guidance on the implementation of knowledge-based computer management systems emphasizing an integrated approach oriented to the requirements of decision-makers. There is a need for a study on the application of remotely sensed data to agriculture to review and test algorithms in support of an international remotely sensed database, to define standard data formats, and to compile a guide on the application of remote sensing data to agrometeorology and agriculture. Appropriate terms of reference should be included in one of the working groups of CAgM-XI.

- The Working Group recommends active WMO-CAgM participation with the FAO’s Expert Consultation Steering Committees to coordinate meta databases, to establish standard data exchange formats, and to implement agrometeorological procedures for both database and software applications.

- The Working Group also recommends the appointment of a rapporteur on the inventory of data base management systems for agricultural applications, which would be provided to all member countries of the WMO.

- There was significant discussion during the Working Group meeting on the development of a suitable code for agricultural and phenological characteristics. An international code is necessary. The Working Group thought special emphasis be devoted to the development of a suitable code which is adaptable for all crops grown in highly diversified agroclimatic situations around the world.

- The proposed coding of agricultural meteorological information (METAG) could be referred to the CBS Working Group on Data Management for consideration after approval by the Commission for Agricultural Meteorology. It is recommended that the codes be considered under CREX and/or BUFR codes proposed by the CBS Working Group on Data Management. Consideration of several factors must be noted to avoid confusion. These include the alphanumeric code form of $T_n, T_m,$ and $T_{n}, T_{m}$; the definition of the beginning of the season (i.e., rainy season or cropping season); the precise definition of the percentage of insolation; and, the need for location identifiers of secondary precipitation reporting stations.