Agrometeorology in the 21st century: workshop summary and recommendations on needs and perspectives

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Abstract

A summary is given about the needs and perspectives for agrometeorology in the 21st century as expressed in the papers of the Workshop (published in this volume) and subsequently expanded by invited discussants of, and in general discussions on, these papers during the Workshop. These needs and perspectives have been categorized under the headings ‘Agrometeorological services for agricultural production’ and ‘Agrometeorological support systems to such services’. Four support systems were distinguished: ‘Data’, ‘Research’, ‘Policies’ and ‘Training/Education/Extension’. Issues in agricultural production were differentiated following the classic themes: (1) Land use, as a strategical issue; (2) Choices of farming and cropping systems details and (3) Decisions on day to day operations, both as tactical issues. Needs that were expressed and not challenged were taken as recommendations for action, while perspectives were determined as prospects for the development of means to act on these needs, with indications on how this could be done. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

In the opening paper of the Workshop, Professor Monteith quoted Dr. Austin Bourke who said, in the 1960s, “The agrometeorologist can be helpful only in so far as he inspires the farmer to organize and activate his own resources in order to benefit from technical advice”. This phrase set the scene, because it is relevant at each input level of farming and concerns the essence of the theme: ‘agrometeorological services for agricultural production’. Climate change and increasing climate variability, together with other rapidly changing environmental and socio-economic conditions, make this assistance even more necessary and potentially beneficial.

A special volume on needs and perspectives of agrometeorology in the early part of the 21st century, must conclude with the priorities that were identified during the search for these needs and perspectives, and with the suggestions to address these. This applies to the papers presented as well as to the reactions of the invited discussants and to the general discussion among all participants. This chapter on ‘Workshop Summary and Recommendations’ aims to highlight these priorities and render them easily accessible.

Because the dynamics of priorities are specific in time and location, a suitable ‘level of aggregation’ had to be selected for a key to the formulation of these
needs and perspectives. While ‘Agrometeorological services for agricultural production’ appeared to be the most logical heading for priority-choices of needs and the related perspectives, the term ‘Agrometeorological support systems to such services’ was selected for the other parts of the key. Four such support systems have been distinguished: ‘Data’, ‘Research’, ‘Policies’ and ‘Training/Education/Extension’. The participants in the Workshop concluded that the most important basic needs and perspectives for agrometeorology at the start of the 21st century could be represented in this framework. It was understood that not only scientific or operational limitations, but also political, economic, socio-cultural and financial factors codetermine priorities and influence the related perspectives.

2. Further methodological issues of the approach

To increase the accessibility of the papers in this volume, the needs and perspectives mentioned in the papers, and those brought up by other participants in the Workshop, the material in the papers and the handwritten contributions by the invited and other discussants was extracted and included under the key headings mentioned earlier. In this way the summary communicates the kinds of services and support systems that were most frequently brought up as needed, and for the provision of which prospective avenues were sought. Needs formulated only once during the workshop, but not contested, were not necessarily considered unimportant, given that certain subjects could be discussed in the papers in more detail than others, and they are therefore included in this summary chapter.

For ease of access, the needs for which perspectives were sought are marked with (1) if they can be seen as being part of the strategical issues of land use; (2) if they have to do with the tactical issues of choices of farming and cropping systems details; and (3) if they touch on the tactical issues of decisions on day to day operations. Needs that are relevant to all three different types of issues are marked with (1, 2, 3).

Most of the needs mentioned below as priorities were explicitly mentioned in the papers, be it not in the same wording, while others were only implied; both are covered in this summary. If support is needed by agrometeorologists to defend proposals for funding or otherwise, their proposal can refer to this chapter to indicate the priority given to the subject during the Accra meeting.

Finally, a reference system, set out in Table 1, is used to refer to the papers presented during the workshop in which the respective needs and perspectives were discussed. The material contributed by discussants and comments in further discussions are not necessarily reported on with reference to the papers during which they were brought up, but they appear as needs and perspectives under the key headings concerned.

3. Agrometeorological services for agricultural production

3.1. The types of services needed that were most often cited

The need for priority attention to agrometeorological services for agricultural production was explicitly mentioned by J & AKC, L, M & M, R & B, ZD et al. and S, G & B. S, S & D indicated that existing strategies to fight consequences of relatively slow variations in weather and climate require more widespread application, rather than more development, while preparedness for changes in extreme weather has to a large extent still to be developed. L, M & M and R & B indicate that services must be economically beneficial to the customers and R & B also give examples of such economic benefits. L, M & M and R & B state that cooperation should be fostered between providers and receivers of agrometeorological services and they list basic services required for agriculture.

Five major types of services were mentioned in at least five papers as priority needs, for which perspectives have to be further developed as a matter of urgency. The issues brought up are separately listed.

3.1.1. Services to help reduce the impact of natural disasters, including pests and diseases (1, 2, 3)

- The necessity for preparedness was emphasized (O, B & K);
- S, S & D mention the point in two of their 10 most essential agricultural umbrella projects with agrometeorological priority components: directly for all disasters and indirectly in reductions of contributions of agro-ecosystems to global warming;
Table 1

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Authors of the paper</th>
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<tbody>
<tr>
<td>(Monteith)</td>
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<td>(S, G &amp; B)</td>
<td>Sivakumar, Gommes &amp; Baier</td>
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<td>(R &amp; B)</td>
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<td>(J &amp; AKC)</td>
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<td>(H &amp; H)</td>
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<td>(O, B &amp; K)</td>
<td>Ogallo, Boulahya &amp; Keane</td>
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<td>(S, S &amp; D)</td>
<td>Salinger, Stigter &amp; Das</td>
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<tr>
<td>(D et al.)</td>
<td>Doraiswamy, Pasteris, Jones, Motha &amp; Nejedlik</td>
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<td>(M, P &amp; K)</td>
<td>Maracchi, Perarnaud &amp; Kleschenko</td>
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<td>(W, vC &amp; B)</td>
<td>Weiss, van Crowder &amp; Bernardi</td>
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<td>(L, M &amp; M)</td>
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<td>(V)</td>
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<td>(B)</td>
<td>Burgos</td>
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<td>(ZD et al.)</td>
<td>Zheng Dawei and co-authors: Wu Lianghai; Mei Xurong; Lin Erda; Mrs. Li Yu’e; Mrs. Feng Yuxiang; Yu Qiang and Li Bingbo</td>
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a (ZD et al.), on ‘Agrometeorology in the 21st century: the needs and prospects in China’, (V), on ‘Sustaining crop yields in the semi-arid tropics: agrometeorological needs’, and (B), on ‘Africa: challenges and future perspectives’, can be found in CAgM Report 77 of the Commission for Agricultural Meteorology entitled: contributions from members on operational applications in agrometeorology in the International Workshop: ‘Agrometeorology in the 21st Century, Needs and Perspectives’. The highlights of other contributions to CAgM77 were already in the papers of the Workshop.

- Ranges of examples were given (J & AKC; R & B; ZD et al.; Strand), with those of Strand in particular for pest and disease management.

3.1.2. Early warning and monitoring systems (1, 2)

- A ‘Famine Early Warning System’ with local forecasts and crop models (H & H);
- Inclusion of bad as well as favorable weather (J & AKC);
- Needs for fisheries and a ‘Fishery Early Warning System’ comparable to a ‘Famine Early Warning System’ (K);
- Distribution as warnings, of impending extreme climate events at a time scale of a month to years (O, B & K);
- Warnings, as required by different types of clients (R & B list examples), followed by advice on the use of the information, e.g. for food security programs;
- S, G & B mention these services as a priority in general and indicate that establishment and/or strengthening of these early warning and monitoring systems have been requested under the programs of Agenda 21, UNCCD and WFSPA, which shows the potential support for their implementation;
- Strand deals with such services as risk assessments of long-term weather patterns.

3.1.3. Short-range (3) and medium-range (2) weather forecasting for agriculture

Although this subject may seem so obvious that many participants may not have mentioned it, the service issues raised are very diverse:

- Yield predictions will be more accurate when based on models developed with observed rather than estimated data, especially for tropical regions. Weather forecasts for the remainder of the season are very important, but the format in which they become available needs much adaptation (H & H);
- Special weather forecasts for agriculture are among the main requirements of farmers but the problem of their relative lack of reliability, and consequently the lack of trust in forecasts, exists in many countries of the region covered by J & AKC. As an example of the use of these forecasts, the authors
state that some agricultural agencies in Malaysia are nevertheless using short- and medium-range forecasts for planning daily, weekly and even monthly operational field activities and that they also use long-range forecasts;

- O, B & K report an often inadequate capability by farmers to use the weather forecasts in agricultural production;
- R & B distinguish between pure weather forecasts and forecasts of the agricultural consequences of observed (past and present) and likely future weather. They give examples of the use of weather forecasts in an Appendix on agrometeorological products, their uses and clients in Malaysia;
- Strand reports on the value of the combination of weather forecasts and remote sensing information in crop protection practices.

3.1.4. Climate prediction/forecasting for agriculture (1, 2)

Even though there were more suggestions on this subject under supportive ‘research’ and ‘capacity building’ than under ‘services’, the following needs for services were noted:

- The use of crop models with, as input data, scenarios of climate change and of climate variability (ENSO scenarios), to estimate their consequences for agricultural production. Similarly the outputs of General Circulation Models (GCMs) can be used as inputs in such models (H & H; S, S & D);
- ENSO predictions, combining GCMs with an ocean model, as an extension of long-term weather forecasting, for operational activities (J & AKC);
- Predictions with a 1 km resolution for inland fisheries purposes (K);
- O, B & K have collected a range of examples of the actual use of ENSO forecasting in agricultural advisories. They warn against too high expectations regarding present climate prediction skills but feel that contributions towards the food security for farmers are possible. Therefore, they support a proposal that one consolidated climate forecast be put in place in each NMHS;
- S, G & B indicate that both Agenda 21 and the World Food Summit Plan of Action (WFSPA) emphasize the need for the application of climate forecast information for increased and sustainable agricultural production; they propose, as a priority for agrometeorologists, the development of climate indicators from the UNCED documents;
- Strand connects selection of varieties with the assessment of the risk that changes in climate and its variability change the environmental limits that govern development of crop pests and diseases.

3.1.5. Services to help reduce the contributions of agricultural production to global warming (1, 2)

- Knowledge about the differences in CO2 uptake when forest areas are replaced by different forms of agriculture, is important in the dialogue with environmentalists (J & AKC);
- S, G & B propose for developing countries measures that combine reduction of CO2 emissions from the agricultural sector with clear benefits for themselves: improved efficiency of fertilizer use, improved ruminant digestion, growing biomass more efficiently, etc. They mention elsewhere in their paper that in addition to crop and forestry statistics, other statistics are relevant to the UNFCCC, such as those of rice paddies and ruminant cattle (as major sources of methane) and those of fertilizer use (as a source of nitrous oxide);
- S, S & D opine that for the time being only industrialized countries can be asked to subscribe unconditionally to the demands of reducing their contributions from agricultural production to global warming;
- Development of practices to reduce Greenhouse Gas (GHG) emissions such as CH4 and N2O, by promoting agroforestry, altering management of agricultural soils and rangelands, recovering CH4 from stored manure, and improving the diet quality of ruminants are mentioned by ZD et al.

3.2. Other agrometeorological services needed for agricultural production

Further agrometeorological services for agricultural production were frequently mentioned and sometimes perspectives to meet them were given:

- Developments in response farming, including more knowledge of specific effects of various weather/climate factors on crop growth and performance (1, 2, 3) (J & AKC; S, G & B; S, S & D; W, vC & B);
• Agroclimatic zoning and planning, comprising irrigation requirements; frameworks for agrometeorological characterization (1, 2) (J & AKC; R & B; S; ZD et al.);
• Participatory on-farm validations of sustainable farming systems, including adaptation strategies to increasing climate variability and climate change, and to changing social and economic (e.g. ‘market’) conditions; tests of agrometeorological information products (1, 2, 3) (R & B for examples; S, S & D umbrella project (iii); S, G & B);
• Design of Integrated Pest/Disease Management systems that provide control achievements (2, 3) (J & AKC; Strand);
• Design of management and manipulation techniques for microclimate improvement (wind protection; shading; contour terracing etc.) (1, 2, 3) (J & AKC; O, B & K; R & B; S, S & D);
• Improved agrometeorological assistance for development, to be included in better project design and operation by NGOs and Governments, in the form of technical advances, including integrated information systems, that facilitate improved choices by farmers (1, 2, 3) (J & AKC; O, B & K; S, S & D);
• Supply of information enabling to keep an optimum level of non-degraded land dedicated to agricultural use (1, 2) (J & AKC; S, G & B; ZD et al.).

Some services (and sometimes their perspectives) were mentioned only once but they appear, nevertheless, to be important:
• Determination of crop water requirements and computerized crop water use simulations (2, 3) (S);
• Evaluation of the impact of agrometeorological information (1, 2, 3) (W, vC & B);
• Provision of access to agrometeorological information by new information and communication technologies (1, 2, 3) (W, vC & B);
• Promotion of the actual use of GIS in developed countries, e.g. as for forest fire prevention, and, very preliminarily, in developing countries, e.g. for the monitoring of the cropping season (1, 2) (M, P & K);
• Constitution of a readily accessible inventory (data base) of proven techniques of application of agrometeorological information (1, 2, 3) (R & B);
• Design of decision support system software that gives access to special information, and that is regularly updated (2, 3) (J & AKC).

3.3. Needs and perspectives for services coming from the discussions

The material received from discussants and from those bringing up discussion points from the floor appeared to contain almost exclusively issues on support systems. The only direct issue under services was:
• User fees may be a self-defeating solution if it restricts information delivery. A partnership between the public and private sectors might be feasible. A partnership between responsible agencies and organizations, to avoid duplication and to achieve a cost-effective approach, would benefit all end-users (1, 2, 3).

4. Agrometeorological and other support systems to (agrometeorological) services: data

4.1. Needs for data (and directly derived products)

The needs for the following data support systems (and sometimes the perspectives to meet them) were at least mentioned twice in the papers.

4.1.1. Geo-information systems for sustainable land management (1, 2)
• M, P & K present full details on GIS/LIS (with L for Land) and remote sensing in agrometeorology, including aspects of hardware in their definitions;
• D et al. treat extensively the use of remotely sensed data, including the satellite data of the Tropical Rainfall Measuring Mission (TRMM);
• J & AKC indicate that GIS (with G for Geographical) is a proven software, appropriate for use by national meteorological agencies;
• S, S & D indicate the necessary inclusion of a Global Terrestrial Observing System (GTOS) when mentioning work on GIS as one of the 10 most essential agricultural umbrella projects with agrometeorological components proposed in the literature;
• ZD et al. mention GIS to assist in spatial and temporal analysis of the climatic resources, in combination with conventional methods, with priority for rainfall and temperature;
• dP, G & A mention the role of Digital Elevation Models (DEMs) in the integration of thematic layers in GIS-based land and water resource information
systems. They indicate the major role for remote sensing to monitor changes in edaphic factors;

- O, B & K and S, S & D indicate that GIS, while not yet adequate at the farm level in developing countries, can support advisory services;
- S, G & B mention, as one of the priorities for agrometeorologists, the promotion of GIS and applications of remote sensing in the integration and mapping of a wide range of databases.

4.1.2. Agroclimatic zoning (1, 2)

- The usefulness of agroclimatic and crop suitability maps depends on the accuracy of the input data used, the viability of the methodology and the scale of the maps. At present, there are, in most countries, more reliable climate data than crop data available (or at least accessible), in time and space (J & AKC);
- A discussion on data problems and agroclimatic variations in the arid zones and some techniques for spatialization of climatic data are presented by dP, G & A. In remote areas agro-ecological frameworks can be used as a basis for siting (automatic) weather stations in representative locations. To take existing confusion away, complete agro-ecological zoning would explain differences with climatic and agroclimatic zoning, add features of climate variability, take into account also certain advantages in arid regions, and address the dynamics of zoning with time;
- Simple agro-ecological zoning can be used for the assessment of the agroclimatic production potential (S, G & B);
- The usefulness of the results of traditional zoning techniques can be enhanced if they are complemented by a detailed agroclimatic characterization, and if the areal extent of conditions is determined with the use of remote sensing (R & B);
- V proposes to install, maintain and interlink automatic weather stations, established in the rural settings in well-defined eco-production zones, to meet the future needs for weather information;
- Reports and charts of agroclimatic zonation have been comprehensively applied for the integrated regional development of agriculture, to obtain a reasonable distribution of varieties, crops, farming systems, etc. and for the better exploitation of potential productivity in China (ZD et al.).

4.1.3. Data base management for agricultural purposes: data trends and statistics (1, 2, 3)

- The major concerns for the availability of climate and agrometeorological data will continue to be in areas of data collection and data base management (D et al.). The authors present an example for a conceptual data base management system as a framework for the future acquisition, maintenance and distribution of climate and agrometeorological data;
- Historical data or observations during the current growing season will play a critical role in increased applications of crop models and model-generated output by farmers, consultants and other policy and decision-makers. Weather generators for daily rainfall, maximum and minimum temperature and solar radiation are also mentioned, even though the accurate generation of precipitation data, both the occurrence of an event and the amount, remains a most difficult task, especially for tropical and sub-tropical regions. A uniform file format should be defined to store weather data for easy exchange between users of crop simulation models (H & H);
- Specialized statistical packages, such as INSTAT, can easily provide important additional agroclimatic information, such as the occurrence of multi-parameter events that determine phenological or agricultural developments (R & B);
- Plant requirements for and responses to climatic conditions are difficult to obtain and should be collected in data bases. Research on data base management should be undertaken to assure efficient storage and indexing of data for use in different agricultural activities. Through communication and processing, integrated information/data systems can be created for analyzing, diagnosing and predicting plant responses (ZD et al.).

4.1.4. Long-period high-quality climate and agricultural records and new data sources for operational agrometeorology (1, 2)

- Long-period, high-quality climate and agricultural records are crucial for widespread application of climate information and for prediction services for agricultural planning and operations. The length and quality of the climate and agricultural records are key issues to satisfy the specific requirements of the farming communities (O, B & K; L, M & M).
The collection and use in operational agrometeorology should be promoted for new types of data, such as those that come from recent developments in remote sensing, that provide global coverage and that may improve and extend ground data (S, G & B).

4.1.5. Rapid dissemination of near-real-time data so that farm-level decisions are made in time to ensure high and sustainable yields (2, 3)

- The most widely expressed need for meteorological information to plan and guide operational activities in agriculture has always been a simple short-term weather forecast. Users of real-time and near-real-time data require timely availability of the agrometeorological information from a data support system (J & AKC; R & B; O, B & K);
- Attempts have been made recently to use remote sensing techniques for such purposes, but in developing countries calibration attempts of such techniques have only rarely been made (O, B & K);
- V summarizes, as one of three issues that need to be considered by the community of meteorologists, that land managers would like to receive the following meteorological information within 24–48 h: rainfall, solar radiation and thermal regime. To supply these data, extensive information technology tools will have to be employed.

4.2. Other needs for data support systems to (agrometeorological) services

The following important issues related to needs for data support systems (and sometimes their perspectives) were mentioned only once in the papers:
- Methods to obtain reliable data by monitoring droughts, heavy rainfall and other extreme events (1, 2, 3) (S, G & B);
- Improved timeliness, resolution and predictive capability (of central tendencies and extremes) for agrometeorological data, which would have a carry-over effect for fisheries (1, 2) (K);
- Better prediction of water temperature from weather and climate data for fisheries (2) (K);
- Diurnal data, on a daily basis, for applications of simulation modeling, but at times with intervals as small as 1 s for terms in the soil water balance (3) (H & H);
- Standards for equipment and sensors at weather stations, and for the installation and maintenance of automatic weather stations, for the (diurnal) data generation for crop simulation models employed in yield forecasting (2, 3) (H & H);
- Determination of requirements for data and directly derived products expressed by individual users (1, 2, 3) (R & B).

4.3. Needs and perspectives for data support systems coming from the discussions

The following additional needs and perspectives were brought up by the discussants and in the general discussions:
- Although successes have been obtained in calculating evaporation for irrigation scheduling, improved calculation methods for evaporation under conditions of water deficit are still required. Ideally the two steps procedure involving crop coefficients should be replaced by a one step procedure with only crop and canopy resistances; effects of advection should be studied more closely (2, 3);
- Improved quality of crop and agrometeorological data depends on the availability of resources for maintenance of an adequate network. Such resources have been generally insufficient. Nevertheless, better use can be made of existing (historic) data, both analyzed and not yet analyzed, and more effort can be expended on their interpretation. Clearer awards for taking good data would have a positive influence (1, 2, 3);
- Routine measurement of water temperature of inland water bodies used for fisheries, was recommended; good quality historical data are wanted to develop production models in fisheries, while short- and long-range climate predictions are needed for risk evaluation and food security as provided by fishery sources (1, 2, 3);
- Remote sensing data were considered, for the time being, as a good indirect indicator of soil moisture as judged by the crop status (2, 3);
- Alternative means for data collection should be developed by NMHSs in developing countries, under pressure to generate their own funds, using local human resources and training means (1, 2, 3);
- Use of Automatic Weather Stations may trade one set of problems for another, because automatic stations need specialized technicians for servicing (1, 2, 3).
5. Agrometeorological and other support systems to (agrometeorological) services: research

5.1. Research needs (and directly related policies)

The following needs for research support systems (and sometimes the perspectives to meet them) were at least mentioned twice in the papers. In this summary they are grouped under eight sub-headings.

5.1.1. Efficiencies of the use and management of resources, including the whole production environment: climate, water, light, nutrients, space (above and below the soil surface), germplasm, biomass (1, 2, 3)

- J & AKC believe that intensification of production can be accelerated through research, that should consider all of the socio-economic, natural resource, technical and institutional factors that influence productivity and sustainability. Ecological and economic sustainability can be achieved when the natural resources of land, crops, animals and water are used to reinforce each other’s benefits. Such holistic research on production systems needs to be reinforced, particularly in many regions of the developing world. In Africa, more emphasis should be given to research on resource management than to commodity improvement research, but in much of Asia there is room for more crop-specific research;

- Variations in the behavior of the Inter Tropical Convergence Zone have enormous effects on the organization and outputs of farming systems, particularly in drier areas; the reasons for these variations deserve considerably increased research efforts (J & AKC);

- In their summary of proposals for new areas of agrometeorological research activities in response to UNCED documents, S, G & B mention: (i) in the context of the Convention of Biological Diversity: research on management and conservation including the rehabilitation of critical resources through ‘eco-systems approaches’; and (ii) in the context of the Statement of Principles on Forests: to encourage provision of information on proper resource management. These proposals illustrate the fact that in their table on definitions of sustainability, ‘resources’ and ‘resource base’ are the most frequently returning keywords;

- Among the 10 most essential agricultural umbrella projects with agrometeorological priority components selected from the literature, S, S & D note the need for research on efficiencies of the use of resources (germplasm, soil, water and energy in agricultural production) and their protection;

- S sees considerable scope for research on increasing water use efficiency in rain-fed crop production as well as increasing irrigation water use efficiency;

- ZD et al. mention, among the many research needs they define in each of their sections, the research priorities on climate resources and regional development.

5.1.2. Research on agrometeorological aspects of management in agriculture at different scales for different purposes (1, 2, 3)

- Research on microclimate modification by means of shelterbelts, shading, and mulching that can result, among others, in the suppression of evaporation and on ways in which microclimate can be managed otherwise (J & AKC). This may be in integrated pest/disease management systems, the combat of wind damage, the matching of shade and the use of fertilizers in cocoa, or other shade management, contour and other terracing, pruning in cash crops as rubber, oil palm and coffee, or improving other growth conditions (J & AKC);

- Research on the consequences of modifications of the microclimatic environment and of cultural practices in integrated pest management could improve the efficiency of the biological control agents that are introduced (Strand);

- V describes research that developed land and water management methods in a watershed-based system, with positive results for carrying capacity, erosion control and water use efficiency;

- Monteith indicates that agricultural meteorology has its roots in centuries of experience gathered and organized by farmers, but only recently has this got the highly needed attention in the application of agrometeorology in the management of tropical agriculture;

- dP, G & A think that much wanted adaptive water management research will be boosted by water scarcity. In dry areas agro-ecological niches with higher agricultural potential will receive the management research priority that was lacking;
Further research is needed on the agrometeorological information to manage the major inputs in farming system, their amount and timing (R & B); in connection with this, S, S & D give three strategies for support to farmers that use relatively low amounts of inputs, and these strategies may also be considered a research agenda;

At the end of the research chain, on-farm validations of new approaches and technologies, that take traditional and more recent local knowledge into account, are needed most of all for the management of agricultural production (S, S & D);

‘Needs’ and ‘Strategies’ (= ‘Perspectives’) for agrometeorological research in water management and conservation, and for microclimate, topoclimate and other environmental engineering are described by ZD et al.

5.1.3. Validation and application of models (e.g. phenology; morphological predictions; yields); limitations of models; models for specific users (1, 2, 3)

- The contributions of agrometeorology to the simulation of crop production and its validation and applications, starting with a definition of the critical agrometeorological parameters involved, are described in detail by H & H;
- J & AKC present 23 major applications of crop models in sub-Saharan Africa developed by Jagtap et al. and a description of some of these models. Conventional empirical approaches are considered inadequate for addressing the complexity of the interaction between global climate, regional weather variability, decision making, agricultural productivity and economic responses. Models must be further developed to continue opportunities and challenges for agrometeorologists to assist in solving the complex agricultural problems in these areas;
- Positive and negative extremes in successes with the application of modeling have been shown by Montith. Two warnings are made: (i) on the compatibility of sources of empirical and other information that is entered into the models; (ii) on the appropriate calculation of errors as part of the model output, including those caused by input parameters, that are not devoid of errors;
- The more active applications of models for phenology, yield forecasting and related subjects are considered a priority area (S, G & B). In the context of the United Nations Framework Convention of Climate Change a comprehensive model for predicting changes in GHG emissions associated with different management practices in agricultural and forestry systems should be developed;
- Needs for the development and the validation of models for crop-pest management systems are described by Strand;
- There is not much agreement between outputs of models on changes in extreme events, except for high intensity rainfall, and research is required to change this situation (S, S & D);
- Research on ‘crop simulation modeling’, especially for models guiding production and including the influence of pests, diseases, weeds, and various technology measures and economic factors is needed (ZD et al.). The perspectives seem to have few limits.

5.1.4. Research methods and approaches at the eco-regional level, including the assessment of socio-economic effects of weather/climate variability on food production (1, 2, 3)

- The research concept of ‘agro-ecological niche’ may help in understanding and managing agricultural productivity in the arid zones (dP, G & A);
- In the context of the Convention on Biological Diversity research, an ‘eco-systems approach’ and its methods may benefit the management, conservation and rehabilitation of critical resources; in research activities springing from the Climate Change Framework also socio-economic effects of variabilities should be included (S, G & B);
- (S, S & D) mention as the first of their 10 most essential agricultural umbrella projects with agrometeorological priority components that they found proposed in the literature, research on methods and approaches with specific ecoregional applications;
- Methodological tools of decision support systems will have to be researched and used to help farming systems achieve sustainable production as near to the ecological potential as economically feasible (V);
- Research strategies have been identified to curb the degradation of the agro-ecological environment, one of the main factors limiting the capacity of aggregate agricultural production (ZD et al.).
5.1.5. Determination of the impact of climate change/variability and matters of climate forecasting and prediction in general (1, 2, 3)

- H & H feel that the application of crop models towards effects of climate change and climate variability is at present the closest connection with agrometeorology. They exemplify that the combined GCMs and crop simulation models provide a good scientific approach to study the impact of climate variability and/or change on agricultural production and on the world food supply. Unfortunately most of the results of such studies on climate change and their potential impact are at present not conclusive;

- Few papers have appeared in Agricultural and Forest Meteorology on the likely effects of increases in global temperature on increase in crop growth rates, shortening the length of the growing season and shortening the life cycles of pests and pathogens (Monteith);

- O, B & K review the status of seasonal to interannual climate prediction research and the quality of its practical uses at present. They feel that the use of such products in agriculture will require basic and applied agrometeorological research, including understanding of the local climate/agricultural systems and the associated linkages, especially with respect to extreme events, linkages between climate and pests and diseases development, adaptation of agricultural systems to the local climate variability, etc.;

- In the summary of the proposals for activities in agrometeorology that follow from the UNCED documents, it is suggested to strengthen research in the area of climate prediction and services to agriculture; similarly, Commitment 3 of the World Food Summit Plan of Action stresses the need to promote the research needed to continue international efforts to develop, disseminate and apply climate forecast information (S, G & B);

5.1.6. Research on the reduction of the impact of natural disasters (including pests and diseases) (1, 2)

- Climatic indicators to be used in research on minimizing adverse impacts in countries with extreme climate variability will have to be developed (S, G & B);

- (S, S & D) include in their list of the 10 most essential agricultural umbrella projects, research on ‘(environmentally sound) impact reduction (from sources to targets and from forecasting to preparedness) of natural disasters, including pests and diseases, reducing agricultural production’;

- ZD et al. mention as ‘strategies’ for ‘mitigation and reduction of agrometeorological disasters’, eight research highlights, among which are: (i) mechanisms of some important stresses and disasters in most field crops; (ii) making pre-plans of disaster reduction for different types and levels in ecological regions; (iii) new techniques of mitigating stresses using physics and chemistry; (iv) assessments of risks and making policies of insurance in agriculture.

5.1.7. Consideration of ways to ensure that results of research are adopted by farmers: holistic, interdisciplinary field studies, of sufficient duration and coordination, on an operational scale (2, 3)

- There is virtually no adoption by small farmers of improved soil and crop management technologies recommended by research and extension systems. J & AKC emphasize that to change this situation, research on production systems in Africa should be holistic, based on suitable baseline data, with a methodology to measure benefits, arranging for qualified personnel and an institutional infrastructure;

- V proposes, as one of the main issues to be tackled in the new millennium, a collaborative effort between WMO, FAO, IARCs and NARSs to lay out operational-scale long-term interdisciplinary field studies at well-defined benchmark locations in order to evaluate the needs for agricultural and meteorological data for system modeling, transfer of technology, and technical, back-up support required by the farming community, at large, to sustain agricultural development.

5.1.8. Natural climate variability (1, 2)

- Better understanding of the climate (variability) of the major eco-systems of the world where biodiversity is at risk could help develop effective in situ conservation strategies (S, G & B). Both the UN Framework Convention for Climate Change and Convention to Combat Desertification emphasize the need for such research;

- Progress could be made if natural climate variability was better understood (J & AKC), especially in
respect of: (i) the phenomena happening around the ITCZ; (ii) ENSO phenomena; (iii) rainfall variability; and (iv) variabilities in other extreme events.

5.2. Other needs for research support systems to (agrometeorological) services

The following important issues related to needs for research support systems (and sometimes their perspectives) were only mentioned once in the papers:

- Improving and strengthening agrometeorological networks to support data collection for research (1, 2, 3) (S, G & B);
- Developing agrometeorology based alternatives to pesticides and the use of environmentally more benign pesticides; applying technology to reduce unintended effects of pesticides (2, 3) (Strand);
- Development of methodologies for the interpolation of regional data to integrate weather in farm management schemes, also including satellite information, with improvements in mesoscale models (2, 3) (Strand);
- Downscaling of short- and medium-term weather forecasting in developing countries, using knowledge of local/regional climate processes (2, 3) (O, B & K);
- A key challenge of the next century is to procure climate change information useful to those managing agricultural systems. This refers to the core agrometeorological factors to optimize use of climate information and prediction services (1, 2, 3) (O, B & K);
- The need to adapt to increasing climate variability and climate change is determined initially by changing and often worsening limiting factors of agricultural production and the vulnerability of farming systems. Therefore UNCED documents/WF Summit Plan of Action should be taken as a framework and scientists should play a guiding role (1, 2, 3) (S, S & D).

5.3. Needs and perspectives for research support systems coming from discussants and discussions

The following needs and perspectives were brought up in the discussions:

- To prepare methodologies for evaluation of training events, both immediately following such training events and 4–5 years later (1, 2, 3);
- Appropriate parameters, useful agrometeorological indices and biological indicators, for use in arid regions, should be further developed (1, 2, 3);
- The effect of global climate warming on inland fisheries should be subject of simulation models (1, 2);
- Agrometeorologists should actively contribute to research on crop pest/disease reduction management, including desert locust control. Modeling can have a function here, including fine tuning of inputs to control damage, so that financial savings may be made (2, 3);
- Models should be given operational capability directed towards the needs for products of end users (2, 3);
- Reporting on pest/diseases research, relationships between weather, (micro-)climate and yield and aspects of management in agricultural production has been infrequent in Agricultural and Forest Meteorology. The question ‘does it give practical results’ has not often been asked (2, 3);
- Research on the practical contributions and applications of remote sensing should be summarized regularly and products made available to end users (1, 2, 3);
- A watershed based approach for the choice of farming systems was suggested (1, 2).

6. Agrometeorological and other support systems to (agrometeorological) services: policies

6.1. Policy needs (and directly related issues)

The following needs for support from policy systems (and sometimes the perspectives to meet them) were at least mentioned twice in the papers of this volume:

6.1.1. Protection and use of (tropical) forests and large scale afforestation, including agroforestry and subjects mentioned in the Statement of Principles on Forests (1, 2)

- In the humid zone man has modified most of the rainforest in Africa, except that the forest in the Zaire basin is still nearly intact and, by global standards, has a relatively slow rate of clearing. The present forest is a mosaic of different forms of land use. Population density determines its fate. In
the sub-humid zone, the natural vegetation changes from forest in the derived savanna through savanna woodlands to open savanna in the drier part of the northern Guinea savanna. Most areas have been modified through agricultural use, which will continue. Policies should include fostering of all kinds and forms of agroforestry systems with cash crop trees. This is not different for other parts of the world (J & AKC);

- The vegetation of the arid savanna zone in Africa consists mainly of *Acacia* spp. and grasses. Nearly all the trees have uses and many of the trees and bushes are heavily lopped. The only developed management technology, introduced so far, is alley cropping on sloping degraded land. The zone is widely considered at great risk because agricultural production is declining. Policies to adapt agricultural production include more intense use of scattered farm trees, whether as isolated trees, farm boundaries, contour hedgerows or woodlots. This applies also to drier areas elsewhere (J & AKC);

- dP, G & A indicate that actual afforestation in the arid zone is mainly for purposes of conservation or protection, in particular to protect agricultural land against sand dune invasion and to provide shelter against dry and strong winds;

- Agenda 21 includes action to enhance the protection, sustainable management and conservation of all forests, and the greening of degraded areas, through forest rehabilitation, afforestation, reforestation and other rehabilitative means. The Convention on Biological Diversity supports this action in view of the role of forests in the sequestration of carbon and the fact that forest ecosystems are vital for biological diversity (S, G & B); further new activities of importance for agricultural meteorology are given in the Statement of Principles on Forests (S, G & B); many of these subjects are also mentioned by S, S & D in one of their 10 most essential agricultural umbrella projects with agrometeorological priority components.

6.1.2. Priority for all aspects of water management (1, 2, 3)

- Given that in countries in the arid zone water, at present used for agriculture, will most likely be requested by other sectors, policy measures must be adopted: (i) to increase water use efficiencies, including perhaps changes in cropping patterns; (ii) to redress mismanagement of groundwater; and (iii) to promote the possible use of additional sources of water (dP, G & A);
- Defining effective strategies in planning and management of water for rainfed and irrigated agriculture is a national and global priority. The World Food Summit and the framework of Agenda 21 are mentioned as FAO’s action fields on the subject (S). They include options for effective water use (S) and integrated packages at the farm and watershed level, such as alternative cropping strategies, soil and water conservation and promotion of water harvesting techniques (S, G & B);
- Proposals for efficient use of water, including policy measures that were successful in enticing people to use energy more efficiently, are given by S, S & D;
- A policy of improved management of natural resources as practiced in a watershed scheme in India, that has succeeded to utilize, on average, 80% of the seasonal rainfall, while it could stand the climate risks of the region and reduced soil erosion, can be adapted and adopted for use elsewhere (V);
- In China policies are recommended as follows: (i) awareness of water shortage and environmental protection should have priority above other issues and (ii) water conservation should be advertised to extension and producers, while water conservation services by the private sector should be encouraged. Practical strategies include: (i) rainwater harvesting and conservation; (ii) meteorology-driven scheduling of irrigation; and (iii) environmental and economic evaluation of water use in agriculture (ZD et al.).

6.1.3. Keep or create special attention for the tropics (1, 2, 3)

- A policy of promotion of more intensive production systems in the tropics will lead to increases in (seasonal) labor productivity. More internal sources of inputs (crop residues, leguminous properties) should be used for maintaining and enhancing fertility, because new medium-input production systems with response potential will be more successful, while intercropping should be maintained (J & AKC); also, technology development in tropical dryland Africa should, as a matter of policy,
concentrate on rainfed systems; V fears that production in the semi-arid tropics will remain in decline if water (and land) resources are not properly harnessed;

- Monteith shows that attention for tropical agrometeorology, as a policy, has recently increased with attention for fields like agrometeorology of multiple cropping, including agroforestry, and storage;
- S, G & B show that when policies of sustainability, and also the policies proposed in the UNCED documents, were generally accepted, agriculture in the tropics came suddenly into focus. Among the actions are the identification of hazard prone areas and more attention for extreme events in tropical regions, that are often vulnerable to increasing climate variability and climate change, that appear to exacerbate these extremes (S, S & D).

6.1.4. Strengthening of agrometeorological observation and information networks: people, hardware, software (1, 2)

- A world-wide policy of maintenance of sufficiently dense agrometeorological networks, especially in tropical and arid zones, is needed and must be complemented by a policy of spatialization of climatic parameters through multivariate approaches and remote sensing techniques. National Meteorological Services should have policies of servicing these areas using agro-ecological frameworks as a basis for siting weather stations in representative locations. In such policies it should be realized that in most developing countries the agricultural user community has the highest data requirements but the least financial resources (dP, G & A); in some cases data may be collected jointly by the NMS and interested users (R & B);
- A revaluation of the existing networks, including the use of automatic weather stations, is essential to respond adequately to the needs of the vulnerable priority regions, often in remote areas (S, G & B);
- To meet the needs for weather information in the new millennium, the policy should be to install, maintain and interlink automatic weather stations, established in the rural settings in well-defined eco-production zones (V).

6.1.5. Strategies to adapt to increasing climate variability and climate change (1, 2)

- Strategies to adapt to climate variability and change demand improved weather and climate forecast and prediction services (O, B & K);
- The priority agrometeorological adaptation strategies for regions that are identified as being most vulnerable to the effects of climate variability and climate change should be identified and such strategies should be disseminated quickly within such regions (S, G & B); they should be adapted in consultation with the end-users (R & B);
- S, S & D describe the currently needed and actually possible adaptation strategies, in general and separately for the industrialized and the developing world. Challenges for applications of such policies in different regions, together with resources, structures and strategies required for sustained efforts are indicated.

6.1.6. Choice of focuses: food and/or cash crops; single crops and/or intercropping; crops and/or fodder and/or animals; more food and/or better quality? (1, 2)

These are location specific choices, influenced by changes in climate, soils, economies, available/accessible varieties and other inputs (including those due to migration). These choices are normally made at the farm level but can be influenced by national and international policies (1, 2). The papers gave indications on reasons for changes in the policies.

- J & AKC illustrate many changes taking place in such focuses and why;
- Monteith indicates the changes in focus that took place in major topics covered by publications in Agricultural and Forest Meteorology, illustrating the change in time of priorities in research;
- dP, G & A indicate, in their section on development pathways of the agricultural production systems of the arid zones, the factors that are most likely to transform the existing agricultural production systems of the arid zones within a generation and exemplify the changes of focus;
- ZD et al. describe agrometeorological information services that provide input into policy choices of the kind mentioned here. They mention, in their section ‘Agrometeorology: facing the challenges’, some changes in these focuses that could take place.
6.1.7. Supporting and/or convincing decision makers, by evaluating applications (1, 2, 3)

- Monteith observes how little there is in Agricultural and Forest Meteorology on ‘Decision making, Management and Economics’ in comparison to the Handbook of Agricultural Meteorology edited by Griffiths;
- A practice of ‘convincing decision makers to support research and validation exercises in any of the (......) fields, by presenting proper examples of successes, i.e. of sustainable economic and social benefits, in particular for the most vulnerable people, countries and regions and for the planet as a whole’ was selected as priority by S, S & D; examples of such benefits are given by R & B and ZD et al.

6.1.8. Identification of initial and boundary conditions for all the above: e.g. economics, resources, other public policies, population and gender issues (1, 2, 3)

- J & AKC give examples of such factors that are limiting or enhancing production outside any recommendation domain of agrometeorology;
- Monteith thinks with Austin Bourke that as an initial and as a boundary condition there is ultimately a ‘strictly utilitarian path mapped out for us’;
- S, S & D refer to the need to meet ‘important aspects’ … ‘that have to do with macro-economic policies, gender aspects, agreements in global conventions and public policies’ … ‘that should be taken care of as other boundary conditions for projects…’.

6.2. Other needs for supporting policies to (agrometeorological) services

The following issues related to needs for policy support systems (and sometimes their perspectives) were mentioned only once in the papers:

- Take measures to increase the application of existing agrometeorological knowledge, to create ‘windows of opportunities’ for the practice of sustainable agriculture (1, 2) (R & B);
- Identify actively clients of agrometeorological ‘products’, their precise needs for agrometeorological applications, defined in their language, and presented according to their wishes, before the product is finalized (1, 2) (R & B);
- Support land tenure reforms that adapt the combination of private flock ownership and communal land in livestock systems in arid zone countries (1, 2) (dP, G & A);
- Propagate complementarity of irrigated indigenously bred fodder crops and livestock production systems in arid zone countries as an example of possible transition to economically attractive and environmentally sustainable systems (1, 2) (dP, G & A);
- Promote the spirit of unrestricted sharing of and access to information and data that has made meteorology a showcase of international co-operation (2, 3) (dP, G & A);
- In cases of diminishing public support, set a reasonable price for ‘products’ whenever possible, because often people can be induced to pay (2, 3) (W, vC & B);
- Reduce the gaps between the outputs generated by crop models (and decision support systems) and the application of these data by potential users (2, 3) (H & H);
- Efficient use of environmentally friendly energy supplies seems imperative (1, 2, 3) (S, S & D).

6.3. Needs and perspectives for policy support systems, coming from the discussions

The following additional needs and perspectives were brought up in the discussions:

- Improve the position given to agrometeorology and its contributions in the national economies (1, 2, 3);
- Promote agrometeorological applications at the grassroots by creating, developing and assisting ‘(Agro-)Meteorological Development Agents’ (in French: ‘Acteurs de Developpement en (Agro-)climatologie’), that apply agrometeorology where and when it is needed most (2, 3);
- The experience gathered by farmers should be taken as a starting point for services, strengthening it with scientific understanding (1, 2, 3);
- Before starting any scientific undertaking in agrometeorology, such as modeling, the users’ needs should be identified, by them and with them, and be formulated in their language (2, 3);
- Practical agrometeorological research should, as a policy, be interdisciplinary (1, 2, 3);
Climate should primarily be seen as a resource and only occasionally as a hazard. Resource use always bears risks. As an example: a principle in dryland agriculture is to farm in accordance with the natural climate resources of the region (2);

Through its support to environmentally sustainable agriculture agrometeorology can help preserve biologically diverse ecosystems (1, 2);

Policies on fertilizer applications should take into account the need for productive soils (which means the use of agrometeorological information) and the drawbacks of high inputs of inorganic fertilizers (1, 2, 3);

National conventional (agro-)meteorological observing networks in Africa should be reconstructed, upgraded and expanded (2, 3);

The coordination between the NMHSs and the agricultural extension services should be promoted by demonstration of the advantages to be gained by cooperation (2, 3);

Establish strategic synergies with food- and technological-product companies, farmer associations, etc. to reinforce the application of meteorology to the agricultural environment (2, 3);

Assist Members of WMO in providing meaningful agrometeorological services through the publication of specific case studies of agrometeorological ‘products’ for specific crops or crop combinations or intercropping systems (2, 3);

Establish committees for cooperation in seasonal climate prediction at the regional and national levels and in this way promote actual dissemination of the information to farmers and other end users in a jointly organized practical system set up. NMHSs should play a crucial role in organizing this. Meetings should be arranged for evaluation, exchange and improvement of the products, also including users (1, 2).

7. Agrometeorological and other support systems to (agrometeorological) services: training/education/extension

7.1. Needs for training/education/extension (and directly related issues)

The following needs for training/education/extension support systems (and sometimes the perspectives to meet them) were at least mentioned thrice in the papers of this volume:

7.1.1. Technology transfer (1, 2)

The transfer, from developed to developing countries, of new techniques on processing and interpreting remote sensing data has been limited by many factors, and developing countries still need modern tools, training and funds. Attempts are made to limit costs, and recommendations have been made to improve the use of the present global satellite observation system (M, P & K);

In developing countries, GISs are often obtained from developed countries through a transfer of the technologies and often information. This may mean that the basic considerations are generalizations of the knowledge of and studies carried out in other realities. In developing countries in a first phase relatively simple systems are used, which answer specific problems, improving gradually to incorporate the different informative layers to become fully operative GISs. Reinforcement of training in these new fields, with multimedia training tools, is necessary to make learning and updating of competencies easier (M, P & K);

Training in the relationships between agrometeorological and pest management disciplines will have to be provided to agricultural meteorologists, to extension personnel involved in this work, and to farmers. Differences in resources will mean differences in the ability to implement all components of a cropping system, therefore only those technologies that take into account local constraints can be implemented. For many areas a broad range of options is needed rather than narrow technological packages. The local culture is likely to influence the dissemination system, and must be taken into account to assure that information on techniques will reach the right participants (Strand);

In possible adaptation strategies to increasing climate variability and climate change, easy access to developed and well tested technology is important for many countries, but so are local innovations. Extreme weather causes damage everywhere, but regions with more resources have more possibilities to adapt (e.g. organize insurance). Absorption of new technologies is fast in these situations, also because investments are available for improvements.
A major challenge is to minimize the vulnerability of farmers (S, S & D);

- The Internet will play a major role in agrometeorological information either through direct or indirect access. In developing countries, Multipurpose Community Telecentres can be a focal point for many types of information, some of which will come from the Internet (W, vC & B);
- ZD et al. also recommend that technology transfer in agrometeorology should be emphasized.

7.1.2. Methods, procedures and techniques for disseminating agrometeorological information to cooperative extension services and other users, that understand its value (2, 3)

- An understanding and cooperative extension service is conducive, if not essential, to the acceptance by the farming community of the agrometeorological products that can be supplied (L, M & M);
- Monteith thinks that progress will come from more effectively integrated and deployed skills to influence production systems;
- The manner of delivery of the product is important. Regular contacts and dialogue, an open eye for the client’s production process, an indication of the benefits that the client will derive from the product, are among the points that determine the success of the delivery and use of a product (R & B);
- Rapid advances made in the recent past in information technology, especially in audio visual media, need to be quickly operationalized to diffuse agrometeorological information more effectively to the user community. The development of a bottom-up approach with full involvement of users is important to ensure that the methods and procedures derived this way will adequately respond to the needs of the users (S, G & B);
- Several methods of dissemination exist, from radio to agrometeorological bulletins and from local extension services to specialized advisory services (W, vC & B).

7.1.3. Awareness and training for disaster mitigation and climate disaster prediction (2, 3)

- It is crucial to educate the users of agrometeorological products in the use, skill and limitations of any climate prediction products (O, B & K);
- Capacity building for climate prediction and its use is proposed as a new agrometeorological activity. Areas identified in the UN Convention to Combat Desertification, that may be of specific interest to agrometeorologists, are the training of decision makers, managers, and personnel who are responsible for the collection and analysis of data, for the dissemination and use of early warning information on drought conditions and for food production (S, G & B);
- A training infrastructure is proposed as part of a strategy to enhance adaptation to ICV & CC and promote sustainable development. This structure would rely on a two-way training process between researchers and farmers, particularly in developing countries where education of rural workers is rather limited (S, S & D);
- High-quality advisory and training services to development workers can be provided by Regional Centres for Communication for Development, such as the FAO-assisted Centre in Harare. Agrometeorological data and information systems and GIS services will in future be connected to this centre to provide information on agricultural production conditions and the food security outlook (W, vC & B);
- In China, strategies are proposed to train (i) local agrometeorological technicians, agronomists and farmers in knowledge on, and techniques to mitigate, the effects of the most frequent disasters; (ii) provincial meteorologists in methodologies of disaster monitoring, forecasts, risk assessment and mitigating measures; and (iii) local officers in techniques for management, risk assessment and decision making (ZD et al.). This training is complemented by the publication of booklets and handbooks for farmers and local technicians. In cases where farming systems do not have sufficient short-term flexibility, adaptation to climate variability and climate change should be planned in anticipation, or new technologies should be developed and then validated with farmers, which will also be a training exercise.

7.1.4. International cooperation (1, 2, 3)

- In addition to the activities of the Regional Meteorological Training Centres, regional or international cooperation in training for agrometeorological research between Universities should be strengthened,
similar to the ongoing project between African Universities and a Dutch one (L, M & M);

- New tools to increase the use of agrometeorology and to improve its applications are everywhere based on the reinforcement of the agrometeorological sector in the national services, research, and training. Participation in international programs can facilitate this reinforcement (M, P & K);

- The potential of the new information and communications technologies should be exploited to foster international cooperation in agrometeorology (W, vC & B; ZD et al.).

7.1.5. Training assistance focused on priority services and on priority needs mentioned under data, research, policies and education (1, 2, 3)

- Particular needs for training in the fields of agrometeorological services and their support systems are illustrated by L, M & M;

- Many training programs can address multiple purposes, e.g. new tools but at the same time data use and research applications (M, P & K);

- O, B & K are among those who emphasize general training aspects as a challenge to optimum utilization of the climate information and prediction products their paper deals with. They state that skilled multidisciplinary human resources for integrated agrometeorological applications are relatively limited, especially in developing countries. There is therefore a great need to strengthen the capacity of the national/regional climate and agrometeorological institutions to pursue the development of such a multidisciplinary resource;

- S, S & D have as their last essential agricultural umbrella project with agrometeorological priority components ‘any educational and teaching exercises that assist in promoting work on the above mentioned priority umbrella projects’;

- W, vC & B recommend that information and communication technologies, the use of which must be seen as a policy issue, be a component of the training of agrometeorologists in order to eventually provide the best possible advice to farmers.

7.1.6. Methods, techniques, software packages for specific applications by the clients themselves (2, 3)

- For models to become an effective decision support tool, a concerted effort is needed to narrow the gap between the supply and the application of information, e.g. the outputs generated by crop simulation models and decision support systems, and the application of these data by potential users. This is illustrated with the outputs of a crop simulation model for on-farm management, with respect to irrigation and nitrogen management decisions for cotton, and its use (H & H);

- Agrometeorological services should be able to provide tested software packages (or parts thereof), such as those for the calculation of the water balance, for the monitoring and control of some pests and diseases, or for crop growth monitoring, for clients that wish to operate their own daily information service. Another much-demanded product is a reference data bank for comparing actual data with e.g. the mean, those of last year or those of any other period (R & B);

- Roving seminars on computerized crop water use simulations for irrigated agriculture, such as those set up by WMO/FAO, should continue to be organized (S).

7.1.7. Interdisciplinary extension services for local development (2, 3)

- A syllabus should be prepared urgently, acceptable to academic institutions, for agricultural extension and farm advisory officers, because these persons are more frequently in contact with the farming community than most agrometeorologists. L, M & M list the extension services required in applications of technology by agriculture for development and the different requirements for agrometeorology in the developing and the developed world;

- Farmers need to be given training in the best ways to integrate new agrometeorological and pest and disease information into their farming activities, but should also be given a basic understanding of relationships between pest and disease development and agricultural meteorology to enhance their own observations and experiences (Strand);

- ZD et al. indicate that in China agrometeorological information has been applied comprehensively to regional integrated development of agriculture, and to help achieve a reasonable distribution of different varieties, crops, farming systems and exploitation of potential productivity.
7.1.8. Agrometeorological networks, including CLIPS products (2, 3)
- Agricultural users should be provided with good knowledge of the skill and limitations of any climate prediction products (O, B & K);
- Improved management and exchange of information and networking, including maximum use of available CLIPS products should be promoted; attention was drawn to the FAO/WMO agromet e-mail site (agromet-L@mailserv.fao.org) (S, G & B);
- The interaction of people, from scientist to extension worker, in the continuum from basic understanding to practical applications should be improved through better integration of the human capital available at all levels of organization, so that the generation and dissemination of agrometeorological information in the future should be as functional as possible (W, vC & B).

7.1.9. Training in general, including there where agriculture is on the decline (1, 2, 3)
- More training to cope with the demand of agrometeorological services is required in Asia (J & AKC);
- Research and research education in agrometeorology should receive priority, be focused and proposed for funding in relation to strategies of adaptation to ICV & CC (S, S & D); this point is also mentioned in Agenda 21, Chapter 36, the text of which on promoting education, public awareness and training is of specific interest to agrometeorology (S, G & B).

7.2. Other needs for training/education/extension support systems to (agrometeorological) services

The following important issues related to needs for support systems from training/education/extension (and sometimes their perspectives) were only mentioned once or twice in the papers:
- Learn from tradition, e.g. indigenous pest control (2, 3) (Monteith; S, G & B);
- After a proper selection system has been applied, evaluation of post-training performances should be systematically followed up (1, 2, 3) (L, M & M);
- Regional workshops on the impact of climate on agricultural production, on the application of agrometeorology to the planning of sustainable agriculture, and on the interaction between climate and applications of technology, should be prepared for educationalists (2) (L, M & M);
- In view of the economic importance of the agricultural sector in the national economy in the developing world, national efforts to improve the coordination between the meteorological services and the agricultural extension and research departments should continue, with the purpose to educate the agricultural and the horticultural communities and to demonstrate the application of available agrometeorological knowledge in both planning and application of technologies. The need for agrometeorological graduates who know this context is expected to increase (2, 3) (L, M & M).

7.3. Needs and perspectives for training/education/extension support systems, coming from discussants and discussions

The following additional needs and perspectives were brought up in the discussions:
- Training and education in agrometeorology in French do need special attention from WMO and other relevant organizations (1, 2, 3);
- The experience with operational pilot projects obtained in Mali should be further transferred to other countries and funded by the Consortium in charge (2, 3);
- WMO/FAO should strengthen joint regional training of meteorological and agricultural personnel in general agrometeorology, business management, and public relations tailored for grassroot levels (2, 3);
- Agrometeorological personnel should also be trained in pest and disease management; and in phenological observations and the development and management of phenological databases (3);
- Training seminars were suggested for senior agrometeorologists in various regions on the quality control of data and observation practices (2, 3);
- A working group should be established to prepare requirements for agrometeorological syllabi for agronomy personnel of the universities and agricultural colleges, by WMO/FAO/???(2, 3);
- RADIO (rural), TELEVISION (special programs) and INTERNET as ‘common means of communications’ should permit their use to the
benefit of all. This will lead to ‘education permanente’, ‘ongoing learning’ via these special ‘means to overcome distance’, which still are not part of the daily life of very many people in this world (1, 2, 3);

- The formulation of agrometeorological information for farmers and farm workers should take into account farmers’ wishes in respect of the messages on weather, climate and agricultural information: form and design; accessibility; regularity and simplicity; reliability (1, 2, 3);
- A request was made to assist fire practitioners (farmers, foresters) by helping their countries to establish agrometeorological networks for the collection, analysis, forecast and dissemination of fire weather information, especially in developing countries. These fire risks exist particularly in forests and rangelands. Because of the importance of these areas for carbon storage, sustainability of agriculture and as a reservoir of biodiversity (next to sources of economic revenue, fresh water and food), contacts with colleagues in forestry and rangelands should be extended (1, 2).