REPORT OF THE RA VI WORKING GROUP ON AGRICULTURAL METEOROLOGY

Submitted by

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CONTENTS

Section I  Introduction  5

Resolution of RA VI XII concerning WG on Agricultural Meteorology  7
Report of WG meeting was held in Budapest, 26-28 February 2001  9
Opening Remarks by M. V. K. Sivakumar  21
Opening Remarks by R. Motha  25
List of Participants  27
Report of the chairperson of the Working Group by Z. Dunkel  31

Section II  Technical Reports  35

Kleschenko, A. D.:  
Physical and Mathematical Models on Anthropogenic Contamination of Agroecosystem  37

Özalp, H. Y.  
The recent Developments in the Use of Remote Sensing as a Tool for the Detection of Droughts, Forest fires etc., and the Potential for using the next generation of meteorological satellites  45

Guerreiro, R., Gat, Z. and Alexandrov, V.:  
State-of-the-Art of Education in Agrometeorology in Europe at the Level of Technical Schools and Universities  59

Friesland, H.:  
Review of the Scientific Literature on the Effect of Climate and Weather, Especially During the Ripening Period, on the Quality and Storage Capacity of Grapes, Spring Barley and Potatoes  81

Alexandrov, V.:  
Summarizing Crop Growth Simulation Models in Europe with Potential for Operational Assessment of Crop Status and Yield Prognosis  119

APPENDIX; Filled in Questionnaires  157

Braslavska, O.:  
The Economic Consequence of Draught in Spring of 2000 for the Cereal Production in Slovakia  215
SECTION I

INTRODUCTION
RESOLUTION 8 (XII-RA VI)
WORKING GROUP ON AGRICULTURAL METEOROLOGY

REGIONAL ASSOCIATION VI (EUROPE), NOTING:
(1) Resolution 13 (Cg-XII) - Agricultural Meteorology Programme,
(2) The final report of the eleventh session of CAGM (WMO-No. 825),
(3) Resolution 9 (XI-RA VI) - Working Group on Agricultural Meteorology,
(4) The report of the working group submitted to the twelfth session of the Association, including its recommendations,

RECOGNIZING:
(1) The increased awareness, especially in many developed countries, of the importance of the quality of agricultural products,
(2) The increased concern with the pollution of water and air resources,

RECOGNIZING FURTHER:
(1) The need for promotion of agrometeorological forecasts and products,
(2) The need for assessment of agrometeorological education at the level of technical schools and universities,

DECIDES:
(1) To re-establish a Working Group on Agricultural Meteorology with the following terms of reference:
   (a) To review the scientific literature on the effect of climate and weather, especially during the ripening period, on the quality and storage capacity of grapes, spring barley, potatoes and tomatoes;
   (b) To review the conservational aspects of environmental resources, i.e. climate, water and soils, and agricultural methodologies that describe quantitatively the pollution of water and air resources (e.g. nitrogen application, use of fungicides and pesticides, etc.) and land management techniques;
   (c) To summarize the recent developments in the use of remote sensing as a tool for the detection of droughts, forest fires, frost risks etc., and the potential for using the next generation of meteorological satellites;
   (d) To assess the cost/benefit ratios of the provision of agrometeorological information;
   (e) To promote information campaigns and training of farmers' associations and water resource managers regarding use of agrometeorological forecasts and products through publications and multimedia approaches;
   (f) To review the state-of-the-art of education in agrometeorology in Europe at the level of technical schools and universities;
   (g) To summarize the status in Europe of weather-dependent agrometeorological growth simulation models with potential for operational crop state monitoring and yield forecasting;

(2) To nominate the following experts as core members to serve on the group:
   H. Dobesch (Austria)
   P. Nejedlik (Slovakia)
   H. Friesland (Germany)
   G. Zipoli (Italy)
   Z. Gat (Ms) (Israel)
   Y. Özalp (Turkey)
   V. Alexandrov (Bulgaria)
   A. Klechenko (Russian Federation)
   R. Guerreiro (Ms) (Portugal)
   A. Marroquin (Spain)
   I. Matajc (Slovenia)

(3) To designate Z. Dunkel (Hungary) as chairman of the working group;

(4) That Members may nominate other experts to serve on the working group;

(5) To invite the chairman of the working group to submit annual progress reports on the activities of the group and a final report to the president of the Association six months prior to the thirteenth session of the Association.

NOTE: This resolution replaces Resolution 9 (XI-RA VI), which is no longer in force.
1. Opening of the Meeting

1.1 The meeting of the Working Group on Agricultural Meteorology of Regional Association VI (Europe) of the World Meteorological Organization was held at the Headquarters of the Meteorological Service of the Republic of Hungary from 26 to 28 February 2001. Thirteen participants attended the meeting (please see Annex I).

1.2 The meeting was opened at 1000 hrs on Monday, 26 February 2001 by Dr. Zoltan Dunkel, Chairman of the Working Group for Agricultural Meteorology of RA VI on behalf of Mr Ivan Merisch, President of the Meteorological Service of the Republic of Hungary and the Permanent Representative of the Republic of Hungary with WMO. Dr. Dunkel welcomed the participants to the Hungarian Meteorological Service (HMS) and expressed his thanks to WMO for accepting the invitation to hold the meeting in Budapest and for providing support to organize the meeting. He also welcomed Dr. Ray Motha, President of the Commission for Agricultural Meteorology of WMO and thanked him for agreeing to participate in the meeting.

1.3 Dr. Ivan Mersich was able to address the group on Tuesday, 27 February. He welcomed the group to Budapest and stressed on the importance of the activities of the Working Group on Agricultural Meteorology to the RA VI Region. He felt that the group should be renewed for the next session with revised terms of reference. In this connection, he suggested that the group should focus on a few important priorities of specific interest to the Region and asked to group to evaluate carefully the priorities and include them in a few well defined terms of reference. Given the overproduction in agriculture in Europe, Dr. Mersich asked the group to reflect carefully on the future role for agrometeorology in Europe. Also it is important to review its role in the age of information world that is rapidly commercialising. Finally, Dr. Merisch wished the participants a pleasant stay in Budapest.

1.6 On behalf of the Secretary-General of WMO, M.V.K. Sivakumar, Chief of the Agricultural Meteorology Division, welcomed the participants and thanked the authorities of HMS, in particular Dr. Ivan Merisch, got hosting the meeting and for placing the excellent facilities of the HMS at the disposal of the Working Group (please see Annex II for a copy of his remarks).

1.7 Sivakumar referred to the discussions of the tenth session of the RA VI and the origins of the establishment of the Working Group and its terms of reference. The Association strongly supported the strengthening of training in agrometeorology and in applied meteorology in appropriate institutions in the Member countries and Dr. Sivakumar gave two examples of training conducted recently in Lubljiana, Slovenia and Tashkent, Uzbekistan.

1.8 One of the important tasks of the Group during the meeting was to review the draft reports prepared by the members of the Group and discuss the modalities for the preparation of the final report of the Working Group which will be presented by the Chairman of the Group at the next meeting of the RA VI which will be held in Budapest, Hungary in 2002. Dr. Sivakumar asked the Group to discuss the important issues in order to make proposals/recommendations to the Regional Association regarding the re-establishment of the Working Group and its future activities. Finally he wished the participants successful deliberations.
1.9 Dr Ray Motha, President of the Commission for Agricultural Meteorology thanked Dr Dunkel for the invitation to participate in the meeting (please see Annex III for a copy of his remarks). He felt that the group has the opportunity to keep the RA VI Region in the forefront of many of the new and innovative technologies that can be shared with other regions and the entire international community. One example is the work on phenology and how to incorporate phenological observation codes in a format for inclusion in the global data flow.

1.10 Dr Motha mentioned that pest and disease modeling, drought monitoring, irrigation management, frost protection, forest fire assessment are all extremely important issues that are world-wide problems but need regional solutions. He reviewed some of the activities of CAgM and some of the activities planned for the near future.

1.11 The Chairman of the Working Group, Zoltan Dunkel, thanked both the speakers for their remarks and promised that these remarks would be taken into account in the work of the session.

2. Organization of the Session

2.1 Approval of the Agenda

2.1.1 The chairman submitted the provisional agenda for consideration (please see Annex IV) which was approved by the group without any change.

2.2 Other organizational matters

2.2.1 Members of the Group introduced themselves giving a brief description of their background and current interests. It was agreed that the working hours for the meeting would be 0900 hrs to 1200 hrs and 1330 hrs to 1700 hrs.

3. Review of the Terms of Reference of the Working Group

3.1 The terms of reference of the working group as contained in Resolution 8 of the Twelfth Session of RA VI held in 1998 were examined. The following summary is presented according to terms of reference (a) to (g).

a) Review the scientific literature on the effect of climate and weather, especially during the ripening period, on the quality and storage capacity of grapes, spring barley, potatoes and tomatoes

3.2 Friesland raised a question was raised about what we mean by “storage capacity”. Motha suggested that we could perhaps use the expression “longivity in storage” rather than “storage capacity”. The group agreed with this suggestion.

3.3 Motha suggested that it would be valuable to use a standardized code for description of crop phenological stages. Zipoli agreed with the suggestion and mentioned that it would enable easy exchange of data.

3.4 Gat mentioned that if it is only to summarize the scientific literature, there should be no problem to deal with the term of reference as given. She also asked whether the literature review should be restricted to Europe. Sivakumar suggested that the primary emphasis should be on literature from Europe, but the group could draw upon important findings from other regions, where necessary.
3.5 Gat asked whether the review on grapes should deal with table grapes or grapes for wine. The group agreed that both kinds of grapes should be included in the review.

3.6 Zipoli asked as to how we define the quality. Friesland explained that it could be related to the product. Gat asked whether we should refer only to the crop in the open field or also in greenhouses. Sivakumar explained that it could depend on where the product comes from.

3.7 Friesland explained that he had not yet started work on this aspect and hence he could not comment at this stage how the work would be dealt with. Alexandrov mentioned that although quality and storage aspects are not his expertise, he would try to collect as much information as possible.

3.8 Zipoli asked as to what the goal is for the group with reference to this term of reference. Dunkel explained that the basic goal is to conduct literature survey for the few crops included in the term of reference.

3.9 Dobesch explained that in Europe, quality would mainly imply products from organic farming. In the Agricultural Meteorology and Forestry journal and others, a lot of literature is on climate change. He asked whether this aspect should be included in considerations of quality and storage aspects. There is a very strong argument to include this as well in the final report of the group.

3.10 Friesland suggested that the group could delete tomatoes since a lot of its production takes place under greenhouse conditions. Following the agreement of the group, Dunkel accepted the suggestion to delete tomatoes from this term of reference.

**b) Review the conservational aspects of environmental resources ie., climate, water and soils, and agricultural methodologies that describe quantitatively the pollution of water and air resources (eg., nitrogen application, use of fungicides and pesticides etc.,) and land management techniques**

3.11 Dunkel pointed out that this term of reference is a difficult one to deal with and he invited the group to suggest as to how one could address this aspect.

3.12 Kleschenko suggested that it may be necessary to subdivide this topic and offered to provide information on asymmetrical models to deal partly with the pollution aspects. The topic as given is of course quite wide.

3.13 Sivakumar felt that agrometeorological aspects of soil erosion should also be dealt with under this term of reference since information on land management techniques was included in this item.

3.14 Motha mentioned that Natural Resource Conservation Service in the United States offers considerable information on this topic and he provided the web address for this service: www.wcc.nrcs.usda.gov

3.15 Gat pointed out that this is a global problem and suggested that it should be brought to the level of the Commission. She mentioned that perhaps some preliminary information could be provided by the group at this point. Sivakumar suggested that the group may wish to provide at least a short report and provide guidance for the future working groups as to how this topic could be dealt with.
c) To summarize the recent developments in the use of remote sensing as a tool for the detection of droughts, forest fires, frost risks etc., and the potential for using the next generation of meteorological satellites

3.16 Dunkel mentioned that there are four volunteers in the group for this term of reference, hence there should be no problem in dealing with this item.

3.17 Gat suggested that we could add also the aspect of prediction of droughts in addition to their detection.

3.18 Zipoli pointed out that it would be useful to also include GIS as one of the tools and volunteered to contribute information on this aspect.

3.19 Sivakumar mentioned that in the Proceedings of the Expert Group Meeting on Drought Preparedness and Drought Management held in Lisbon in 2000, the paper by Felix Kogan also provides a lot of information on the use of remote sensing for detection of droughts.

d) To assess the cost/benefit ratios of the provision of agrometeorological information

3.20 Dunkel mentioned that there are four volunteers for preparation of reports on this topic. He suggested that the group could examine this further during presentation of the reports by the members.

e) To promote information campaigns and training of farmers’ associations and water resource managers regarding the use of agrometeorological forecasts and products through publications and multimedia approaches

3.21 Gat volunteered to prepare a case study from Israel on this topic. Dunkel suggested that she could prepare a questionnaire and circulate it to the members of the group. After receiving the comments from the members, she could finalize the questionnaire and WMO could help circulate the questionnaire.

3.22 Dunkel informed the group that there is one volunteer on this topic from the group.

f) To review the state-of-the-art of education in agrometeorology in Europe at the level of technical schools and universities

3.23 Guerreiro asked if this term of reference to the present or if the group should also address the future needs. Education in agrometeorology is not well organized and it is quite scattered. There are no specific degrees or courses in universities. There is a lot to be done in this respect.

3.24 Sivakumar informed the group about the initiative in WMO for organizing a workshop on education and training in agrometeorology in 2002 where representatives of universities and Regional Training Centers offering university level training in agrometeorology will be invited to discuss all aspects related to this issue. He also pointed out that the phrase “state-of-the-art” in this term of reference is very important as it is intended to provide a clear description of the current status in education and training and to what extent it addresses the felt needs in the Region.

3.25 Sivakumar also informed the group that a workshop will be organized by WMO in 2002 to address the issue of education in agrometeorology.

3.26 Dunkel informed the group that there is one volunteer on this topic from the group.

g) Summarize the status in Europe of weather-dependent agrometeorological growth simul-
tion models with potential for operational crop state monitoring and yield forecasting

3.25 Alexandrov suggested using the term “crop-weather simulation models” to replace weather-dependent agrometeorological growth simulation models and the group accepted this suggestion.

4. Report of the Chairman of the Working Group

4.1 Dunkel presented a short report on the activities of the group. He gave a copy of the letter received in December 1999 from the Director of the World Climate Programme regarding the constitution of the working group. Dunkel then contacted the members of the group and made a summary of the responsibilities assigned to the working group members by August 2000. He was able to find volunteers for all the terms of reference except item (b) of the terms of reference.

4.2 Dunkel referred the group to the report of the previous working group which he hoped would be well received by all members of CAgM. He felt that it would be useful to organize a meeting of the working group early enough to discuss the terms of reference, review the draft reports already prepared and decide on the structure of the final report. Hence the current meeting in Budapest was organized with financial assistance from WMO.

5. Presentation of reports

a) Review the scientific literature on the effect of climate and weather, especially during the ripening period, on the quality and storage capacity of grapes, spring barley, potatoes and tomatoes

5.1 Friesland in his presentation made some preliminary remarks regarding the research station on Agrometeorological Research in Braunschweig which is a division of the Business Unit Agriculture of the German Weather Service. Their main objectives are to attain further insights into the microclimate of canopies and to develop weather-driven agrometeorological models and IT-software for the Advisory Service Offices in Germany.

5.2 For work on point (a), on the quality and longevity of storage of grapes, spring barley and potatoes, Friesland presented a detailed work plan. The meaning of the phrase “quality of agricultural products” can be many fold and aspects of proteins, sugar percentage, starch etc., have to be examined. In addition to these invisible quality measures, more visible characteristics important for consumers and trade will also have to be looked at eg., absence or low level of direct damages from weather effects like hail, drought or frost, weather effects inhibiting full ripening, visible diseases and other unwanted spots etc., Estimation of quantitative dependence of product quality and storage capacity from weather by prognostic tools or models could serve as an outlook for trade and agriculture.

5.3 Regarding the next steps, Friesland proposed that in addition to the conservative literature search, internet research also will be undertaken. Later, scientists and institutes found in the literature survey will be contacted about missing information and about the latest developments in the field. Afterwards, any tools/models available can be tested in different regions for different crops. In the end, the report will summarize results for a wider area of scientists in agrometeorology and agriculture.
5.4 Sivakumar mentioned that some private companies dealing with food products may also have information on quality and storage aspects on their web sites.

5.5 Gat mentioned about the need to also look at positive aspects of quality, not just negative qualities as proposed in the work to be done. Friesland agreed with this suggestion. Gat also mentioned to look at aspects such as size, color etc.,

5.6 Sivakumar mentioned about a previous Technical Note published by WMO on quality which is included in the CD-ROMs recently brought out by WMO. He also suggested that ICARDA And CIP could be contacted for more information on barley and potatoes.

b) Review the conservational aspects of environmental resources ie., climate, water and soils, and agricultural methodologies that describe quantitatively the pollution of water and air resources (eg., nitrogen applicaton, use of fungicides and pesticides etc.,) and land management techniques

5.7 Kleschenko presented information on the percentage of land in Russian Federation that is affected by acid rain and the percentage of land affected by fluoride compounds. He also showed another map showing the percentage of land affected by heavy metals. Currently in the Russian Federation, fertilizer use decreased significantly and hence pollution problems in future may indeed be less severe. Models are being used currently to evaluate residual effects of fertilizers and pesticides in soils.

5.8 Kleschenko showed some of the preliminary conclusions of his study. Problems of conservational aspects coincide with the problems of sustainable agriculture. UNCED summit emphasized the need to examine these aspects. In this connection, Kleschenko referred to the recent paper by Sivakumar on Agrometeorology and Sustainable Agriculture.

5.9 Sivakumar suggested that contact be established with European Environmental Organization and offered to send the address details to Dunkel who could then contact him.

5.10 Zipoli suggested that meteorological models could be used to examine the aspect of how some pollutants are distributed over a given territory. Ozone is known to be responsible for reduction of yields. There are models at European scale with sparse resolution showing the dynamic distribution of pollutants, He offered to provide this information.

5.11 Gat informed the group about a project carried out in Israel on the influence of pollutants on agricultural crops. There are details available and she asked if this could be beneficial for the final report. Kleschenko welcomed the inclusion of this information in the final report.
c) To summarize the recent developments in the use of remote sensing as a tool for the detection of droughts, forest fires, frost risks etc., and the potential for using the next generation of meteorological satellites

5.12 Alexandrov informed the group that he would prefer to deal with item (g) of the terms of reference.

5.13 Ozalp presented a brief summary of the recent developments in the use of remote sensing as a tool for the detection of droughts, forest fires etc. These covered the following aspects: use of NDVI and satellite-derived soil moisture data for drought assessment, detecting forest fires using NOAA AVHRR data, flood monitoring using NOAA AVHRR data, global satellite update and land SAF, and next generation meteorological satellites applications in agrometeorology.

5.14 Dunkel asked if Turkey has experience in monitoring soil moisture with satellite. Ozalp mentioned that China has a lot of experience in this regard. Zipoli mentioned that Germany is involved with soil moisture monitoring using MSG data. The approach for using remote sensing data for soil moisture is mainly with microwave radar methods.

5.15 Ozalp could not find information on Land SAF from the Portugal Met Service webpage. Dunkel asked if Guerreiro could submit more information from Portugal on the Land SAF. She agreed to provide this information. Zipoli mentioned that they are part of the consortium and could provide information on Land SAF developments.

5.16 Dobesch mentioned that information on Landsat could be obtained from Eumetsat webpage, but it requires a password. However, the password can be requested and obtained on this web page.

5.17 Motha made an observation that some of the aspects described in the report could also be cross referenced in the term of reference (b).

5.18 Kleschenko presented a report on remote sensing data applications to agrometeorology. He mentioned that CAgM already published some reports on this aspect. Corresponding projects and applications of remote sensing in agrometeorology are well known eg., drought monitoring. Kleschenko showed some examples of drought forecasting in the Russian Federation using remote sensing information including NDVI. Maps of distribution of winter crop growth stage evolution using remote sensing information were prepared for Russian Federation and are being used quite widely. A promising area of remote sensing application is in the area of fire detection. Kleschenko then referred to WMO’s efforts to improve satellite system utilization which is based on a strategic vision, the long term strategic goal, major objectives and development of meteorological services to meet these objectives.

5.19 Zipoli agreed with the emphasis placed by Kleschenko and stressed in particular the applications in the area of forest fire forecasting. He illustrated this aspect with some of the work carried out in Italy. Remote sensing data could be used for the management of summer fires as the length of the dry period could be estimated and the risk for spreading of fires could be assessed. Dunkel referred to the work carried out by the previous Working Group on Agricultural Meteorology in this area which had been presented in the published report of the working group.
5.20 Gat asked if operationally the system used in Italy was helpful in stopping forest fires. Zipoli responded that in 2000, forest fires in Italy could be controlled significantly, thanks to the system developed to forecast these fires.

d) To assess the cost/benefit ratios of the provision of agrometeorological information

5.21 Dunkel mentioned that there were three submissions on this subject from the members.

5.22 Gat presented a report on the economic benefits of frost avoidance for Avocado in Israel. The economic success of subtropical crop production depends climatically on frost avoidance by topographically correct siting. Frost risk mapping on a regional scale and farm scale is an important tool for land use planning and crop management in agriculture and horticulture and is the basis for frost forecasting. The benefit to be gained by frost avoidance ie., by planting in the correct place is $ 225 per ha per year. The selection of a more favourable site shows a benefit of $ 46-57/°C/year. Advice was sought from economists in adopting the procedure used to calculate these cost/benefit ratios.

5.23 Gat felt that in view of the fact that only one example is given under this term of reference, perhaps the group might wish to eliminate this aspect in the final report. Dunkel agreed with the suggestion and felt that this aspect could be deleted.

5.24 Sivakumar presented a contrarian view that information on cost/benefit ratios of the provision of agrometeorological information is most important and is necessary to demonstrate the value of agrometeorological information to the end user. Motha also agreed. Dunkel agreed that although there is no possibility to make a big survey, members may wish to at least document what is possible to do.

5.25 Zipoli suggested that in the final report, the benefit for environment of using agrometeorological information could be included. What happened to the Adriatic sea because of nitrogen leakages into the sea had a tremendous impact on tourism.

5.26 Dunkel requested the members to carry out a little survey at home on cost/benefit ratios and submit a 1-2 page report.

e) To promote information campaigns and training of farmers’ associations and water resource managers regarding the use of agrometeorological forecasts and products through publications and multimedia approaches

5.27 Gat presented a report on this topic. She suggested that the basic available material should be as follows: publication of books according to regions/crops/climatic or agroclimatic parameters or problems; basic maps and tables for planning and other uses; agrometeorological maps presenting limiting factors; recent and real time data; ten day bulletins; articles on weather in agricultural journals; recorded messages; seminars and workshops for growers and meetings of diversity of growers etc., Promotion of the Institute and its image could be enhanced using pamphlets, web sites with info box for queries and computers in closed circle. Dissemination of information could be promoted through mail, fax, internet, computer to computer electronic linkage and through specific educational material. Gat also provided some general ideas such as exchange of agrometeorological knowledge in specific problems between various groups of regions eg., Mediterranean region, Scandinavian countries, Central European countries etc.,

5.28 Dunkel asked the working group members to conduct a survey at home in this subject and submit a short report.
f) To review the state-of-the-art of education in agrometeorology in Europe

5.29 Guerreiro explained that agricultural meteorology is an inter-disciplinary science and that there are no specific academic courses in agrometeorology in Portugal. In Agronomy curricula there are some courses in agricultural meteorology. In the Institute of Meteorology, there is some research conducted in Agricultural Meteorology. Collaboration between the Institutes in agricultural meteorology is inadequate. This seems to be a common problem in all the countries. There is insufficient training of users. Around the world, there are some universities offering degrees in agricultural meteorology (M.Sc and Ph.D). There is a lot of heterogeneity in the courses offered by Regional Training Centers. There is a need to sensitize the general public about the utility of agrometeorological applications. Guerreiro referred the group to the questionnaire she prepared and invited their comments.

5.30 Gat referred to the paper of Lomas, Milford and Mukala wherein it was concluded that education and training in agricultural meteorology currently is inadequate. Even if there are courses offered in agricultural meteorology in some universities, they tend to emphasize theoretical aspects rather than practical applications. At some RMTCs around the world, training in agricultural meteorology is offered. Gat agreed with the questionnaire prepared by Guerreiro to seek the needed information in Europe and made a number of suggestions to improve the questionnaire.

5.31 Guerreiro presented the questionnaire which includes questions on current status, future needs and remarks. Members of the working group made a number of suggestions to modify and improve the questionnaire.

g) Summarize the status in Europe of weather-dependent agrometeorological growth simulation models with potential for operational crop state monitoring and yield forecasting

5.32 Alexandrov made a presentation on summarizing the status of crop-weather simulation models in Europe. He proposed to review previous WMO reports, papers and books on crop weather simulation models applied in Europe. Development and dissemination of a questionnaire and contacting members of the working group and national, regional and international organizations as well as the model developers and members of e-mail conferences was proposed. These steps will be followed by searching and collecting literature on crop-weather models in standard and electronic libraries. The final task is the summarization of all collected information on crop-weather simulation models used in Europe.

5.33 Friesland asked if microclimate models will be included in the proposed work. Alexandrov responded that they will be included if they are related to operational crop state monitoring and yield forecasting as stated in the terms of reference for the group.

5.34 Gat asked as to what information will be provided in terms of crop models in the report. Alexandrov replied that in general information will be provided on the model name, version, operational system, model scale, model outputs and model applications in Europe.

5.35 Gat wondered if the proposed work will lead to a very voluminous report and suggested that it may be useful to prepare a summary for the report of the working group.

5.36 Dunkel felt that the proposed work is quite ambitious and hoped that Alexandrov will be able to achieve a fairly good rate of success in his work. Alexandrov clarified that the proposed questionnaire will be circulated only in an electronic form.
6. Preparation of the Final Report

6.1 The group was informed that the Thirteenth session of the Regional Association would be held in Budapest, Hungary in 2002 and that two reports were expected to be submitted under item 7.2 on the Agricultural Meteorology Programme. These include:

(i) Report of the chairman of the Working Group on Agricultural Meteorology

This brief report is to be prepared by the chairman himself and submitted to the president of the Association, with a copy to WMO. The report should include the following:

- Activities of the Group prior to the session of the group in Budapest (26-28 Feb 2001).
- Brief account of the meeting of the Group. This would be a summary of the report prepared for the session in Budapest.
- Any important activities carried out after this session.
- Brief summaries of the various contributions made by the individual members to the final technical report of the group
- Recommendations (eg., reestablishment of the RA VI Working Group on Agricultural Meteorology with renewed terms of reference or recommendations on follow-up activities on the XII-RA VI Working Group report).


This would be the finalized version of the Technical Report of the Group discussed during the session in Budapest and finalised for submission to the thirteenth session of RA VI and consideration for publication. This report should include references (bibliography), conclusions and recommendations.

6.2 It was agreed that the Secretariat should receive the original copies of the final technical report with clear diagrams, photographs etc., ready for publication. The report should be submitted as a hard copy, along with diskette (text in MS Word 6.0 along with computer files of line diagrams, maps etc., ), in order to facilitate early publication.

6.3 The following time table was adopted for submission of the final report:

(i) Final reports from members to the leaders of different terms of reference 31 December 2001

(ii) Final reports from leaders of different terms of reference to the chairman of the working group 31 January 2002

(iii) Chairman to send the final report to the President of the Regional Association, with a copy to WMO (see paragraph 6.2 above) 31 March 2002
7. Conclusions and Recommendations

The Working Group complimented the organizers for the excellent arrangements made for the meeting and for the good working atmosphere provided and made the following conclusions and recommendations.

7.1 Conclusions

7.1.1 The Working Group agreed that the presentations made by individual members addressed the terms of reference and that the discussion on all subjects was of a high standard.

7.1.2 The group felt that the meeting of the Working Group took place a bit late since the final report of the group is to be submitted within an year.

7.1.2 The group concluded that the terms of reference included too many items for one small working group to tackle and that some of the terms are far too general and not well focussed eg., terms (a) and (b).

7.2 Recommendations

7.2.1 Efforts should be made to ensure that all parts of Europe are represented in the Working Group. For example, at least one member from northern Europe (Scandanavia) and one from Western Europe (UK, France, Netherlands etc.,)

7.2.2 In future, an expert from the field of Environment should be invited to join the group to provide input in this important area. In addition, an Economist should be invited as a member or as an expert to cooperate in the studies on cost/benefit ratios of agrometeorological products and services.

7.2.3 In view of the fact that educational facilities in agrometeorology at various levels are insufficient in the Region and since such lack of facilities creates a "bottle neck" for the progress of agrometeorology in the Region, strong attention should be paid to improving such facilities in the Region.

7.2.4 Topics such as climate and forestry and climate and animal husbandry relevant to the Region should be included in the future working plans of the group.

7.2.5 It is strongly recommended that co-operation between NMHSs and the entire agricultural community in the member countries should be strengthened. This includes strengthening links with ministry of agriculture, grower associations, farmers, faculties of agriculture, agricultural insurance companies etc.,

7.2.6 In formulating future terms of reference for the group, it is important to take into account the most important problems facing the Region and also the professional background of the members. Currently the Foot and Mouth disease is causing a major problem and agrometeorological aspects of this disease may be of interest to the member countries.

7.2.7 The group agreed with the recommendation of the Acting President of RA VI, Dr Ivan Merisch to update the Guide to Agrometeorological Practices (Last Edition 1982) in order to develop agrometeorological units and functions according to a high standards. As CAgM is currently undertaking this task, it is important to ensure that essential topics of interest to RA VI are updated in the proposed revision of the Guide.
7.2.8 The Group recommended that a Working Group on Agricultural Meteorology for RA VI should be reestablished with renewed terms of reference which might include the following:

(a) To summarize recent developments in drought and flood management, and promote greater collaboration for early-warning and detection keeping in mind the user needs for this information;

(b) To review the current status, and recommend ways of strengthening phenological observation networks;

(c) To encourage and identify specialized training facilities across Europe with a cadre of specialists to develop and conduct unique agricultural meteorology training programme;

(d) To assess the impact of climate variability / climate change on agriculture across Europe.

8. Closure of the Session

8.1 M.V.K. Sivakumar thanked the President of the Hungarian Meteorological Service (HMS) for hosting the session and for keeping at the disposal of the Group all the necessary facilities. He thanked all the staff of HMS who have in various ways contributed to the successful organization of the meeting. He thanked the chairman and the members of the group for their contributions to the successful completion of the meeting.

8.2 The chairman of the working group thanked the Secretary-General of WMO for making it possible for the Working Group to meet. This has greatly facilitated the preparation of the report. He thanked all the members for their contributions and wished all the participants a safe journey to their various countries.

8.3 The meeting closed at 1130 hrs on Wednesday, 28 February 2001.
Opening Remarks

M.V.K. Sivakumar
Chief, Agricultural Meteorology Division
World Meteorological Organization

On behalf of the Secretary-General of WMO, Prof. G.O.P. Obasi, I have great pleasure in welcoming you all to this session of the Working Group on Agricultural Meteorology of the Regional Association for Europe (RA VI). We are fortunate in meeting here in Hungary, which is one of the greatest survivors of history and has a very special language originating from the Finno-Ugric tribe of languages. Hungary has a long history of learning with the first University founded in 1367 and the second in 1395. The first book was published in 1473 under the title Budai Kronika. While there are 10 million Hungarians inside this beautiful country, there are 5 million Hungarians living in other countries making very important contributions in science, technology, finance and art.

I hope during this week you will find time to visit this historic city of Budapest. This is the first town built by the Celts in the first century BC and became the most important city in Central Europe east of Vienna. In 1910, Budapest was larger than Rome, Madrid or Milan and was the world’s second largest center of milling industry.

I seize the opportunity to thank the authorities of the Meteorological Service of the Republic of Hungary, in particular, Dr. Ivan Mersich, Permanent Representative of the Republic of Hungary with WMO and the Acting President of RA VI, for agreeing to host this session of the Working Group and for placing excellent facilities at our disposal, even at such a short notice.

Dr. Zoltan Dunkel, President of this Working Group has been very active in contacting all the members of the Group and in liaising with the WMO Secretariat in organizing this meeting and in ensuring that all of us felt most welcomed in Hungary and I convey my sincere thanks to him.

I am indeed very pleased that Dr Ray Motha, President of the Commission for Agricultural Meteorology of WMO is with us here for this meeting. I am indeed grateful to him for agreeing to participate in this meeting, despite his busy schedule.

At its session held in Oslo, Norway in May 1994, the Regional Association VI established the Working Group on Agricultural Meteorology and the report of this working group had been published by WMO and you might have seen a copy of this excellent report. Considering the importance of the applications of meteorology to agriculture in the Region, at its Twelfth Session held in Tel Aviv, the RA VI re-established the Working Group on Agricultural Meteorology with renewed terms of reference. The group is to review scientific literature on the effect of climate and weather, especially during the ripening period, as the quality and storage capacity of grapes, spring barley, potatoes and tomatoes. The group was asked to review conservational aspects of environmental resources that describe quantitatively the pollution of water and air resources and land management techniques. The group was
requested to summarize recent developments in the use of remote sensing as a tool for the
detection of droughts, forest fires, frost risks etc. There is an ongoing debate on the cost/benefit
ratios of the provision of agrometeorological information and the group was asked to assess
these ratios. In view of the importance of education and training, the group was also asked to
review the state-of-the-art of education in agrometeorology in Europe at the level of technical
schools and universities. The final term of reference for the group asks for a summary of the
status of weather-dependent agrometeorological growth simulation models with potential for
operational crop monitoring and yield forecasting.

The Association strongly supported the strengthening of training in agrometeorology in
appropriate institutions in Member countries and recognized the Institute of Agrometeorology
and Environmental Analysis for Agriculture in Florence, Italy as a specialized centre for
training in remote-sensing applications to agrometeorology. I am pleased to report to you that
WMO organized two training events in the RA VI region since we met the last time. A Roving
Seminar on Crop-Yield Weather Modelling was held in Ljubljana, Slovenia from 6-17
September 1999. Four participants from Slovenia and ten from other Central and South-eastern
European countries participated at the roving seminar. A Roving Seminar on Data Management
for Applications to Agriculture was held from 8 to 19 November 1999 in Tashkent, Uzbekistan
at the kind invitation of the Main Administration of Hydrometeorology of Uzbekistan. The
seminar which was attended by 14 participants from the Hydrometeorological Center,
SANIGMI, Fergana Administration, Samarkand Administration, Surkhandarya Administration
and Karakalpak Administration of GLAVGIDROMET; two participants each from Kazakhstan,
Tadjikistan and Kyrgyz Republic.

WMO, in cooperation with the Secretariat for the United Nations Convention to
Combat Desertification (UNCCD), the UNDP Office to Combat Desertification and Drought
(UNSO) and the U.S. National Drought Mitigation Center (NDMC) organized an Expert Group
Meeting on Early Warning Systems for Drought Preparedness and Drought Management in
Lisbon, Portugal from 5-7 September 2000 at the kind invitation of the
Instituto de Meteorologia of Portugal. Nineteen experts from Brazil, China, Hungary, India, Nigeria,
Portugal, South Africa, Syria, United Kingdom and the United States of America participated in
the meeting. Proceedings of this meeting have been published and copies have already been sent
to the Members.

One of the important tasks for us during this meeting is to review the draft reports
prepared by the members of the Group and discuss the modalities for the preparation of the final
report of this Working Group which will be presented by the Chairman of this Working Group
at the next meeting of the Regional Association VI which will be held here in Budapest in
November 2002. This Group should also make proposals to the Regional Association regarding
the re-establishment of this Working Group to discuss and review new and emerging
developments in the field of agrometeorology in the region, taking into consideration recent
environmental conventions including the Framework Convention on Climate Change, the
Convention on Biological Diversity and the United Nations Convention to Combat
Desertification, and make recommendations on the future activities of the Group.

Reports of the Working Group on Agricultural Meteorology of the Regional
Association for Europe in the past have always been of a very high quality and have been well
received and appreciated by agrometeorologists and agriculturists. The last report of this group
provides adequate testimony in this regard. I am therefore confident that this Group also will
rise up to the expectations of the end users of our information. I hope that you will deal with the
above tasks and propose concrete suggestions for finalization of the draft contributions.
I wish you all very successful deliberations.
Meeting of the RA VI Working Group on Agricultural Meteorology
Budapest, Hungary, 26 to 28 February 2001

Opening Remarks

Ray Motha
President
Commission for Agricultural Meteorology

It is a great pleasure to be here in this beautiful, historic city of Budapest. I also want to thank the Meteorological Service of the Republic of Hungary and, especially Dr. Mersich, for hosting this meeting.

Thank you, Dr. Dunkel, for the invitation to participate in this working group session. I see some old friends and look forward to meeting some new friends here. It is always a pleasure to work with my colleague and friend, Shiv.

I appreciate the opportunity to share some thoughts and exchange ideas on our mutual efforts and new directions to ensure an efficient and modernized system of data, information, and technology transfer.

I reviewed the report from your last working group session. An observation is that you are a very active working group with a vast pool of scientific and technical resources, representing a wide range of expertise. You have the opportunity to keep this region in the forefront of many of the new and innovative technologies that can be shared with other regions and the entire international community.

One example is the work on phenology and how to incorporate phenological observation codes in a format for inclusion in the global data flow. Such information would be a valuable and much-needed contribution to research, modeling, and assessment efforts. Pest and disease modeling, drought monitoring, irrigation management, frost protection, forest fire assessment are all extremely important issues that are world-wide problems but need regional solutions. However, regional solutions can be adapted to other regions to expedite efficient technology transfer.

I personally want to express my appreciation to all of you for the extra effort being made by this working group toward achieving the goals set forth in your terms of reference.

Allow me to briefly review some of the Commission activities of the past year or so, and some of the activities planned for the near future. The intent is not to review every meeting or training session, nor to list all of the Commission working groups, but to highlight some of the areas where the Commission has focused attention.

- The first area of interest is a better understanding of extreme meteorological event affecting agriculture, forestry, cattle, and fisheries. As I mentioned earlier, drought and freeze episodes, as well as floods and heat waves all have significant agricultural impacts, and, finding better ways and means to cope with these events are crucial both in developing and developed agricultural systems. An RA III/IV Expert Group Meeting in Venezuela in July 1999 produced a useful proceedings on this topic.

- An International Workshop on “Coping with Drought in sub-Saharan Africa: Best Use of Climate Information” in Zimbabwe in October 1999 was a successful collaborative effort.
between UNDP/UNSO and WMO. The WMO Executive Council fully endorsed continued collaboration in the implementation of pilot projects to promote the best use of climate information at the farm level.

- Recognizing the advances in automated weather station technology, an International Workshop on “Automated Weather Stations for Applications in Agriculture and Water Resources Management: Current Use and Future Perspectives” was held in Nebraska in March 2000.

- An Expert Group Meeting on “Software for Agroclimatic Data Management” was held in October 2000.

Looking ahead, we are planning an Inter-Regional Workshop on “Improving Agrometeorological Bulletins”. We have asked the Presidents of each Regional Association to nominate two experts to participate in this meeting. An International Workshop on “ENSO and its Impact on Agriculture” is also being planned.

Finally, as we prepare for the next CAgM Meeting to be held in Slovenia in October 2002, we are planning an International Workshop on Reducing Vulnerability of Agriculture and Forestry to Climate Variability and Climate Change—very relevant issues of importance for the next century!

In summary, we have much work ahead of us as the issues become more complex and the demand for information increases. However, scientific progress and technological advances offer great opportunities to bridge the gaps between data management, information delivery, and technology transfer. I look forward to working with you so that we can accomplish some of these worthwhile goals through collaborative partnerships.

Thank you.
WORLD METEOROLOGICAL ORGANIZATION

REGIONAL ASSOCIATION VI

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2 Participants of Budapest meeting but not formal member of the WG

2 Participants of Budapest meeting but not formal member of the WG
REPORT OF THE CHAIRPERSON OF THE WORKING
GROUP ABOUT THE ACTIVITY OF THE RA VI WG ON
AGRICULTURAL METEOROLOGY WAS CARRIED OUT IN
1998-2002

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Introduction

The Regional Association VI of WMO decided to re-establish the Working Group on Agricultural Meteorology during its twelfth session was held in Tel-Aviv in 1998 (Resolution 8 XII-RA VI: Working Group on Agricultural Meteorology), with seven terms of references:

(a) To review the scientific literature on the effect of climate and weather, especially during the ripening period, on the quality and storage capacity of grapes, spring barley, potatoes and tomatoes;
(b) To review the conservational aspects of environmental resources, i.e. climate, water and soils, and agricultural methodologies that describe quantitatively the pollution of water and air resources (e.g. nitrogen application, use of fungicides and pesticides, etc.) and land management techniques;
(c) To summarise the recent developments in the use of remote sensing as a tool for the detection of droughts, forest fires, frost risks etc., and the potential for using the next generation of meteorological satellites;
(d) To assess the cost/benefit ratios of the provision of agrometeorological information;
(e) To promote information campaigns and training of farmers' associations and water resource managers regarding use of agrometeorological forecasts and products through publications and multimedia approaches;
(f) To review the state-of-the-art of education in agrometeorology in Europe at the level of technical schools and universities;
(g) To summarise the status in Europe of weather-dependent agrometeorological growth simulation models with potential for operational crop state monitoring and yield forecasting.

The terms of references based on the suggestion of previous Working Group on Agricultural Meteorology worked between 1994 and 1998. Eleven experts were nominated as core members to serve on the group: H. Dobesch (Austria), P. Nejedlik (Slovakia), H. Friesland (Germany), G. Zipoli (Italy), Z. Gat (Ms) (Israel), Y. Özalp (Turkey), V. Alexandrov (Bulgaria), A. Kleschenko (Russian Federation), R. Guerreiro (Portugal), A. Marroquin (Spain), I. Matajc (Slovenia). No new member was nominated after the 12th session of RA VI but one replacement was carried out. Mr. Nejedlik changed his post at home institute and O. Braslavská replaced him. Mr. Z. Dunkel (Hungary) designated as chairman of the working group. He served on his 3rd period as WG member and he was
the chair of the group for the second time. Unfortunately he was far from his home institute for 3 years as seconded national expert. A. Marroquin became ill and he was not able to participate in the activity of the Working Group. No replacement was done.

**Activities of the Group prior to the meeting of the WG was held in Budapest 26-28 February 2001**

The twelfth Session of RA VI was held in May 1998 but the WMO Secretariat informed the chairman formally only on 17 December 1999. It was problem because the chairman has got no information about the addresses of the members. Of course it would have been possible to collect the necessary information informal way. Nevertheless the chairman supposed to follow the formal way and waited for the official confirmation. Practically two years were lost. Maybe it was bad policy from the chairman’s side but his previous practice was that the WMO Secretariat will inform the chairman and the members as it was done in 1994.

Using the list of the members a circular was issued inviting for work-plan. The situation was the same as during the previous period of WG. The WMO practice is that only one WG meeting is sponsored during the four-year interval. This practice was criticised previously. The terms of references are established on the suggestion of the previous group. The members of the group change and the new member have to carry out the idea of the previous group. If two meetings would be held the new members could discuss about the general terms of references and establish a work plan would like to carry out. This work is very difficult to carry out by correspondence.

The Acting President of RA VI invited the group submitting report prior the 52nd Session of Executive Council. Very simple report was submitted. The fact of the establishment of the Working Group and the preliminary correspondence of the WG was reported and the ask organising two meetings for the Group. To avoid the problem arose from the late organisation of the WG meeting in 1997, the as early as possible meeting was suggested if only one meeting would be approved by WMO Secretariat.

Upon the circular was issued by the chairperson the members reported theirs interest in the terms of references of the WG. Nobody was interested in the conservation aspects of environmental resources (Ref. B). Four members wanted to deal with the remote sensing showing the change of the interest of ‘agrometeorology’ recently. Three members were interested in the Term G (weather-dependent agrometeorological growth simulation models with potential for operational crop state monitoring and yield forecasting). But four people showed interest in the estimation of cost/benefit ratio of agrometeorological information, finally only one short summary was submitted.

The Members were informed about the common interest in the second circular was issued by the chairperson in August 2000. The only meeting, after correspondence with WMO, was planned before the end of 2000. As a preparation of the meeting very intensive correspondence was carried out in the second part of 2000 preparing the meeting mainly electronically. Because of unexpected organisation problems the meeting was held in the end of February 2001. The Group and OMSZ were very happy that the President of CAgM accepted our invitation and was able to join the meeting. The Hungarian Meteorological Service (OMSZ) hosted the meeting. Thanks to the Secretary-General of WMO for making possible for the Working Group to meet. The meeting was held in Budapest 26-28 February 2001.
Brief summary of the meeting was held in Budapest 26-28 February 2001

The meeting of the Working Group on Agricultural Meteorology of Regional Association of WMO was held at the Headquarters of OMSZ (Hungarian Meteorological Service) 26-28 February 2001. Thirteen participants attended the meeting. The meeting was opened by the chair. Mr. Mersich, the President of the OMSZ and Acting President of RA VI, welcomed the meeting on the second day. On behalf of the Secretary-General, Mr. Sivakumar, the Chief of Agricultural Meteorology Division of WMO welcomed the participants. Mr. R. Motha, the President of the CAgM addressed the meeting as well. The work of the meeting started with a discussion about the term of references of the WG. The chairperson summarised the activity of the Group during the preparation of the meeting. The discussion was very intensive and effective. Finally the member agreed what part of the terms of references will be carried out. Because no volunteer was found for few terms the participants were agreed to omit these terms. Taking into consideration of the deadlines of WMO and the capacities of the WG members and the chairman the Group agreed that the final reports from members to the leaders of different terms of reference will be send before 31 December 2001, the final reports from leaders of different terms of reference to the chairman of the working group not later then 31 January 2002, and the chairperson should send the final report to the President of the Regional Association, with a copy to WMO not later then 31 March 2002.

The general conclusions of the Working Group meeting

The participants were agreed that efforts should be made to ensure that all parts of Europe are represented in such a type Working Group. For example, at least one member from northern Europe (Scandinavia) and one from Western Europe (UK, France, Netherlands etc.,). In future, an expert from the field of environment should be invited to join the group to provide input in this important area. In addition, an Economist should be invited as a member or as an expert to co-operate in the studies on cost/benefit ratios of agricultural meteorology products and services. In view of the fact that educational facilities in agrometeorology at various levels are insufficient in the Region and since such lack of facilities creates a ‘bottle neck’ for the progress of agrometeorology in the Region.

The members strongly recommended that co-operation between NMHSs and the entire agricultural community in the member countries should be strengthened. This includes strengthening links with ministry of agriculture, grower associations, farmers, faculties of agriculture, agricultural insurance companies etc.,

In formulating future terms of reference for the group, it is important to take into account the most important problems facing the Region and also the professional background of the members. Currently the Foot and Mouth disease is causing a major problem and agrometeorological aspects of this disease may be of interest to the member countries. Among others the group agreed with the recommendation of the Acting President of RA VI, Dr. Mersich to update the Guide to Agrometeorological Practices.

The Group recommended that a Working Group on Agricultural Meteorology for RA VI should be re-established with renewed terms of reference which might include the following:
(a) To summarise recent developments in drought and flood management, and promote greater collaboration for early-warning and detection keeping in mind the user needs for this information;
(b) To review the current status, and recommend ways of strengthening phenological observation networks;
(c) To encourage and identify specialised training facilities across Europe with a cadre of specialists to develop and conduct unique agricultural meteorology training programme;
(d) To assess the impact of climate variability / climate change on agriculture across Europe.

Activities carried out after the meeting

Two questionnaires were issued in the frame of the Working Group activity as WMO questionnaire distributed in the RA VI Region. The first one dealt with the education problem and was developed and evaluated by R. Guerreiro (Portugal) and Z. Gat (Israel). The second one concentrated on the plant-growth models. It was developed and evaluated by V. Alexandrov (Bulgaria). The evaluation of both questionnaires are built in the submitted papers for the final report of WG.

The chairperson partly as representative of RA VI participated in the CAgM ad-hoc working group meeting ‘Inter-Regional Workshop on Improving Agrometeorological Bulletins’ was held in Barbados in October 2001. A questionnaire was issued by the chairman about the agrometeorological bulletins in RA VI region. The evaluation of this activity was submitted for the proceedings of the ad-hoc working group.

The members according to the decisions of the Budapest working group meeting submitted the chairperson theirs report on time. The chairman edited the submitted papers and completed the Final Report of the WG. The report contents more then 200 pages and was sent to the WMO on 15 April 2002.
SECTION II

TECHNICAL REPORTS
One of the serious problems of environmental control is associated with the increased application of chemicals in agriculture and the total increased nature load. Soil, being the most powerful natural accumulator, can accumulate pesticides, radionuclides, heavy metals and other pollutants that results in soil microflora variations and, hence, variations in soil fertility: accumulation of pesticide residuals in agricultural products; atmospheric contamination on all scales, from local to global one; reservoir contamination with undesirable variations in water quality and adverse impact on aquatic ecosystems.

From the standpoint of environmental control, the regulation of chemical application should involve a prognostic model of their behavior in an agricultural field, a watershed and a region which allows to forecast the expected concentrations of chemicals and their metabolite residuals in all media.

In the world, including Russia, such models are being developed from the 70th and they are continued to be improved. A dynamic model [3] that allows to calculate the pesticide content in soil and pesticide runoff into watercourses was developed under the guidance of Dr. V.A.Borzilov (Science Production Association “Typhoon”) in Roshydromet. It is based on the Agricultural Runoff Management (ARM) model developed from the Stanford model (USA) [1,2,5].

In a way of realization, the Stanford model is a simulation one which uses a set of empirical relations with the account of space inhomogeneity over a watershed area. It is intended for calculating water balance from the 5-min rain intervals and diurnal mean evaporation values. The SPA “Typhoon’s” model represents the Stanford runoff model supplemented with the submodels of “solid” runoff and sorption, volatilization and transformation processes. The last model versions are supplemented with the submodels that take into account snow melting and other processes allowing to consider the removal of inorganic fertilizers.

This model involves the following prerequisites. Water, falling on the soil surface in a form of precipitation or meltwater, is redistributed depending on the structure and the initial watershed conditions according to different runoff components forming the surface runoff, intrasoil runoff, downflow to groundwater and upflow to the atmosphere. When moving, water transports the dissolved pesticide. The pesticide content in water and soil at any point is specified by the equilibrium values of water solubility and sorption isotherms. Besides this runoff, depending on the soil surface conditions and precipitation intensity, there may be the solid runoff which washes off the sorpted pesticides from a watershed. In addition to the above factors stipulating the decrease of pesticide content in a watershed, the model considers also
pesticide evaporation from the soil surface and their degradation under the action of chemical, photochemical and microbiological processes.

Soil profile inhomogeneity is simulated by four zones of pesticide accumulation. Various accumulation zones are divided into the surface, the upper, the lower and the groundwater ones. They are necessary to determine exactly the water volume and the soil mass involved in the pesticide-soil interaction. The surface runoff is formed in the area without water infiltration. In the lower zone there is the intrasoil runoff which together with the surface and the groundwater ones forms the total runoff. Evaporation in every zone and water infiltration from the upper zone into the lower one and then into the groundwater zone are considered. Horizontal inhomogeneity of the watershed surface is simulated by a simple infiltration scheme. A watershed is divided into five zones, the area of which is 20% of the total watershed area. The zonal division is based on a different infiltration capacity of watershed sections. The zones with low infiltration capacity are the primary sources of the surface runoff, the suspended drift discharge (“solid” runoff) and the pesticide loss.

A solid runoff submodel considers the formation of suspended drifts (muck and clay fractions) as a result of soil aggregate destruction under the action of raindrops. This process depends on the precipitation layer, soil properties and the degree of plant cover:

\[ R(t) = (1 - V_c(T)) K_R P(t)^{b_1}, \]  \hspace{1cm} (1)

where \( R(t) \) are the small soil fractions, formed in the rain interval \( t, t/h? \); \( V_c(T) \) is the watershed area, covered with plants, as a function of the vegetation period duration; \( K_R \) is the coefficient of aggregate destruction (depends on soil properties); \( P(t) \) is precipitation during the time interval \( t \) in mm; \( b_1 \) is the precipitation intensity index.

The transport of suspended drifts by the surface runoff is described by

\[ S(t) = K_s S_R(t) H(t)^{b_2}, \]
\[ E(t) = S(t) F_s, \] \hspace{1cm} (2)

where \( S(t) \) is the discharge of suspended drifts in the surface runoff, \( t/h? \); \( K_s \) is the coefficient of suspended particle capture; \( S_R(t) \) is the soil particle reserve by the time interval \( t, t/h? \); \( H(t) \) is the surface runoff layer in the time interval \( t, mm \); \( F_s \) is surface runoff part reaching the water course in the time interval \( t \); \( E(t) \) is the suspended particle loss with the solid runoff in the time interval \( t, t/h? \); \( b_2 \) is the empirical constant.

A sorption submodel is based on the supposed existence of sorption equilibrium at any point and at every time moment, i.e. on the supposition that the specific periods of transport are much longer as compared to the specific sorption periods. It allows to confine oneself to the sorption isotherm only:

\[ X_{equil}/M = K_F C_{equil}^{1/N} + F/M, \] \hspace{1cm} (3)

where \( X_{equil}/M \) is the pesticide amount adsorbed per soil weight unit, mg/g; \( F/M \) is the pesticide amount, not subjected to desorption, per soil weight unit (the term \( F/M \) is associated with the cation-anion exchange capacity of pesticide); \( C_{equil} \) is the equilibrium concentration in solution, mg/ml; \( N \) is the degree index; \( K_F \) is the distribution coefficient (depends on the concrete combination of physical-chemical properties of soil and pesticide).
Equation (3) is the standard Freidlich isotherm with the added empirical term describing the irreversible pesticide binding with soil. Parameters, involved in the sorption submodel, require laboratory assessment; at the first stage of operations with the model these may be the parameters estimated for every specific soil. Later on it is necessary to establish the functional bonds between the Freidlich isotherm parameters and the specific physical-chemical soil properties (e.g. organic content, pH and etc.).

A degradation submodel is very complex in its physical nature as it includes many processes: volatilisation, microbiological, photochemical and chemical degradation. Earlier attempts to isolate if only volatilisation proved to be unsuccessful and now degradation is approximated by the first-order kinetics

\[ C' = -K_D C, \quad (4) \]

where the degradation rate constant \( K_D \) considers the whole totality of processes, therefore it is difficult to say anything about the \( K_D \) value a priori, as it depends on a great number of factors. Therefore the opportunities of a model can be estimated before operations. The model should give more or less correct values of liquid (dissolved in water) and solid (sorbed on soil particles) pesticide runoff into the water bodies, approximately estimate the reserve in a watershed (the vertical distribution should be given more precisely), however, it does not describe pesticide ingress into the atmosphere and plants.

For this model to be in operation, a series of meteorological, topographical and hydrological data is necessary. All meteorological data are diurnal mean values, except air temperature and precipitation. The model is a continuous simulation one, therefore the period of meteorological data recording should correspond to the simulation period.

To calculate a water balance and, on its basis, a pesticide mass balance, it is necessary to know the working parameters of a pesticide transport model. A model provides for the diurnal, monthly and annual data on a water balance and a pesticide mass balance. The mass and the content of a pesticide found in various soil zones are calculated alongside with the pesticide mass lost as a result of surface runoff and total degradation.

After computer realization, a model was calibrated under specific field conditions to assess its parameters under a great variety of climate, soil and water quality conditions. The application of a dynamic simulation model with prolonged calibration under different soil-climate conditions gives correct visualization of the relationship between different components of a hydrological cycle and water quality in the specific watershed after toxicant use. To use this model in real forecasting for an agricultural region, the following is essential:

1) model calibration under the conditions of regional watersheds aimed at creating the map of hydrology and solid runoff submodel parameters; the solution of this problem is impossible without a database including all essential input and output data on the model;
2) development of sorption and degradation submodels to establish the relationships between these model parameters and measured environmental parameters;
3) model elucidation: consideration of the kinetics of solubility and sorption, sorption irreversibility.

This program realization allows to forecast the behaviour of new pesticides only based on a laboratory experiment. To forecast a behaviour of radionuclides ingressed in the environment after the Chernobyl accident, the SPA “Typhoon” has developed three mathematical submodels: the model of vertical migration (deepering) of a radionuclide found in the exchangeable form; the model of radionuclide washoff from a watershed which describes its
Ingress in a river network in the exchangeable and irreversibly sorbed forms and the model of radionuclide distribution over a river network which considers the processes of advective transport, dispersion, sedimentation, adsorption, turbidity, diffusion exchange with the sediment layer.

A series of special experiments has been carried out to assess the model parameters that allowed to use the models for predicting radiation situation near the CNPP. A vertical migration in soil is to be considered for the exchangeable form of radionuclides only. By denoting the concentration of this form in soil solution as $C_w$ and the concentration on soil particles, referred to the soil mass, as $C_s$, the vertical migration (the z axis is directly downward) can be described by

$$\frac{\partial}{\partial t} [K_p d + T] C_w + \frac{\partial}{\partial z} T v_w C_w = \frac{\partial}{\partial z} (D?/?z TC_w) + d(t) d(z) a A(5)$$

with the boundary conditions

$$-D \frac{\partial}{\partial z} C_w \bigg|_{z=0} + v_w C_w = 0, \quad z = 0,$$

$$C_w = 0, \quad z = 8, \quad C_w = 0, \quad t < 0,$$

where $K_p = K_p(T) = \frac{?}{C_w}$ is the distribution coefficient, $d$ is the soil density, $T$ is the total water content, $v_w$ is the vertical water rate component, $D$ is the dispersion coefficient, $a$ is the fraction of exchangeable forms in the radionuclides settled, $A$ is the surface contamination density.

Model experiments have shown that when applied for forecasting, this model allows to determine the river radionuclide content in a contaminated region from laboratory and runoff experiments. This team of SPA “Typhoon” researchers (V.A.Borzilov, O.I.Voszhennikov, I.V.Dragolyubova, M.I.Novitsky) has developed a physical-mathematical model of chemical migration and transformation in the surface soil layer [4].

The model includes all processes of solution, transport, sorption and transformation without any supposition on the simultaneous chemical solubility and sorption equilibrium. This model considers the intersoil agent application as crystals of the similar initial radius $R_0$, the concentration of which or a number of crystals per soil volume is $n$. The supposition on radius equality is not principal and used for the sake of simplicity. The concentration $n$ is linked with the initial chemical concentration $C_0$ (chemical mass per soil volume unit) by a simple relation

$$n = 3C_0/4pR_0^3 ????$$

where $???$ is the density of a chemical in the crystalline state.

Some time after the application, a chemical in soil will be found not only in the crystalline state, but also in dissolved, sorbed and gaseous ones. According to these states, the concentrations $C_a$, $C_w$ and $C_s$, referred to the volumes of soil solution, soil skeleton and free threshold area, are introduced. Then with the account of chemical transport in soil, only in gaseous and dissolved states, the following set of equations (on the assumption of horizontal homogeneity the z axis is downward, the co-ordinates origin is the surface) is given:

$$\frac{\partial}{\partial t} [(g - ?) C_a + ? C_w + (1 - g) C_s] =$$

$$= \frac{\partial}{\partial z} [D_a \frac{\partial}{\partial z} C_a + D_w \frac{\partial}{\partial z} C_w \pm v ? C_w] + 4pRn (D_a K_H^{-1} + D_w) (C_{w0} - C_w) \cdot ? C_w , \quad (7)$$
(1 − g) C_s = B (C_w − K_p^{-1} C_a), \tag{8}

K_H^{-1} = C_a / C_w. \tag{9}

R = - D_a K_H + D_w / R ? (\overline{C_w} - C_w). \tag{10}

Here R is the chemical crystal radius, g is the soil porosity, ± v is the water flow rate downward (upward) in a soil profile, C_w is the saturated chemical concentration in soil solution, B- is the typical time of sorption, K_H is the Henry constant; K_p is the distribution coefficient in the water-soil skeleton system, ? is the volume water content in soil, ? is the rate constant of chemical decomposition in a water phase. The effective diffusion coefficients D_a and D_w are connected with the molecular chemical diffusion coefficients D_{am} and D_{wm} in air and water, respectively, as follows

\begin{align*}
D_a &= D_{am} (g - ?)^{10/3} \cdot g^{-2}, \\
D_w &= D_{wm} \cdot ?^{10/3} \cdot g^{-2}. \tag{11}
\end{align*}

A set of equations (7)–(10) describes the processes of crystal dissolution in soil solution (the penultimate term in the right-hand part of Eq.(7) and Eq.(10)), chemical transport in the pore air and soil solution, its sorption by the soil skeleton and transfromation in a water phase. It is considered that there are no transformations in other phases. From the viewpoint of a model it is not principally, however, it is stipulated by the data used later. The terms, describing dissolution, involve the total coefficient D_a K_H + D_w. It is caused by the fact that mass transfer is present in both phases as the size of crystals is assumed to be much greater than that of pores.

A set of equations is solved only for the upper soil layer as it is assumed that differentiation of processes is essential just here. Boundary conditions are prescribed by the ARM model. Accordingly, the chemical flux j_p at the lower boundary (with the upper layer depth L) [3] is

\[ J_p \bigg|_{z = L} = J_{ARM}, \tag{12}\]

where J_{ARM} is the flux specified by the ARM model. In virtue of limited soil evaporation at the upper boundary at the cost of mass transfer in soil the condition takes the following form

\[ C_a \bigg|_{z = 0} = 0. \tag{13}\]

So, in case of evaporation this description is suitable only for intrasoi application of this chemical. In case of surface application a set (6)-(13) should be supplemented with the equations of chemical transport in the atmosphere.

A model can be used independently in the ARM model when calculating the surface runoff with no any assumption on the immediate dissolution and sorption. Results of model verification in a watershed of 45 ha allowed to determine the integral runoff coefficients of chemicals in different forms: crystalline, dissolved and sorpted and can be used to obtain the integral runoff coefficients and chemical ingress in a river system. Further development of theoretical and experimental activities on studying the pollutant migration in a soil cover and their plant ingress in root and aerial ways allowed to develop the complex models of crop yield formation which describe both the effect of a hydrological regime and anthropogenic contamination on the formation of crop amount, quality and ecological purity [8].
The formation of crop amount, quality and ecological purity is considered as the totality of synthesis, decomposition and mutual transformation of principal biomass components, pollutant accumulation by plants. By crop amount the accumulation is meant of agriculturally valuable dry biomass, i.e. grain, by crop quality – protein and starch content in grain, by ecological purity – radionuclide and heavy metal content in grain.

A model consists of ten blocks: input data, radiation and water-heat regimes of plant cover, mineral plant nutrition, photosynthesis, respiration, pollutant accumulation by plants, growth and development and grain. To describe the photosynthesis of all organs (leaves, stems, flocules) the formula of Yu.K.Ross [9] and G.V.Menzhulin [7] is used which is modified with the account of photosynthesis effect of mineral nutrition, plant development phase, temperature regime and crop water supply. Considered are the amount of easily hydrolized nitrogen, mobile forms of phosphorus and potassium at the beginning of vegetation as well as the amount of nitrogen, phosphorus and potassium applied with mineral and organic fertilizers. Plant respiration and support losses are simulated according to the McCree concept [6]. The formation of a free nitrogen fund is described by nitrogen absorption $N_{abs}$ from soil and tissue decomposition products $N_{dec}$ with the account of renewal losses $N_{ren}$ of vital tissue structures.

$$\frac{dN}{dt} = N_{sorp} + N_{dec} - N_{ren}. \quad (14)$$

The free radionuclide fund in plants $dA_{free}/dt$ is formed as a result of radionuclide ingress in plants in the root $A_{root}$, the aerial $A_{aer}$ ways as well as transport from ageing tissues $A_{age}$.

$$\frac{dA}{dt} = A_{root} + A_{aer} + A_{age}. \quad (15)$$

Radionuclide ingress into plants from soil in a root way $A_{root}$ is estimated with the Langmuir isotherm

$$A_{root} = a_1 A_{soil}/(b_2 B_{soil} + 1), \quad (16)$$

where $A_{soil}$ and $B_{soil}$ are the concentrations of radionuclide and macrolelement-analog in soil in a form accessible for plants, respectively; $a_1$, $b_2$ are the Langmuir isotherm coefficients;

$$a_1 = b_1 B^j_p$$

The value of aerosol plant contamination with radionuclides is proportional to the radionuclide content in air and the size of the aboveground plant part. The heavy metal fund in plants $dH_q/dt$ is formed as a result of root accumulation of heavy metals in soil and aerosol contamination with heavy metals $H_{aq}$. The rate of heavy metal ingress into plants through roots is described by

$$H_{q}^{root} = [(a_{q}^{absor} H_{soil}^{q} m_{q})/a_{q}] \times a_{absor}, \quad (17)$$

$q$ ? Cd, Cu, Hg, Pb, Zn, F,
where $H_{q}^{\text{root}}$ is the rate of heavy metal accumulation in plants; $a_{q}^{\text{absor}}$ is the root absorption capacity; $H_{q}^{\text{soil}}$ is the concentration of mobile forms of the $q$-th heavy metal in soil; $a_{r}$ is the root radius; $a_{\text{absorp}}$ is the function of soil temperature impact on root microelement absorption; $q$ is the heavy metal form. Plant contamination with heavy metals through aerosols is described by

$$a_{\text{aer}} f = R_{A} V_{g} \bar{A}_{\text{aer}} m_{\text{above}},$$  \hspace{1cm} (18)

where $R_{A}$ is the coefficient of plant contamination with aerosols; $V_{g}$ is the effective rate of radionuclide settlement on plants.

The sulfur fund formation in plants $dS_{\text{free}}/dt$ proceeds at the cost of its compound ingress from soil $S_{\text{root}}$ and the atmosphere $S_{\text{aer}}$ through the leaf surface. Plant root sulfur absorption from soil in a form of sulphate follows the Michaeillis-Menthen kinetics

$$S_{\text{root}} = [S_{\text{max}}^{\text{sorp}} (\overline{S}_{\text{soil}} - \overline{S}_{\text{min}})/(K_{S_{\text{sorp}}}^{S} + (S_{\text{soil}} - S_{\text{min}}))] ^{a_{\text{sorp}}},$$  \hspace{1cm} (19)

where $S_{\text{max}}^{\text{sorp}}$ is the maximum rate of sulphate absorption by plant roots; $\overline{S}_{\text{soil}}$ is the sulphate concentration near the root surface; $\overline{S}_{\text{min}}$ is the minimum sulphate concentration in soil solution below which the absorption stops; $K_{S_{\text{sorp}}}^{S}$ is the Michaeillis-Menthen constant.

The atmospheric sulfur ingress into plants takes place when gaseous or liquid sulfur dioxide penetrates via the stoma apparatus or leaf cuticle. There are two parallel ways of sulfur transport: stomata or cuticles. The pesticide fund in plants is a balance between aerial and root contamination as well as pesticide degradation in plant tissues. Pesticide absorption is described by a formula similar to Eq.(19).

Aerosol plant contamination sometimes is observed in chemical crop treatment. Pesticides are sorpted by the leaf, stem and floescule surface. If plants are cultivated on soils with residual pesticides, the contamination is stipulated mainly by root absorption. Pesticide penetration proceeds at the leaf (stem, floescule)-air interface through a cuticle. This process is described by the Freindlich isotherm equation. Root absorption of pesticides depending on their content in soil solution is described by a similar equation. To describe the distribution of pollutants absorbed by a plant, the following set of equations is given:

$$d G_{x}^{i}/dt = \beta_{x}^{i} d G_{x}^{\text{sorp}}/dt - w_{x}^{i} G_{x}^{i},$$

$$d G_{x}^{p}/dt = \beta_{x}^{p} d G_{x}^{\text{sorp}}/dt + \sum_{i} \lambda_{x,i}^{p} w_{x}^{i} G_{x}^{i},$$

$x$ ? $A^{i}$, $H_{s}$, $S$, $D_{h}$, where $\beta_{x}$ and $w_{x}$ are the functions of pollutant distribution during a vegetation growth and their redistribution during a reproduction growth, respectively.

A suggested model allows the quantitative assessment to be performed of expected variations in productivity and ecological crop purity depending on the atmosphere and soil pollutant content, agrometeorological (extreme, in particular) conditions and culture farming. With this model based on standard agrometeorological data as well as data on soil and atmospheric pollutant contamination it is possible to calculate and to forecast the ecological crop purity and the phytotoxic crop impact of pollutants.
A model was tested under soil-climate conditions of Polesje(Ukraine). The calculations have been performed to study the expected $^{137}$Cs radionuclide accumulation in grain and straw of winter wheat under different moistening conditions. Numerical experiments have been also carried out in the south chernozem region of Ukraine. Assessments were performed for three scenarios of weather conditions: 1) averaged many year conditions with 50% precipitation – “usual” years; 2) weather conditions with 20% precipitation - “dry” years; 3) “wet” years – 80% precipitation. The results show that heavy metal accumulation in the crop yield at similar irrigation norms proceeds rather intensively in “dry” years, somewhat less intensively in “usual” years and most slowly in “wet” ones. The heavy metal content in grain decreases as the irrigation norm increases. The comparison of these data and the maximum permissible concentrations(MPC) in food products (bread) shows that even in “usual” years the content of mercury, cadmium and lead in the winter wheat grain exceeds MPC in food products by 1.5–2 times. In “wet” years this excess is less and it is most significant (up to 1.5 – 3.5 fold) in “dry” years. So, the described models allow to carry out numerical experiments in order to study the effect of different soil-climate and weather conditions on crop productivity and ecological crop purity.

References


THE RECENT DEVELOPMENTS IN THE USE OF REMOTE SENSING AS A TOOL FOR THE DETECTION OF DROUGHTS, FOREST FIRES ETC., AND THE POTENTIAL FOR USING THE NEXT GENERATION OF METEOROLOGICAL SATELLITES

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1. INTRODUCTION

This report summarizes the recent developments in use of remote sensing as a tool for monitoring vegetation and detecting and risk assessments of natural hazards, including droughts, forest fires, floods and describes present status and potential use of the next generation of meteorological satellites. The report is compiled from studies which included examples of most common applications in the above fields.

In the report, recent developments in the use of remote sensing as a tool for detecting natural disasters and use in agrometeorological applications cover the following aspects:

- Use of NDVI and satellite-derived soil moisture data for drought assessment
- Detecting forest fires and risk assessment using NOAA AVHRR data
- Flood monitoring using NOAA/AVHHR data
- Global Satellite Update
- Next Generation Meteorological Satellites Applications in Agrometeorology
- Land SAF (Satellite Application Facility)

1.1. Spectral Characteristics of Vegetation

The spectral characteristics of vegetation mainly depend on the leaf structure. The upper and lower epidermis of leaves have a protective function with regard to the interaction with electromagnetic radiation, the mesophyll region being the most important part. The spectrum of plant leaves can be divided into the following distinctive ranges:

1. The range between 0.4 μm and 0.7 μm (visible band) is characterised by very low reflectance due to intense absorption of the incident radiation by pigments in the plant: All pigments absorb at 0.43 - 0.45 μm (blue), and chlorophyll has an additional absorption band at about 0.65 μm (red). Therefore, a small reflectance peak exists at about 0.55 μm band (green).

2. The range between 0.7 μm and 1.3 μm is characterised by very little absorption and high reflectance. The high reflectance peak in this range is caused by the mesophyll structure, which causes multiple reflection of near infrared radiation at cell walls.
3. The range between 1.3 µm and 2.6 µm is characterised by pronounced minima.

1.2. Factors Affecting Vegetation Spectrum

Many factors affect the spectral characteristics of vegetation, including vegetation type, phase in the growing period, and plant condition. Hence, by monitoring the spectrum inferences it is possible to draw information about all of these characteristics.

On the Advanced Very High Resolution Radiometer (AVHRR), the most useful channels for vegetation monitoring are channel 1 (Ch1) and channel 2 (Ch2). Channel 1, with wavelength 0.58 µm-0.68 µm, is the chlorophyll absorption band, while channel 2, with wavelength between 0.725 and 1.1 µm, is the high reflectance band for vegetation. These channel performances correspond closely to the actual radiative properties of leaves. Therefore, vegetation indices derived from meteorological satellite data are amongst the most important in remote sensing and form the basis of many applications.

1.3. Normalised Difference Vegetation Index (NDVI)

The NDVI has been shown to be a good indicator of photosynthetic activity of terrestrial vegetation and of large scale ecosystem distributions (Kidwell, 1990). The basic method is very simple, although care has to be taken in interpreting the data and many corrections to the basic data are needed for optimal use. The method can be applied to instrument data from many satellites but for many purposes the data from meteorological satellites are extremely useful. This is a consequence of the fact that these satellites observe the entire planet twice in each 24 hour period. This not only implies extensive coverage but also that it is possible to obtain frequent images during the growing season, even in the presence of variable cloud cover - if it is cloudy on one day it may be clear on subsequent days. This is a considerable advantage over instruments with less frequent imagery of particular regions, even though they may have higher horizontal and spectral resolutions.

The NDVI takes advantage of the relatively unique spectral reflectance characteristics of green vegetation. AVHRR channel 1 (0.58-0.68 um) senses an area of the spectrum which shows an inversely proportional relationship to the amount of chlorophyll in the plant canopy, and consequently shows an inverse relationship to the amount of green biomass present. More simply, healthy, green (photosynthetically active) vegetation absorbs red light. As the density of the vegetation increases, the amount of red light reflected decreases. Definition of NDVI is given by;

\[
NDVI = \frac{(Ch2 - Ch1)}{(Ch2 + Ch1)}
\]

By taking the difference between channels 2 and 1, the NDVI shows a strong positive correlation to the amount of photosynthetically active biomass. By dividing the channel 2 and 1 difference by the sum of both channels, the values are normalised between -1 and +1 for the amount of incident radiation, somewhat reducing the impact of factors such as slope and aspect which would otherwise skew the resultant NDVI value (Kidwell, 1990). The values of 0.5 indicate dense vegetation and values smaller than 0 indicate no vegetation.
2. Use of satellite-derived soil moisture data for drought assessment

Another method used to assess drought using satellite data is monitoring soil moisture. There are several methods for soil moisture derivation from AVHRR data but most of them are experimental and cannot yet be used routinely (EUMETSAT CGMS, 1999). One of the methods is Thermal Inertia (TI), which is based on the principle that soil moisture is directly proportional to thermal inertia. Thermal inertia can be derived from AVHRR data using the following formula:

\[ P = \frac{c.(1-A)}{(T_{\text{day}} - T_{\text{night}})} \]

Where, \( c \) is an experimental coefficient, related to soil type. \( A \) is the albedo of the land surface, calculated as:

\[ A = 0.526 \times \text{Ch1} + 0.47 \times \text{Ch2} \]

and \( T_{\text{day}} \) and \( T_{\text{night}} \) are the surface temperatures in daytime and night respectively, derived from AVHRR Ch4. Using \( PP = \frac{(T_{\text{day}} - T_{\text{night}})}{(1-A)} \) instead of \( P \), soil moisture is a function of \( PP \). This function can be established by regression methods.

The method, however, is efficient only in areas with low vegetation cover, because vegetation cover reduces the temperature difference between day and night, making the relationship between thermal inertia and soil moisture less close. To detect the soil moisture situation in a given location, diurnal temperature difference derived from AVHRR/Ch4 is needed. However, it is not always easy to get cloud-free AVHRR images both in day and night within the same 24-hour period if the area is large, so this method may not be used efficiently in real-time monitoring.

3. Detecting forest fires and risk assessment using NOAA AVHHR data

Forest fires are among the major environmental problems in many countries, with large areas affected every summer. Remote sensing of forest fires is important to climate change studies and sustainable development, in addition to fire management. For climate studies, information is needed on the amount of aerosols and greenhouse gases (GHGs) such as CO\textsubscript{2} released from fires. Smoke aerosols exert a cooling effect on climate, while GHGs have a warming effect. Remote sensing is the only potential means of estimating fire emissions on large scales over a long period of time. Besides, fire activity itself may serve as an index of climate change. For sustainable development, fire statistics and damage provide key inputs to the criteria and indicators of the forest ecosystem, as the carbon balance, timber supply, forest health, and bio-diversity are all affected severely by forest fires.

The Advanced Very High Resolution Radiometers (AVHRR) flown on NOAA satellites provide images several times in a day containing information about the radiation reflected and emitted by the earth (Goward et al, 1991). They can be used to calculate the so-called vegetation indices related to crop growth and allow for the calculation of the radiation emitted by the earth related to its temperature. The middle and thermal infrared channels are used for automatic fire detection. Finally, the temporal sequences of NDVI are used to generate a danger index for future fires. The Advanced Very High Resolution Radiometer, or AVHRR, flown on the NOAA satellite series, is one of the best systems for fire monitoring due to the combination of a very good temporal resolution of several images a day, a medium spatial resolution of 1 x 1 km and an acceptable spectral resolution with images in five channels: ch1: red; ch2: near infrared; ch3: middle infrared; ch4 and ch5: thermal infrared.
AVHRR has two major advantages for fire monitoring. First, it provides daily global coverage at a moderate resolution (~1 km), which is critical for near-real time fire monitoring. Second, it has a wide spectral coverage ranging from visible (ch.1, 0.63 µm), near-infrared (ch.2, 0.83 µm), mid-infrared (ch.3, 3.4 µm) and thermal infrared (ch.4-5, 10-12 µm) channels. Each of these five channels pertains to certain attributes of a fire. For example, the extent of total area burned can be assessed from the difference between the reflectance in the visible and NIR channels. Fire temperature and coverage within a pixel may be determined from two infrared channels. The mid-infrared channel is more sensitive to the number of fires, as it is readily saturated by a very small ignition. Smoke is discernible in the visible channel and consequently channel 1 measurements may be used to infer aerosol loading. The satellite monitors fairly well the evolution of each fire, and more importantly, fires are usually detected earlier by satellite than by ground observers, providing an opportunity to suppress them before they expand. However, AVHRR still suffers from various shortcomings, notably the insufficient diurnal sampling, cloud cover and contamination, and easy saturation of channel 3.

According to the laws of radiation, sources with high temperatures emit at shorter wavelengths making Channel 3 highly satisfactory for fire detection. Best results are obtained by using the difference T3 - T4 (or -T5) but the problem lies in determining the appropriate thresholds (EUMETSAT, 1995). This problem is solved by carrying out local analysis in windows of 20 x 20 pixels. An active fire focus is detected if:

1. T3 > µ3 + 2 \sigma_3
2. T3 - T4 > µ3-4 + 2 \sigma_3-4
3. R2 < µ2 - 2 \sigma_2

where in each case µ and \sigma are the average and standard deviation of T3, T3 - T4 or R2 in the window.

Prior to the fire, danger indices can be estimated by measuring the moisture content or the hydric stress of the vegetation. The suggested procedure is based on the analysis of the NDVI temporal evolution, the decrease of which may be related to an increase in water stress. Preliminary studies show promising results for large scale fires but more work needs to be done on this topic. During a fire, fire-affected pixels are automatically detected and grouped if they establish part of the same fire. Fires at sub-pixel resolution such as agricultural burning can also be detected. The differences in the NDVI values before and after the fire occurrence are used to quickly generate maps of the affected areas. The system automatically detects the affected pixels around the approximate fire location using two different techniques: differences of the NDVI values before and after the fire and linear regression of the two dates. The perimeters, in the case of large scale fires, are also shown to be well determined when compared with on-ground results obtained with the help of Global Positioning Satellite (GPS) navigation data.

3.1 Use of NDVI for forest fires risk assessment

The time evolution of the vegetation conditions between week (t) and week (t-1) can be obtained using Relative NDVI Differences (RND) as follows:

\[
RND(t) = \frac{(NDVI(t) - NDVI(t-1))}{NDVI(t-1)}
\]

Negative values for RND(t) show a decrease in the photosynthetic activity of the plants, which is as dangerous for fires as a low value of the initial NDVI. Analysis of RND accumulation
values in a forest from early spring (the time of greatest biological activity) until forest fires actually occur gives an idea of the water stress and therefore of the fire propagation danger.

4. Flood monitoring using NOAA AVHHR data

4.1. Key points in flood monitoring using AVHRR data:

1. Identify waterbody effectively;
2. Eliminate cloud influences;
3. Estimate the flooding area accurately;
4. Monitor the flood process dynamically.

4.2. Spectral Reflectivity of Water

The recognition and identification of ground cover types in remote sensing images is mainly based on the spectral characteristics.

Flood usually occurs in the period from late spring to early autumn when vegetation is luxuriant. Water, vegetation and soil are the main ground cover types needed to be distinguished. Their spectral characteristics are illustrated in the diagram (Figure 1), where we can see that in the near infrared channel, water has low albedo, while the vegetation and other objects on land have much higher values (EUMETSAT CGMS, 1999).

4.3. Pre-processing of satellite data for accurate flood area estimate

In order to perform effective monitoring of flood, the original satellite data were pre-processed by several procedures, including radiometric calibration and geometric correction. In the pre-processing procedures, the albedo of each reflective channel (ch1, ch2) of AVHRR is calculated, and each pixel in the images is projected on to a grid with an equi-longitude-latitude projection. Precise geometric correction must be done carefully to locate the images exactly. Then, natural and administrative boundaries are overlaid.

4.4. Waterbody Identification in Partly Cloudy Conditions

Although flood distribution can be displayed in the 3-channel colour composite images of AVHRR, it is not very easy to distinguish water from land objectively. Several indicators can be used to identify water:

1. ch2: albedo of channel 2
2. ch4: brightness temperature of channel 4
3. ch2 - ch1: difference between channel 2 and channel 1
4. ch2/ch1: ratio of channel 2 to channel 1

Among the above indicators, the ratio of ch2 and ch1 performs best. It partly removes the influence of cloud contamination. In the ratio image, water has extremely low value, and land has relatively high value. The histogram of the ratio image presents remarkable bi-peak distribution. Under the support of image processing software, the threshold value T0 which is located between the two peaks in the histogram can be determined interactively, identifying the water covered areas.
5. Global satellite update

This section reviews major developments and future programmes of satellites planned to be launched in different countries (EUMETSAT, 2001).

**Europe:** Meteosat-7 supports the primary service at 0° Longitude. The Rapid Scanning Service from Meteosat-6 (back-up at 9°W) became operational on 18 September 2001. Meteosat-5 at 63°E continues the Indian Ocean Data Coverage service. MSG-1 is planned for launch in Summer 2002 and Metop-1 in late 2005.

**USA:** GOES-10 (West) at 135°W and GOES-8 (East) at 75°W continue to function with no significant changes. GOES-11 is stationed at 105°W as back-up. GOES-12 (launched in July 2001) will be placed into in-orbit storage in December 2001 after post-launch checkout. NOAA-15 is the primary morning polar satellite with NOAA-12 as back-up. NOAA-15 is experiencing HIRS and AVHRR instrument difficulties, and three high-gain downlink antennas have failed. NOAA-16 (launched in September 2000) has replaced NOAA-14 as the primary spacecraft in the afternoon orbit. The HRPT downlink on NOAA-16 was moved to 1695 MHz following degradation of the high-frequency 1707 MHz transmitter, but the VHF transmitter failure in November 2000 affects the APT broadcast. NOAA-M is tentatively scheduled for launch in March 2002.

**Russia:** Two satellites of the Meteor-2 and -3 series, in circular orbit inclined at approximately 82°, continue operating beyond their lifetimes and with reduced capabilities. The first of the new Meteor-3M generation of polar satellite, Meteor-3M-N1, is being prepared for launch into a morning sun-synchronous orbit late in 2001. Meteor-3M-N2 is planned for launch in 2004-2005. The second Russian geostationary satellite, GOMS-Electro-N2, is planned for launch in 2005 and will be positioned at 76°E.
China: The FY-2B satellite (launched in June 2000) is located at 105°E. Power supply problems during the 2001 spring eclipse interfered with image transmission and the DCP subsystem. Operations have since recovered but the state of the satellite is closely monitored during eclipse periods. FY-2A (back-up at 86°E since April 2000) remains in good condition except for a de-spin subsystem defect. Because of good performance of the FY-1C polar satellite, the launch of FY-1D has been postponed to the first half of 2002. The first of a second generation of polar satellites, FY-3A, is scheduled for launch in 2004.

Japan: GMS-5, the current operational geostationary meteorological satellite, will continue to operate at 140°E until the next generation. MTSAT-1R is planned to be launched in early 2003 and MTSAT-2 in 2004.

India: INSAT-1D operates at 74°E and INSAT-2E at 83°E. INSAT-2B has an inclined orbit and is the back-up satellite. INSAT-3A and METSAT (with an imager similar to the INSAT-2E VHRR) are scheduled to be launched mid-2002. INSAT-3D is planned for launch in 2004. It will have an advanced imager with six channels and a 19-channel sounder.

6. Next Generation Meteorological Satellites Applications in Agrometeorology

6.1. EPS (Eumetsat Polar System)/METOP Satellites

METOP satellites are considered to be continuation of the present NOAA satellites in that sense they have the same sensors which enable agrometeorological applications mentioned previously.

European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) is currently preparing the European component of a joint European/US polar satellite system. EUMETSAT plans to assume responsibility for the "morning" (local time) orbit and the US will continue with the "afternoon" coverage. It is planned to carry EUMETSAT instruments on the METOP satellite, developed in cooperation with ESA and planned to be launched in the late 2005. METOP-1 will be the first of a series of operational satellites providing coverage into the second decade of the 21st century.

6.2. MSG (Meteosat Second Generation) Satellites

The new satellites will be based on the concepts of the first generation but will make effective use of advanced technology to provide a greatly improved data stream. There will be a total of 12 channels and images will be generated at 15 minute intervals instead of each half-hour. The resolution of the infrared channels will be improved from 5 km to 3 km, while one of the new visible channels will provide 1 km imagery instead of the current 2.5 km capability. Improvements in the quality of the data and adding new instrument will effectively generate a ten-fold increase in the information gathered by the satellite.

6.3.1. Potential of new generation of EUMETSAT systems

Subject of new remote sensing opportunities for Land Surface Research and Applications has been receiving considerable attention in the recent years. In general terms it is anticipated that the new generation of satellite sensors will provide a better characterization of land surfaces which is expected to foster operational activities in a wide range of fields including weather forecasting, climate modelling, hydrology, agriculture and forestry, environmental management and land use, and natural hazards monitoring and management.
In fact, the new generation of satellite sensors (e.g. MODIS and MISR on TERRA platform, POLDER on ADEOS, VEGETATION on SPOT, SEVIRI on MSG, AVHRR-3 on EPS/NOAA) will bring an upgraded level of remote-sensed information to the user community (e.g. MacDonald, 2000). The time resolution and global coverage provided by the new instruments, together with the extensive sampling in both the spectral and angular domains, will lead to broader spectrum of applications, namely within the scope of land surface processes and land-atmosphere interactions.

Table 1. Instrument Payload of the Metop Satellites

<table>
<thead>
<tr>
<th>INSTRUMENT</th>
<th>FULL NAME</th>
<th>PRIMARY FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVHRR/3*</td>
<td>Advanced Very High Resolution Radiometer</td>
<td>Global imagery of clouds, the ocean and land surface</td>
</tr>
<tr>
<td>HIRS/4</td>
<td>High Resolution Infrared Radiation Sounder</td>
<td>Temperature and humidity of the global atmosphere in cloud-free conditions</td>
</tr>
<tr>
<td>AMSU-A*</td>
<td>Advanced Microwave Sounding Unit-A</td>
<td>Temperature of the global atmosphere in all weather conditions</td>
</tr>
<tr>
<td>MHS</td>
<td>Microwave Humidity Sounder</td>
<td>Humidity of the global atmosphere</td>
</tr>
<tr>
<td>IASI</td>
<td>Infrared Atmospheric Sounding Interferometer</td>
<td>Enhanced atmospheric soundings</td>
</tr>
<tr>
<td>GRAS</td>
<td>Global Navigation Satellite System Receiver for Atmospheric Sounding</td>
<td>Temperature of the upper troposphere and in the stratosphere with high vertical resolution</td>
</tr>
<tr>
<td>ASCAT</td>
<td>Advanced Scatterometer</td>
<td>Near-surface wind speeds over the global oceans</td>
</tr>
<tr>
<td>GOME-2*</td>
<td>Global Ozone Experiment-2</td>
<td>Monitoring Profiles of ozone and other atmospheric constituents</td>
</tr>
</tbody>
</table>

Note: * Updated instruments considered for Metop-3

It is expected that a synergetic use of data from the new instruments (e.g. Pinty and Verstraete, 2000) may provide information on the two following categories of variables associated to land surface processes:

- variables controlling the radiative fluxes between the surface and the overlying atmosphere, namely Surface Albedo (SA), Land Surface Temperature (LST) and Soil Moisture (SM);
- state variables of the radiative transfer problem, namely the Snow Cover (SC) and biophysical parameters such as the Leaf Area Index (LAI) and the Fractional Vegetation Coverage (FVC).

Although directly designed to improve the observation of meteorological systems, the new generation of EUMETSAT space sensor systems poses a real challenge to improve our knowledge of surface processes. It is expected that combining information between geostationary (MSG) and polar (EPS) systems will bring new insights into the properties of the land surface. In fact, radiative measurements from satellite instruments are obtained as a function of four classes of independent variables, namely space, time, spectral location and directional parameters (e.g. Gerstl, 1990). Since information on the state of the system being observed is obtained from variations of the measured signal with respect to one or more of these independent variables (Verstraete and Pinty, 1996), the richer the sampling the less additional hypotheses and/or independent data sets are needed to retrieve the physical properties.
As shown in Table 3, SEVIRI and AVHRR-3 respectively on-board MSG and EPS present common spectral capabilities that can be used to monitor land surface properties. In recent years, data sets from the AVHRR sensor have proven to contain suitable information to characterize land surface properties.

Table 2. Listing the 12 imagery channels to be flown on the MSG Satellites

<table>
<thead>
<tr>
<th>Basic</th>
<th>Band (µm)</th>
<th>Airmass</th>
<th>Band (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VIS 0.6</td>
<td>0.56 - 0.71</td>
<td>WV 6.2</td>
<td>5.35 - 7.15</td>
</tr>
<tr>
<td>VIS 0.8</td>
<td>0.74 - 0.88</td>
<td>WV 7.3</td>
<td>6.85 - 7.85</td>
</tr>
<tr>
<td>IR 1.6</td>
<td>1.50 - 1.78</td>
<td>R 9.7</td>
<td>9.38 - 9.94</td>
</tr>
<tr>
<td>IR 3.9</td>
<td>3.48 - 4.36</td>
<td>IR 13.4</td>
<td>12.40 - 14.40</td>
</tr>
<tr>
<td>IR 8.7</td>
<td>8.30 - 9.10</td>
<td>High Res VIS, 1 km Sampling</td>
<td></td>
</tr>
<tr>
<td>IR 10.8</td>
<td>9.80 - 11.80</td>
<td>HRV</td>
<td>0.5 - 0.9</td>
</tr>
<tr>
<td>IR 12.0</td>
<td>11.00 - 13.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

However most traditional approaches (Govaerts, 2000) have relied on empirical or statistical exploitations of the spectral information (e.g. image compositing) that may introduce biases since large fluctuations related to the surface anisotropic properties are usually induced on time series of reflectances (Gutman, 1989, Roujean et al., 1992).

Table 3. SEVIRI/MSG and AVHRR-3/EPS spectral characteristics

<table>
<thead>
<tr>
<th>SEVIRI/MSG</th>
<th>Remarks</th>
<th>AVHRR-3/EPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel</td>
<td>Band (µm)</td>
<td></td>
</tr>
<tr>
<td>HRV</td>
<td>0.50 – 1.00</td>
<td>Solar</td>
</tr>
<tr>
<td>VIS 0.6</td>
<td>0.56 - 0.71</td>
<td>Solar (RED)</td>
</tr>
<tr>
<td>VIS 0.8</td>
<td>0.74 - 0.88</td>
<td>Solar (NIR)</td>
</tr>
<tr>
<td>IR 1.6</td>
<td>1.50 - 1.78</td>
<td>Solar</td>
</tr>
<tr>
<td>IR 3.9</td>
<td>3.48 - 4.36</td>
<td>Window</td>
</tr>
<tr>
<td>IR 6.2</td>
<td>5.35 - 7.15</td>
<td>Water vapor</td>
</tr>
<tr>
<td>IR 7.3</td>
<td>6.85 - 7.85</td>
<td>Water vapor</td>
</tr>
<tr>
<td>IR 8.7</td>
<td>8.30 - 9.10</td>
<td>Window</td>
</tr>
<tr>
<td>IR 9.7</td>
<td>9.38 - 9.94</td>
<td>Ozone</td>
</tr>
<tr>
<td>IR 10.8</td>
<td>9.80 - 11.80</td>
<td>Window</td>
</tr>
<tr>
<td>IR 12.0</td>
<td>11.00 - 13.00</td>
<td>Window</td>
</tr>
<tr>
<td>IR 13.4</td>
<td>12.40 - 14.40</td>
<td>CO₂</td>
</tr>
</tbody>
</table>

MSG and EPS systems will however provide access to directional information on a daily composite basis, allowing a proper sampling of effects of surface anisotropy on the observed radiances. In fact, the SEVIRI instrument will provide multiple illumination angles of the surface whereas AVHRR-3 will allow multi-angular viewing of a given ground target. A better determination of anisotropic properties of the land surface is therefore to be expected as a result of the synergy between sun-synchronous and geostationary sensor systems (Roujean, 2000).
7. Land SAF

The spectral characteristics, time resolution and global coverage offered by MSG and EPS allow for their use in a broad spectrum of land surface applications. The scope of Land SAF is therefore to increase the benefits from MSG and EPS data related to land, land-atmosphere interactions and biospheric applications by developing techniques that allow a more effective use of data from the two planned EUMETSAT satellites (EUMETSAT SAF, 2001). MSG will also provide an image repeat cycle of 15 minutes presenting new opportunities to detect short-term evolution of land resources. Such feature is particularly relevant over areas characterized by a high cloud occurrence as well as for semi-arid ecosystems having short vegetation cycles. On the other hand, the diurnal and sub-diurnal sampling of thermal signatures by MSG, together with the access to imagery and soundings from EPS, will also afford solving the land surface temperature cycles (Faysash and Smith, 1999, 2000). Retrieval of the diurnal cycle of temperature may in turn prove useful in characterizing soil moisture. Some studies (Wetzel et al., 1984) suggest that during the mid-morning LST changes are more sensitive to soil moisture than to other components in the surface energy budget.

Availability of high temporal resolution from MSG together with global coverage imagery from EPS are optimally suited to the measurement of environmental parameters that change rapidly in time as well as to those parameters where the signal change over time contains information about the parameter or the process of interest. It is therefore to be expected that data from the forthcoming EUMETSAT sensor systems (MSG and EPS) will provide valuable information on land surface processes associated to atmospheric and weather conditions. The highest priority will however be given to the meteorological community, and especially Numerical Weather Prediction (NWP) is considered as having the greatest potential to fully exploit and utilize the Land SAF products. In fact, importance of continental processes in NWP models has long been recognized and most operational models have incorporated advanced surface parameterization schemes. On the other hand, reduction of conventional observations has significantly increased the impact of assimilating remote sensed radiances over land surfaces.

Given preference to the NWP community was also driven by the two following complementary aspects:
- integration of Land SAF products with state-of-the-art land surface schemes is expected to increase and improve its usage of satellite data over land;
- such integration will pave the way to a future delivery of Land SAF products offering further added value, in comparison to others already existing or expected to exist in the near future.

7.1. Biophysical variables from SEVIRI data

In principle, SEVIRI data are expected to be suitable for retrieving the following geophysical variables (EUMETSAT, 1999):
- Land surface temperature and emissivity;
- Surface albedo;
- Aerosol;
- Global solar radiation;
- Soil moisture;
- Fraction of absorbed photosynthetically active radiation;
- Leaf Area Index;
- Evaporation;
- Fire information
Soil moisture

Soil moisture (SM) is the fraction of water contained in a specified soil layer depth (soil moisture content), and is an important parameter since it controls the partition of net radiation into sensible, latent and soil heat fluxes at the surface.

Figure 2. MSG SEVIRI spectral bands selection.

Soil moisture is not related to any MSG or EPS signal in a direct manner. Nevertheless, a signature of SM may be extracted from the division of the turbulent fluxes into sensible and latent heat driven by the net available energy. Low SM results in initially higher land surface temperatures, which causes higher fluxes of sensible heat which in turn restore the energy balance at a higher land surface temperature level. Therefore, the reaction of land surface temperature to SM may be used for retrieving SM information if cloud cover and snow are absent and other factors determining the land surface temperature – SM relation (especially wind speed) are less significant.

In general, SM has a vertical depth profile in the soil column and the layers which influence the turbulent fluxes, are firstly SM at the top most layer, which directly evaporates into the atmosphere, and secondly the root zone, which transports moisture into the atmosphere by transpiration of vegetation. Very scarce information on vertical SM profile may be retrieved from the land surface temperature information, and that the signal to be exploited will be representative of the soil layer depth that mainly contributes to the components of the surface energy balance. Thus, the SM product is actually the Effective Soil Moisture (ESM).

The SM is evaluated by means of daily values of Effective Soil Moisture with MSG-SEVIRI geometrical resolution for the geographical area of the Low and Mid-Latitudes of Europe, and possibly also of Africa or a subset like North Africa. The ESM is given in 3-5 semi-quantitative wetness classes (from dry to saturated) for areas free of decisive restrictions (e.g. clouds, snow, frozen soil, etc.) with three quality levels (reliable, medium, low. Requirements of the end users, e.g. flood or low-flow forecasting centre, may also include aggregations of the daily values e.g. to 3-daily or 5-daily values, depending on the intensity of change of SM and the quality of the product.
Vegetation

Remote sensing techniques have been developed and tested to derive indicators related to vegetation biophysical parameters. Spectral information provided by remote sensed data are processed to produce vegetation indices that may be used to derive vegetation biophysical parameters such as, Leaf Area Index (LAI).

The EUMETSAT sensors, SEVIRI and AVHRR-3, are able to provide, in an operative way, spectral data needed to calculate vegetation indices and biophysical parameters with a very high temporal resolution and with a spatial resolution useful for global scale analysis.

MSG-SEVIRI bands sensitive to the presence of live green vegetation are VIS 0.6 µm and VIS 0.8 µm (Fig. 2).

In the framework of extending the methodologies for deriving a vegetation index using SEVIRI data to sensors on board Eumetsat Polar System (EPS) payload, a similar approach will be applied using AVHRR/3 spectral bands and spatial characteristics.

8. CONCLUSION

Remote sensing has a wide range of applications in agricultural meteorology, especially with regard to vegetation monitoring, detecting and risk assessment of natural hazards such as forest fires and droughts, and flood monitoring. With the advent of MSG satellites, temporal and spatial resolution of the satellite-derived data and images will be greatly improved with the help additional sensors that are capable of sensing at a finer resolution. Not only agrometeorological sectors but also operational activities in a wide range of fields including weather forecasting, climate modelling, hydrology, forestry, environmental management and land use, and natural hazards monitoring and management will benefit from the improved quality of the satellite data.

Land SAF, which is one of the SAF Centres of the EUMETSAT, will be able to produce several biophysical variables, including soil moisture, vegetation index, leaf area index, and fire information, using data from the new generation satellites (e.g. EPS/METOP and MSG).

In conclusion, improved satellite data derived from the new generation satellites will pave the way for the extended use in various areas of agrometeorology and its applications.
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http://www.noaa.gov
STATE-OF-THE-ART OF EDUCATION IN AGROMETEOROLOGY IN EUROPE AT THE LEVEL OF TECHNICAL SCHOOLS AND UNIVERSITIES

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1. INTRODUCTION

During the twelfth session of WMO Regional Association VI (WMO-No.882, 1998), a Working Group on Agricultural meteorology was established (Resolution 8). One of the terms of reference was:

- To review the state-of-the-art of education in Agrometeorology in Europe at the level of technical schools and universities.

That task specifically to RA VI European countries, follows the work done by Lomas, Milford and Mukhala (2000) on the status of education in Agricultural meteorology worldwide.

According to the Guide to Agricultural Practices (WMO-No.134, 1981), agricultural meteorology is concerned with interactions between meteorological and hydrological factors, on the one hand, and agriculture in the widest sense, including horticulture, animal husbandry and forestry, on the other. Its object is to discover and define such effects, and then to apply knowledge of the atmosphere to practical agricultural use.

Agricultural meteorology is much concerned with climatic conditions and the environment, and recently there has been a concern to predict the effect of climate change, including climate variability, on agricultural production.
In short, Agricultural meteorology is a multidisciplinary science, that includes two main basic subjects:

(a) Earth sciences – Meteorology, Climatology, Hydrology and Soil Physics;

(b) Biological sciences: Physiology, Ecology, Pathology of plants and animals, and ‘technologies’ of agriculture.

In the light of the interdisciplinary character of Agrometeorology, it is understood why the traditional educational bodies and programs do not give answer to the increasing demand of countries to agrometeorological information. The same assessment appears in Lomas et al. (2000), concerning the present status of education in that field. It is indicated in this report that education and training in Agricultural meteorology is currently inadequate.

Additional difficulty rises from the rapid development of intensive and precision agriculture. Such agriculture is based on the optimum utilization of agro-climatic resources, computer technology, satellite remote sensing and GIS (Geographic Information Systems). It brings the large scale agricultural farming systems in the highly developed countries to the brink of the high-tech domain. This trend causes wider gaps between developed countries, other countries with economy in transition and developing countries. Those gaps may be narrowed by more extensive and knowledgeable use of agrometeorological information (Gat and Manes, 2001). To achieve this goal, the process of education should be enhanced.

2. METHODS

In order to study the state-of-the-art of education in Agrometeorology in Europe at the level of technical schools and universities, it was decided to prepare a questionnaire and distribute it to all RA VI countries. The draft questionnaire was prepared by the authors and during the meeting at Budapest, in February 2001, it was discussed by the Working Group, improved and confirmed.

The questionnaire (Appendix A) refers mainly to the present situation, and also to some future needs. It was translated into the various languages of WMO that are used in Europe and was sent to all RA VI countries by CAgM Secretariat.

The number of European countries that answered the questionnaire was twenty four (out of fifty RA VI countries), which represents 48% of the countries. The list of the countries, with the names and addresses of the persons responsible for the answers is presented at Appendix B.

Use was also made of some relevant recent WMO reports. Some of the reports were helpful for those countries which did not answer the questionnaire.

This report presents the analysis of the questionnaire, as well as additional information from WMO reports. It also includes comments and suggestions for follow-up activities.
3. ANALYSIS OF THE QUESTIONNAIRE - RESULTS

3.1. CURRENT STATUS

*Academic level courses*

Among the European countries that answered the questionnaire, 79% hold courses in Agricultural meteorology, of one type or another.

Some countries do not have any kind of education in Agricultural meteorology at university level. These countries represent about 22% of the total.

Among the countries that do hold courses, most are given at faculties of Agronomy, some at faculties of Geography (Spain, Kazakhstan), at Technical Universities (Switzerland, Slovak Republic, Slovenia, Turkey) and at faculties of Physics and Mathematics (Austria, Slovenia).

Referring to the duration of the courses, some countries indicate that it is one or two semesters, at universities or technical schools, while others indicate it as shorter courses at universities or at Regional Meteorological Training Centres (RMTCs).

Sweden, for instance, has a five weeks course in Forest Meteorology / Hydrology at the Swedish University of Agricultural Sciences in Uppsala.

Among the European countries, specialized training programmes of Agricultural meteorology were developed at the RMTC at Bet Dagan, Israel, at the postgraduate level, with fairly good results (Lomas et al., 2000). Those courses are international and basically planned for agrometeorologists from developing countries. Four courses are annually taking place:

- Basic Agrometeorology, Data Base Management in Agrometeorology, Crop Weather Modelling and Hydrometeorology.

The agrometeorological program presented at the University of Wageningen in the Netherlands, is relevant. It is given at the Department of the Environmental Sciences, for students of soil, water and atmospheric sciences. According to Lomas et al. (2000), it is expected that in universities of developed countries, where possible, agricultural meteorology will be placed in Departments of Environmental Sciences.

In Italy, the Institute of Agrometeorology and Environmental Analysis for Agriculture was recognized as an additional component of the WMO RMTC (WMO, No.882, 1998), where training in Agrometeorology is developed. There are also advanced short courses in Agricultural meteorology organized by CNR-IATA at different universities.

*At Reading University, Department of Meteorology and at the University of Nottingham, Agricultural School, post graduate studies in Agrometeorology are developed.

*Norway Agricultural University, Department of Physics and Meteorology, offers Ph.D. courses on Agricultural meteorology (Sequeira, 1998).

*No questionnaire was received; the information is based on WMO reports.*
*In France, University of Montpellier provides courses in Agrometeorology leading to M.Sc. and Ph.D. degrees (Lomas et al., 1999). Also the Meteo-France in Toulouse offers courses in Agrometeorology.

**Announcements and payment**

As concerns a proper announcement of those courses at the National Meteorological and Hydrological Services (NMHSs), only 17% of the countries do that and encourage the staff to attend them: Israel, Spain, Jordan and Cyprus.

In all countries that send staff for agrometeorological courses, it is the Service who pays the fees to attend these courses.

**In-service training**

According to Lomas et al. (2000), in-service training, which is a training received from time to time during the course of employment, plays a significant role in updating personnel from NMHSs with recent technologies and methods and in refreshing the knowledge and skill gained by Agricultural meteorology personnel, a long time ago.

![In-service training chart](image)

Fig. 1. Places where personnel from NMHSs in Europe undertake in-service training in Agricultural meteorology.

Nineteen Regional Meteorological Training Centres (RMTCs), spread all over the world, are recognized by the WMO. In Europe the RMTC at Bet Dagan, Israel, is dealing specifically with Agrometeorology.
As shown in Fig. 1, in-service training in Europe is very heterogeneous and varies very much from one country to another.

Personnel from NMHSs in Europe, and according to the answers to the questionnaire, undertake in-service training at various places and professional frames (Fig. 1): most frequently at NMHSs, international workshops and at the RMTC at Bet Dagan, Israel.

Less frequent is in-service training undertaken at WMO training courses, seminars, agrometeorological research units, University of Reading, ECMWF, as well as other places.

Fig. 2. Main institutions that carry out research in agricultural meteorology in Europe

**Universities providing M.Sc. and Ph.D. degrees in Agricultural meteorology**

According to the available sample, in 42% of the European countries, there are universities that provide M.Sc. and Ph.D. degrees in Agricultural meteorology.

In most countries, the basic requirement to study for M.Sc. and Ph.D. degrees in agricultural meteorology is B.Sc. university degree in Agronomy, Meteorology, Environment Sciences, Physics, Mathematics or Biology.

**Research in Agricultural Meteorology**

As far as the institutions that carry out research in Agricultural meteorology are concerned, the main ones are (Fig. 2): universities and agricultural research institutes,
followed by NMHSs. In a number of countries, research is also carried out at Institutes of Forestry or at other departments or institutes.

**Cooperation between NMHSs and other institutions engaged with Agrometeorology**

Most countries that answered the questionnaire have cooperation in research, applications or other activities, between NMHSs and other institutions (Fig. 3). In this case, Israel indicates that cooperation with the Ministry of Agriculture is more in operational activities and less in research.

Different kinds of cooperation are routine procedure in Ireland, Israel (applications), Italy, Jordan and Switzerland, very frequent in Bulgaria and Republic of Moldova, and such cooperation does not exist in Lithuania.

Although there is, in general, a frequent cooperation between NMHSs and other institutions engaged with agrometeorological studies, it seems that it should be improved. The economic benefits of agrometeorological information and research are more and more recognized.

![Cooperation between NMHSs and other institutions engaged with agrometeorological studies](image)

**Fig. 3.** Level of cooperation (in advisories, research and applications) between NMHSs and other institutions engaged with agrometeorological studies, in European countries.

**Agrometeorological information and advisory service to farmers**

Agrometeorological information and advisory service to farmers is provided in Europe mostly by NMHSs (Fig. 4). In some of the twenty four countries that answered the questionnaire, information to farmers is provided also by agricultural services: Germany, Israel, Cyprus, Macedonia, Portugal, Syrian Arab Republic, Spain and Switzerland. In the Netherlands, such information is provided by agricultural services and other
institutions, like commercial ones, as well as in Italy and in Slovak Republic. Two countries did not answer this question: Lithuania and Poland.

Fig. 4. Institutions that provide agrometeorological information and advisory service to the farmers in European countries.

3.2. FUTURE NEEDS

The second part of the questionnaire is concerned with opinions from European countries about some relevant subjects for the future of education and training in Agricultural meteorology.

Although there is, in general, frequent cooperation, between NMHSs and other institutions engaged with agrometeorological studies, it seems that it should be strengthened. More and more agrometeorological services should take advantage of the economic benefits of agrometeorological advisories, applications and research.

The relevancy of courses in Agrometeorology

Assessments about how relevant specific courses in Agricultural meteorology are, in each country, led to the following distribution (Fig. 5): 37.5% of the countries consider the courses very relevant and 37.5% consider them fairly relevant; for 17% of the countries, they are less relevant and 8% of the countries did not answer the question.

Most countries in Europe agree that the best educational academic institutions or departments to offer Agricultural meteorology are those of Agronomy, followed by Meteorology / Geophysical Sciences (Fig. 6).
Few countries agree that Environment and Geography departments are also suitable to offer education in Agricultural meteorology, and only one country, Bulgaria, referred to Biology Department.

![How relevant specific courses in agrometeorology are in each country](chart.png)

Fig. 5. Assessments about how relevant are specific courses in agricultural meteorology in European countries.

Some questions were asked related to education and training in Agricultural meteorology. The answers were as follow:

- Students should visit other institutions and take courses not available in their home country: 79% of the countries agree with this; 13% do not agree and 8% have no opinion.

- 67% of the countries encourage the idea that suitable institutes should offer a series of short courses for credit and invite students for a few weeks to take these courses; 16.5% of the countries do not agree and 16.5% did not answer.

- Cooperation agreements between institutions in European countries - 83% agree with this, 4% do not and 13% have no opinion.

- To the last question about involvement of Agrometeorology Research Institutes with B.Sc. degree programmes in Agricultural meteorology - 75% of the countries agree, 21% do not agree and 4% have no opinion.

According to Lomas et al. (2000), agricultural meteorologists should be actively involved in B.Sc. degree programmes and in related disciplines that help to prepare students for graduate studies in Agricultural meteorology.
Although in general frequent co-operation exists, it seems that it should be improved and more widespread.

**Fig. 6.** Educational institutions with faculties or departments best placed to offer agrometeorology education.

4. **RECOMMENDATIONS AND CONCLUSIONS**

4.1. **SUGGESTED COOPERATION IN AGROMETEOROLOGICAL EDUCATION**

No doubt that upgrading the general level of education and training in Agrometeorology in Europe is essential. Whilst there are many countries where education in Agrometeorology at the level of universities and technical schools is active, there are also many countries which lack it. Therefore, the conditions and opportunities vary from one country to another.

Cooperation between educational facilities of the various European countries is recommended. This will enable sharing experience as well as facilities. Cooperation among universities, research institutes and the NMHSs inside the countries is suggested.

This recommendation is in accordance with Blad’s statement that co-operative agreements could be established between institutions in various countries to work together in the education of students (Blad, 1994).
4.2. METHODOLOGY AND SYLLABUS

What tools and methods could be used today to improve the level of education and training in Agrometeorology?

All the traditional and classical ways of training such as: academic study, specialized courses and workshops are still the most accepted. Those are not adequately available in all European countries. Such training requires financial resources that are above the abilities of many countries. Reading materials, such as scientific books, publications and journals are extremely important but the difficulties are similar.

There is no doubt that the need for these materials continues to increase. More resources should be given for the development of these educational resources.

Fortunately, at present, high technologies open a new world of information transfer and new training methodologies, that are easier, faster and more efficient.

Suggestions and recommendations for future education and training in Agrometeorology

Education in Agrometeorology should be more attractive to the students at the technical schools and universities. The strong competition between different educational branches for human and financial resources should be taken into account.

The following strategies could be considered:
- Exploring the Internet to the maximum in order to make use of its capabilities.
- Increase and make available professional materials - printed and audiovisual for the good of advertisement and public relations.
- Exploring interesting topics of study such as the environment, pollution and protection of the environment.

Exploring the Internet to the maximum in order to make use of its capabilities

There is no doubt that the Internet network is becoming the most powerful mass media communication tool in Europe in the 21st century. Such a network can contribute to improvement and development of education and training in Agrometeorology.

According to Machua et al. (2001), the major uses of Internet in the field of meteorology are as follows:

- Meteorological data and weather information exchange, access to learning tools, access to software tools, publications of research activities, access to advanced centers with appropriate products for specific applications.

The World Wide Web (WWW) allows users to access text, images and even sound files that are linked together electronically. The attributes of WWW include the flexible to handle a wide range of data presentation methods and the popularity to reach a large audience (Doraiswamy et al., 2000).
Duncan (2001) indicates that now there are major uses of the world web site for education and training in meteorology. The reason that the web has been an effective tool for education is that it has enabled three essentials: interactivity, multimedia and communication to come together. The technological aspect of automation is also relevant.

Some examples of e-learning resources are:
- COMET - Cooperative program for operational meteorology education and training;
- EUROMET - European meteorology education and training;
- CalMet - Computer-aided learning in meteorology;
- WMO education and training and the WMO virtual training library (Duncan, 2001).

Soreide (2001) indicates that the explosive growth of the Internet and the advent of the web, coupled with corresponding increases in computing power, decreases in computing costs and advances in information technology have revolutionized almost every aspect of climate research. Amongst its other advantages is the progress in collaboration technologies. Those enable scientists to share a data visualization, animation or electronic document, even when the scientists are in different locations.

A recent WMO publication includes a chapter on the application of the Internet to agriculture (Pérarnaud et al., 2001). From this publication we learn that at present, various relevant Internet addresses are available to be used by potential users in all aspects of Agrometeorology around the world. From this chapter is taken the selected list of web sites of major international bodies that are relevant for Agrometeorology: WMO, FAO, National Climatic Data Center, The National Drought Mitigation Center, The Agriculture Weather Information Service, The European Federation for Information Technology in Agriculture, etc.

There are also Internet search engines that give access to web sites through key words, such as YAHOO, ALTAVISTA and GOOGLE RESEARCH.

Access to information through the Internet is a promising approach. The possibilities are endless and should ultimately allow more rapid transfer of information and more user-friendly access for many countries (Pérarnaud et al., 2001).

There is no question that the Internet network could serve as an important channel of disseminating agrometeorological information. It is suggested that Internet capabilities will be explored to a maximum. Attractive web courses in Agrometeorology could be organized and managed (including appropriate information, tables, pictures, animation, tests, games, encouragement, awards, etc).

At present, exists the WMO/FAO agromet e-mail list server. Should it be more active and attractive than it is now, it could be an efficient tool of knowledge transfer.

*Increase and make available professional materials - printed and audiovisual, for the good of advertisement and public relations*

On European and national scales, it is recommended that the following materials will be prepared and available for the users and, if possible, disseminated to them. Many materials were prepared for global or continental use by the WMO-CAgM and can be very helpful.
It is suggested that in each country the NMHSs will take responsibility on these matters. Updated lists of the various materials should be available at NMHSs, RMTCs, in agrometeorological bulletins and in Internet web sites.

It is suggested that updating will be done at least once a year on a fixed date, such as the 23rd of March - the World Meteorological Day.

The following materials should be prepared and available for the users and, if possible, disseminated to them:

- Scientific and technical reading material in Agrometeorology – books, journals, articles and posters.
- Publications with agrometeorological research results, to be published regularly and disseminated to the users.
- CDs and updated lists of video cassettes on various agrometeorological topics or field experiments.
- It is recommended that each NMHS will dedicate a portion of its web site to Agrometeorology, that will be informative, educational, dynamic, attractive and updated regularly.
- In addition, we suggest the establishment of an European web site on Agrometeorology that will be independent or, if possible, linked to the WMO web site.

It is also recommended that:

- Brochures on agrometeorological courses are disseminated to a wider potential auditory and users, including also ministries of education, agriculture, etc.

- Seminars, courses, conferences, workshops on various important topics in Agrometeorology are arranged for agrometeorologists of a region/country or for a number of European countries.

**Exploring the interesting topics of study such as the protection of environment, pollution and environment**

Exploring the topic of environment: the topic of pollution and protection of the environment is of great importance on a local, national and continental scale in Europe. Young people can be considered as current and future explorers of the environment and would be interested in its saving, protection and rational utilization.

A stronger connection between the education of Agrometeorology and the environmental issues would be helpful in this field. The young people educated in Agrometeorology should also be given the opportunities to contact the environmental conditions in an appropriate way; for example, carrying out field experiments or visiting agricultural field experiments; organizing “agrotours” - village/agricultural tourism - for students in order to strengthen contacts with farmers.

**5. VISION FOR THE FUTURE**

The diversity of agrometeorological achievements in developing and industrialized countries is high. Hollinger (1994) believes that the demand for Agricultural meteorology services will increase more and more when the agricultural community becomes more aware that using climate and weather information will improve their profitability. This depends, to a large extent, on having scientifically concerned and informed citizens.
who recognize the critical role that agrometeorologists play in meeting critical challenges facing all nations (Blad, 1994).

In-service training programmes are important to prepare personnel from NMHSs for the future challenges. Agrometeorological information and advisory services to the farming community should be developed. This will lead to a better understanding of the contribution of Agrometeorology to economic and social development of the countries.

Agrometeorological information should be presented in a clear and efficient language, on a scientific basis and widespread among the users. Correct use of this information will promote the practise of sustainable and more profitable agriculture, with fewer risks, less cost and less damage to the environment (Rijks and Baradas, 2000).

REFERENCES


APPENDIX A

WORLD METEOROLOGICAL ORGANIZATION

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M/RA VI, ANNEX

QUESTIONNAIRE TO REVIEW THE STATE-OF-THE-ART OF EDUCATION IN AGROMETEOROLOGY IN EUROPE AT THE LEVEL OF TECHNICAL SCHOOLS AND UNIVERSITIES

Country: ............................................. Date: ......................................
Organization: .....................................................................................................
Name of the contact person: ..............................................................................
Position: .............................................................................................................
Address: .............................................................................................................
Telephone: ............................................. Fax: ..........................................
E-mail: .............................................................................................................

CURRENT STATUS

Are there educational institutions in your country with faculties or departments for agricultural meteorology?  Yes  ☐  No  ☐

If yes, identify them, give their addresses, e-mail and web-site:
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2. Are there specific academic courses in agrometeorology in your country?
Yes  ☐  No  ☐

If yes, identify them, and indicate the place where they are given and duration of the course:
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3. Are these courses properly announced at the National Meteorological Service and are the staff encouraged to attend them?  Yes ☐  No ☐

If yes, who pays the fees for the staff to attend these courses?

The Service ☐
The staff ☐

4. Where do personnel from your National Meteorological Service undertake in-service training (training received from time to time during the course of employment)?

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5. Are there universities, in your country, providing M.Sc. and Ph.D. degrees in agricultural meteorology, or specialization courses in agricultural meteorology?  Yes ☐  No ☐

6. What are the basic requirements in your country to obtain M.Sc. and Ph.D. degrees in agricultural meteorology?

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7. What are the main institutions in your country that carry out research in agricultural meteorology?

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8. What is the level of cooperation (in research, application or other activities) between the National Meteorological Service and other institutions engaged with agrometeorological studies in your country?

Routine ☐  Very frequent ☐  Frequent ☐  Less frequent ☐  None ☐
9. **In your country, who provides agrometeorological information and advisory service to the farmers?**

- National Meteorological Service □
- Agricultural Services □
- Multidisciplinary Group □
- Other institutions □

**FUTURE NEEDS**

10. **In your opinion, how relevant are specific courses in agricultural meteorology in your country?**

- Very □
- Fairly □
- Little □

11. **Which educational institutions with faculties or departments for agricultural meteorology in your country are best placed to offer agricultural meteorology:**

- Meteorology/Geophysical Sciences □
- Agronomy □
- Environment Sciences □
- Geography □
- Biology □

*Others, please specify:*

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12. **What is your opinion about the following suggestions, related to education and training in agricultural meteorology?**

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(i) *The students should visit other institutions and take courses not available at their home country*

- Yes □
- No □

(ii) *An institute could offer a series of short courses for credit and invite students for a few weeks to take these courses*

- Yes □
- No □

(iii) *Cooperation agreements could be established between institutions in some European countries to work together in the education of students*

- Yes □
- No □

(iv) *Agrometeorological research institutes should be actively involved in B.Sc. degree programs in agricultural meteorology*

- Yes □
- No □
REMARKS:

If there are any doubts filling in this questionnaire, please contact to:

Mrs. Zipora Gat  
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P.O.Box 25  
Bet Dagan  
Israel  
Tel.: 972 3 9682112  
Fax: 972 3 9604065  
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Karnio@ims.gov.il

Or

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Fax: +351 21 8402370  
E-mail: rita.guerreiro@meteo.pt

PLEASE SEND THE COMPLETED QUESTIONNAIRE BEFORE 30 JUNE 2001 TO:

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Portugal  
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Fax: +351 21 8402370  
E-mail: rita.guerreiro@meteo.pt

with a copy to the WMO Secretariat:  
WMO Secretariat  
Case Postale No. 2300  
1211 GENEVA 2  
Switzerland
APPENDIX B

Questionnaire to review the state-of-the-art of education in Agrometeorology in Europe at the level of technical schools and universities

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<td>Armenia</td>
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<td>Fritz Neuwirth Central Institute for Meteorology and Geodinami, A-1190 Vienna, Hohe Warte 38, P.O.Box 342 Tel: +43 1 36026 Fax:+431369 12 33 Email: <a href="mailto:dion@zamg.ac.at">dion@zamg.ac.at</a></td>
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<td>Bosnia and Herzegovina</td>
<td>Sabina Hodzic Meteorological Institute of Bosna and Herzegovina Bardakcije, 12 Tel:0038771276-717 Fax:0038771276-701 Email: <a href="http://www.fmzbin.com.ba">www.fmzbin.com.ba</a></td>
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<td>Bulgaria</td>
<td>Slavov N.S. National Institute of Meteorology and Hydrology, 1784 Sofia, 66, Bd. Tsarigradsko Chaussee Tel: 975 39 86 Fax: 884 494 Email: <a href="mailto:Nicola.Slavov@meteo.Bg">Nicola.Slavov@meteo.Bg</a></td>
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<td>Stelios Pashiardis Meteorological Service Nikis 28, CY-1418 Nicosia Tel: 003572802911 Fax: 003572305500 Email: <a href="mailto:roc-mete@cytanet.com.cy">roc-mete@cytanet.com.cy</a></td>
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<td>Georgia</td>
<td>Tomaz Ivano-vich State Department of Hydrometeorology 150 Davida Agmashenebeli Str., Tbilisi 380012 Tel: 95 02 53 Fax: 95 50 06</td>
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<tr>
<td>Germany</td>
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<td>Turkish State Meteorology Service</td>
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REVIEW OF THE SCIENTIFIC LITERATURE ON THE EFFECT OF CLIMATE AND WEATHER, ESPECIALLY DURING THE RIPENING PERIOD, ON THE QUALITY AND STORAGE CAPACITY OF GRAPES, SPRING BARLEY AND POTATOES

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Summary

This literature review addresses to the quality of preharvest and postharvest products as influenced by weather and climate: Three very different cultures have been chosen - spring barley as a grain crop, potatoes as a tuber crop, and grapes for the fruit / viticulture sector, more short-lived in storage. All are used in food industry in different ways and thus with differing quality aspects: grapes for wine and raisin production and as table grapes, spring barley mainly for feeding purposes, brewing and distilling, and potatoes as food and as industrial product (processed potatoes, starch etc.). Grapes are restricted to the southern parts of Europe, whereas spring barley is growing in northern areas, too, and the widespread potatoes are rather insensitive to climate and soils.

Singling out the most important meteorological parameters for grape quality temperature and solar radiation appear. For most quality measures of spring barley and potatoes besides temperature conditions rain, soil moisture and humidity (in storage) are important. In many developing quality characteristics plant phenology is involved. The weather and climate dependent traits comprise for grape quality: visible quality, bunch and berry weight, sugar content, must weight, acidity, mineral content, pH value, polyphenols, and aroma, for spring barley quality: grain weight, size grading, dormancy level, germinative capacity, sprouting level and water content, protein and starch content, nitrogen and lignin content, whereas for potatoes these are visible quality, tuber weight and dry matter content, mineral content, protein and starch content, sugar, nitrate and vitamin content, seed viability, and postharvest product quality. Consideration of modelling and forecasting quality traits and longevity by weather data is given at the end of the chapters, but the scarce literature shows that this field is still difficult to work on.

Introduction

Quality of agricultural products is an important issue for consumers, for trade and industry, as well as for the producer. The farmers and vinegrowers are looking for selling good quality yields, as they are paid less for marginal product quality. This is a reflex of the consumers demand for excellent food, i.e. good inner and outer quality. Le Bail (1994, p.562) has stated: “The quality of a product is defined as its fitness for use ... in terms of a nutritional, hy-
gienic, organoleptic, servis and technological criteria." Quality aspects can be divided into visible and internal or subjective and objective quality measures. In the following a larger number of internal quality measures as chemical components are shown. The dependence of such measures often is proved statistically, mostly applied to a set of meteorological variables some of which are interdependent.

In all three reviews on product quality dependence on weather the temperature effects are treated first, then radiation, precipitation and further variables, although often not easily to be separated as they are interrelated. Certain fields are not addressed in this contribution. These are pests and diseases, which of course can affect visual or inner product quality. As an example for barley mycotoxins may exist in the grains after Fusarium infestation. Though important, an analysis of these secondary weather effects would involve a detailed treatment of meteorological factors influencing the occurrence of all relevant pests and diseases in spring barley and grapes.

A better understanding of ongoing processes during plant and quality development determined by environmental variables may lead to forecasting tools, models and decision support systems. Especially in viticulture a meaningful change of the microclimate may increase some aspects of grape quality.

Agrometeorology should contribute more in this field in future by modeling quality aspects and giving product quality forecasts to farmers, enabling them to adapt their producing and harvesting strategy (Le Bail, 1994, Lablans & Mulder, 1997). Additionally there is a need for shelf-life prediction of agricultural and horticultural products (De Baerdemaeker, 1997).

1 Quality and storage capacity of grapes

Grapes are produced for three main purposes: wine making, table grapes, raisin production and to a small extent juice production.

The world’s largest vine growing areas are situated in Europe: Spain, Italy and France, so that Europe comprises about 65% and the European Community about 45% of the global grapevine areas (Vogt & Schruft, 2000). The vine growing areas of the E.C. countries are assigned to seven zones from A to C reflecting the climatic conditions (Riou 1994, Bergner & Lemperle 2001).

Grapes need a certain length of vegetation period dependent on insolation and temperature, which Coombe (1987) considers as the most important factor. Length of vegetation period is an important issue in the marginal northern viticulture areas of Europe. In cool and/or low sunshine hours summers the sugar content in those areas is rather low.

Mesoclimatic factors, as slope angles, river valleys, are often used as viticultural areas to profit from the radiation budget, heat capacity of waters, etc. (Spellman 1999, Vogt & Schruft 2000). Klas (1982) has found a too early harvest (Mosel area, cv. Riesling) in recent years resulting in a lower must quality (in °Oechsle), which could have been avoided by the vinegrowers. Even days of only more than 10°C mean temperature and moderate insolation in autumn could have helped rising quality in the last period of ripening in this northern area. Fox (2000) has described the advantages and possible disadvantages of a later harvest for quality parameters under German climatic conditions. For Spain Palacios et al. (1998) have considered the rain regime of September as the factor for harvesting earlier or later in order to improve must quality. General vintage quality has been investigated by Jones & Davis (2000) together with synoptic climatology and phenology for Bordeaux. They have found quality to be reduced (a) by
higher frequency of cold and moist weather patterns delaying plant physiology and (b) by higher frequency of frontal passages with rain and wind affecting the flowering and setting of berries. For grape juice production, too, the quality components sugar level, acid content and aroma are important (Morris, 1998).

Yield as weight is generally not within the scope of this review, but to show the link to quality aspects, two phrases of Riou (1994, p.113) may be cited: “...the yield only reduces the sugar content above a threshold of the order of 5 t/ha. Its effect is quite variable from one year to next, but the influence of the yields on the other constituents of grapes shows that high yields are bad for quality.” Kast (2001) gives an overview of the indirect relations between quality and yield variegated by biological and environmental factors.

1.1 Visible quality

The appearance of table grapes presents an important quality trait for consumers. Especially after veraison longer rain and humidity conditions lead to berry splitting or loosening and consequent fungal disease attacks (Green, 1963, Jackson & Lombard, 1993). For sandy soils van Rooyen et al. (1980) have found a higher rate of berry-cracking after running a wet soil regime from bud-break to the beginning of ripening compared with normal or subnormal soil water. In warmer climates even slight rainfall during ripening may cause berry splittings (Gladstones, 1992). Berry burst is liable to occur after intense rain following a longer dry spell, because of a too high rate of water transport into the fruit (Vogt & Schruft, 2000). Sunburn coupled with high temperature also may lead to fine cracks in the skin of the berries and consequently reduced keeping quality of table grapes (Green, 1963). Sunburn spots may occasionally develop on hot days of up to 15K difference of near skin berry temperature to ambient air temperature for large, dark berries under low windspeed conditions (Smart, 1987). Especially after leaf cutting the previously shaded berries often get sunburnt, reacting with pink to light brown discolouring and drying, if water is additionally missing (Vogt & Schruft, 2000).

1.2 Quality components bunch weight and berry weight

Grape bunches have to fulfill certain standards of weight for table grapes, and for must production weight has consequences for the quality measures below.

Hofäcker et al. (1976) for southern Germany have found the highest berry weight in years with high precipitation, but also in other years the temperature-radiation complex correlates positively. Daytime temperatures of 30°C compared with 20°C lead to a lower berry weight (Kliewer & Lider, 1970). In his day and night temperature experiment (varying combination between 10° and 35°C) Kliewer (1973) has found no significant berry weight effects. Klenert et al. (1978) have described a further German experiment on heating berries of the north side of grapevine plants by +3 K (day) and +6K (night) during the last ripening stage (period of sugar accumulation) resulting in a mean of 6% higher per-berry weight. This has been explained as an effect of higher cell division and transpiration rate, although the other important plant parts were not heated.

The berry weight of shaded compared to sun-exposed clusters in the mean has been higher in response to berry temperature and subsequent transpiration (Kliewer & Lider, 1968). Comparing the berry weight in their potting trials in the plain, slope and plateau Schrader et al. (1975) have found the smallest berries at the highest altitude reflecting the radiation/temperature conditions on development time.
Modifying the microclimate by shading has resulted in a reduction of berry weight by one third, whereas windbreaks had no significant effects (Klenert, 1974). Under Californian conditions sun-exposed berries have reached a lower berry weight during ripening (Crippen & Morrison, 1986a,b), whereas in a second experiment (same year, place and cultivar) they have found the opposite. Low light intensity (at high or low day temperatures) have resulted in smaller and lighter berries (Kliewer & Lider, 1970). For north Indian viticulture Brar & Bindra (1986) have experimented with different plant stand width between 1.5x2.0m and 3.0x3.0m, which have resulted in a lower mean bunch weight for the densest spacing, whereas the mean berry weight has shown nearly no differences. Changes seem to be more dependent on nutrient competition changes between plants than on microclimate. Carbonneau et al. (1992) have stressed the importance of water supply during the last stages of ripening for a high berry weight, but there is no secure knowledge of an optimum temperature. Surplus rain in late summer or early autumn can lead to too large and watery berries and to poor-quality grapes (Spellman, 1999). For this reason irrigation is widely avoided in regions with sufficient rain. For semiarid regions irrigation is meaningful. Esteban et al. (1999) have measured higher bunch and berry weights after irrigation in the region of Madrid (0.3 ETP) and Yuste et al. (1997) for the region of Ribera del Duero/Spain (0.6 ETP). In contrast McCarthy and Coombe (1985) in their Australian irrigation experiment have found an increase in bunch weight, mostly due to a larger number of berries and not due to per berry weight, but the number of bunches per vine has been significantly higher. Escalona et al. (1999) have stated in their irrigation/no irrigation experiment at Mallorca that one cultivar reacts to an irrigation (30% of potential evapotranspiration) with a weight increase, another cultivar does not.

### 1.3 Quality components sugar content, soluble solids (must weight) and acidity in berries

In the ripening stage sucrose is transported from the leaves to the berries and is accumulated in their vacuoles as glucose and fructose (Davies & Robinson, 1996). Must weight is its specific weight and shows how many g one litre of must is outweighing one litre of water. According to Riou (1994) the sugar content of the berries or the must is measured in g/l and can be called the “ripeness potential”. Sugar content can be measured or expressed as total soluble solids (TTS) or °Brix (=°Balling), °Baumé, or °Oechsle (Huglin, 1986). These quality traits sugar and acids begin to develop at veraison, which “... is the growth stage at which grapes first begin to soften and change colour and the fruit begins to rapidly increase in sugar” (Kliewer, 1973, p.153).

A sugar/acid ratio of 10:1 to 12:1 is defined as harmonic for table grapes, which for some cultivars could reach ratios higher than 50:1 for Austrian conditions (Keppel, 1994). Before grape maturity the berry sugar content may be some percent lower than the soluble solids, but before harvest the are very similar (Jackson & Lombard, 1993). Sugar content and acid content in the berries are not only important for wine production, but for the use as berries, dried grapes or grape juice, too (Turmanidze, 1992). The potential alcohol content of the later wine is largely represented by the sugar content of the ripe berries (Jackson & Lombard, 1993; Jones, 1999). Gladstones (1992) has put the optimum temperature for sugar formation just below the optimum of 23°C to 25°C for photosynthesis. Apart from air temperatures soil temperatures, too, play an important role in sugar formation during the night in the ripening period profiting from the ground longwave radiation as a result from the daily insolation (Gladstones, 1992). In experiments with different day and night temperatures Kliewer (1973) has found a tendency to lower TTS at 35°C day temperature (depending on the cultivar), whereas there has been little influence from different nighttime temperatures. In their daytime 20°C / 30°C experiment Kliewer & Lider (1970) have found a significantly higher TTS level at the higher temperature in one cultivar only. According to Jackson & Lombard (1993) in warmer climates mean temperatures above 30°C during the ripening stage are effecting low soluble solids.
For Riesling x Silvaner Koblet & Zwicky (1965) have calculated a slightly higher correlation coefficient (0.775) between must weight and the maturation period temperature sum (>10°C) than between must weight and sunshine duration (0.760) for 12 years. Schrader et al. (1975) have determined a retarded begin of sugar formation in berries at a plateau, compared with the low level plain (Kaiserstuhl/Germany), and correspondingly the lowest sugar content (separated into saccharose, fructose and glucose) according to the temperature/radiation input. The cultivars Ruländer and Müller-Thurgau have shown different reactions. In his international comparison Becker (1994a) has presented different correlation coefficients for various cultivars for sugar content and climate data (temperature sum above 10°C and precipitation (P) minus potential evapotranspiration (ETP) (April to September)). In a second contribution Becker (1994b) has calculated variety-based regression equations for German viticulture showing a sugar content rise with temperature and sunlight duration and decrease with increasing difference of P-ETP. For the ripeness stage Carbonneau et al. (1992) have considered (for France) the following influences as most important for sugar formation: high global radiation, high mean temperatures, high maximum temperatures (at least for northern regions) and small rain amounts. For photosynthesis (and equally taken for sugar formation) they state an optimum of 400 W/m² for global radiation. Optimum daily mean temperatures are situated around 19°C, while the role of precipitation alone cannot be defined very clearly, as rain is often associated with low radiation and temperatures. But of course soil water and transpiration is important for photosynthesis and thus for the sugar-content increase.

For the Geisenheim area in Germany Hoppmann (1988) has shown that the maximum temperature shows the highest correlation with phenological development and must weight compared with mean temperature or minimum temperature. Certain months of the season contribute more than 60% influence on must weight by sunshine and maximum temperatures alone (Hoppmann & Hüster, 1993). During the ripening stages Hofäcker et al. (1976) has considered the daily maximum temperature (r=+0.883) as the most important factor for the developing must weight (sugar accumulation). In the berry heating experiment Klenert et al. (1978) have found in the mean of 4 years a 14% higher sugar content for a heating during the sugar accumulation period. In parallel the must weight has shown an increase of 9% (from 76°Oe to 83°Oe) for a mean heating of +3K and +6K at day and night. This elevated berry temperature has resulted in a mean reduction of malic acid content by 20% and a mean reduction of tartaric acid content by 7%, while the total acid content has decreased by 5%. Kliewer & Lider (1968) have compared the berry quality of shaded clusters and those exposed to the sun. Sun fruit have shown a lower total acidity, whereas tartrate levels have remained similar. Total soluble solids of sun-exposed and shaded mature berries have been nearly comparable, whereas berry °Brix has been always higher in the rear (shady) part than in the front (sunny) part of a cluster. These findings have been attributed largely to the higher and more variable fruit temperatures of the sun-exposed berries. Also according to Jackson & Lombard (1993) high and low radiation (shade) affects the berry sugar content, whereas Crippen & Morrison (1986) have stated that this is true on a concentration basis (mg/g fresh weight), but on a per berry basis sugar (and acids, too) of sun and shade berries are not significantly different because of the higher weight of shade berries. Also Smart (1984) in his radiation interception experiment has found no effect on sugar levels of shaded and non-shaded bunches, but later (Smart, 1987) has attributed berry quality to differences in light quality due to canopy architecture.

In their experiment of changing the reflective properties of the soil (with differently coloured cloth) Robin et al. (2000) have found red light of maximum reflectance at 680 nm to be most effective in increasing sugar content which is likely to explain the quality advantage of vineyards on red soils. For dark blue grapes Igounet et al. (1995) have stressed the importance of the changing albedo with colouration during ripening leading to higher berry temperatures and thus influencing quality. As another factor they have found the growing compactness of the
bunch leading to a higher heat capacity. Intrieri (1987) has tried different vine training systems (including plant density) to optimise radiation interception at the main fruiting area and succeeded in enhancing quality (higher sugar content, less acidity and lower must pH) in northern Italy. Alleweldt et al. (1984) have reported about the dependence of the duration of berry development and ripening stages after anthesis from meteorological parameters in a seven years period. They have found the stage duration for several varieties affecting the must weight and acidity, where high or low incoming radiation has played the greatest role, the latter being the reason for the positive correlation coefficient between precipitation and stage duration. Especially for the cultivar Riesling in Germany Klenert (1983) has stressed that vintage quality (free titratable acid and must weight) strongly depends on the course of the temperature/radiation complex and precipitation regime after flowering. Low light intensity generally lowers TSS and delayed fruit ripeness (Kliwer & Lider, 1970). Turmanidze (1992) has given a regional equation for the average diurnal sugar increase during maturation dependent on the mean of diurnal temperature of this period, the diurnal temperature range and the precipitation sum of the period. In a combined data set of must weight and meteorological variables for Rhine-Palatinate and Rheingau Hoppmann (1988) has found two effective components which are statistically significant for the final must weight:

(a) radiation and water budget at the stage anthesis to “little berries” and
(b) radiation and precipitation at the stage anthesis to “little berries” and temperature during the end stage of ripening.

He has found important indirect weather effects on quality via the dates and duration of phenological stage. Additionally it is interesting that extremely high radiation as in 1947 reduced must weight. Including the climatically influenced variable ‘date of full anthesis’ Hoppmann (1994) has attained 91% explanation of must weight by meteorological variables for the cultivar ‘Riesling’ in the Geisenheim area.

Lauer & Frankenberger (1986) have succeeded in reconstructing the weather of 1691-1984 in Rhine-Palatinate by regression analysis of a time series of historical grape and wine yield and quality information. They have tested 82 climate variables statistically (for each month before harvest) and for a high must weight have stated as most significant results:

- a cool, moist May in the year before the harvest year (via formation of winter buds),
- high relative humidity in July and high sunshine duration in August in the year before the harvest year (via positive development of anthesis organs),
- high soil temperatures in (harvest year) May,
- high sunshine duration in June and July,
- high soil temperature and sunshine duration during the sugar accumulation period September and October.

As for the acid content of grapes the authors give more or less inverse relations. An unwished high acid content is to be expected after:

- a warm spring in the year before the harvest year,
- low relative humidities in the summer before the harvest year,
- cool, wet and low-radiation weather from May to July (harvest year),
- rainy weather in August,
- low-radiation, cool September and wet, cool October.

It is astonishing that June, July and August climate factors together explain about 50% of the variance of next year must weight. Hoppmann & Schaller (1981a,b) have inspected an 11 years
series of must weight quality and acidity at two places in the Rheingau area. The most prominent results are differentiated in:

- years of low quality, when insolation proves to be most important. For flat vineyards the water supply additionally plays a role.
- years of medium quality, when global radiation effects retreat and water supply effects increase.
- years of good and best quality, when insolation in spring and in autumn and water supply are the decisive factors.

Generally the whole year’s climate together with plant, soil, nutrient and vineyard orientation can produce absolute differences of up to 50°Oe in must weight (with 50°Oe in 1965 as the worst year in this 11 year period). Vogt & Schruff (2000) consider optimum water supply as very important for high sugar transport and production, as dry soils during ripening slow down sugar synthesis and high water supply leads to sugar dilution and must of higher acidity. Van Rooyen et al. (1980) have found in their water regime experiments on sandy soils that during the period from budbreak to start of ripening a wet soil has a profound negative effect on the later sugar/acid ratio, whereas a wet soil during ripening has a positive effect on sugar content of the berries. Riou (1994) considers the water factor as important, but not yet sufficiently researched, although he states the dry years in the Bordeaux region giving the best wine quality. Soil water performance and rooting depth of vine is not easy to incorporate in considerations or calculations. A simplified water balance of a vineyard has been established by Riou (1994). For Franconia Schwab & Peternel (1997) have found that particularly in dry years a permanent grass cover has a negative influence on vine water status and leads to a decreased sugar production, whereas over all years must density and acidity are not significantly affected.

The development of shot berries (French: millerandage) often occurs after longer rain and/or cool weather during anthesis, resulting in small seedless berries together with large berries in one bunch, but leading to uneven ripeness with at least different sugar and acid contents which is difficult for wine making (Jaquinet et al., 1982). Timing of irrigation is an important issue for quality development of berries. Rühl & Alleweldt (1985) have determined for potted vines a higher must weight after irrigation in ripening phase 3 (sugar storage) in contrast to phase 1 (begin of berry development), when must weight turned out to be lower compared with no watering. The acid increase effect has been not so distinct, but most often has been found after an irrigation in phase 1.

Irrigation after berry set (Australian conditions) has little effect on sugar concentration, but lowers must weight (°Brix) due to a delayed ripening (McCarthy & Coombe, 1985). In Spain Esteban et al. (1999) have measured significantly higher total soluble solids and an increase of 2.8% to 14.9% for °Brix for the irrigated plots. This shows that must composition is not diluted by water but overcompensated by sufficient radiation and temperature condition for synthesis. Also Escalona et al. (1999) have received a higher must weight in their irrigation (30% of ETP)/no irrigation experiment at Mallorca during the veraison and maturation period. Yuste et al. (1997) in Ribera del Duero /Spain have shown, too, an increase in °Brix and at the same time an increase in acidity after 60% of ETP irrigation from June to September.

Windspeed reduces enzymatic activities by cooling and blowing out developing temperature layers in the vineyard microclimate, in this way lowering the soluble solids content (Jackson & Lombard, 1993), whereas in warmer climates cool air advection can have positive effects (Gladstones, 1992). In sea breeze areas additionally the advection of moister air during the day prevents drying damages. Igounet et al. (1995) have stressed that the thermal regime in a vineyard and especially of a bunch is influenced by windspeed. In his work of Europe wide zoning of grape sugar content Riou (1994) has calculated different statistical equations for a
maturation index ($R^2=0.61$) using the water reserve at the end of August and end of September, duration of veraison to harvest, date of flowering and mean temperature of the veraison to harvest period.

The organic acids (or total titratable acids) in grapes can be separated into tartaric, malic and citric acids of which the first two amount to 90% (Huglin, 1986). The must acidity is measured in milli-equivalent/litre [me/l] or sometimes in g/l, and Riou (1994) gives the relations:

1 g/l of tartaric acid corresponds to 13.3 me/l,
1 g/l of malic acid corresponds to 14.9 me/l,
1 g/l of sulphuric acid corresponds to 20.4 me/l.

For berry acidity Turmanidze (1992) considers temperature (high acidity after lower temperatures) and humidity as the most important weather factors. The reduction of organic acids (malic and tartaric) has its optimum at temperatures above 25 or 30°C (Vogt & Schruft, 2000). Jackson & Lombard (1993) attribute high level of total titratable acids in fruits to:

- night temperatures below 16°C during ripening or cloudiness during ripening or windy areas (>4m/s mean windspeed) or higher altitudes, and low level titratable acids to:
- night temperatures above 15°C during ripening or mean temperatures above 22°C during (stage I, berry development or at lower latitudes).

The acid content reacts obviously to early or late phenological development with a high positive correlation coefficient, e.g. phenologically late years are those with high acid content and low quality vintage, while the relationship is less distinct with sugar content (Jones, 1999). Lakso & Kliwer (1975) have found the optimum temperature for malic acid accumulation between 20°C and 25°C. Low day and night temperatures significantly rise the level of total titratable acidity (Kliwer, 1973). Amino-acid concentrations are coupled to weather conditions and influence the fermentation of the must and the amount of the later formed bouquet (Schrader, 1976a). Different microclimate in the plain, slope and plateau (Schrader et al., 1976b) have been found responsible for a delayed reduction of free-titratable acids (mainly governed by malic acid) with height and the largest content in berries from the plateau. Tartaric acid development has been rather independent from weather effects, likewise in the case of citric acid. Titratable acids are greatly increased by low light intensity compared with high intensity (Kliwer & Lider, 1970). During the last ripening stages high temperatures result in degradation of tartaric and especially malic acids. Counteracting are excessive rains (Carbonneau et al., 1992). But compared with malic acids the tartaric acids are little influenced by temperature and radiation (Riou, 1994).

Microclimatic changes due to row spacing, cutting or training systems are mostly influencing radiation and temperature, but quality responses to the action itself or to altered microclimate are difficult to measure (Smart, 1985). Yet he has found an increase in malic acid and a decrease in titratable and tartaric acid of shaded bunches (Smart, 1984). Brar & Bindra (1986) have shown in their 3 years plant spacing experiment that for the dense and more open spacing no significant differences have occurred in the total soluble solids [%], acidity [%] and ratio of TSS and acid for cultivar ‘Perlette’. The small microclimatic effects (which had not been measured there), seem to have had no greater influence. In their two-years altitude experiment Schrader et al. (1976a) have found an increase of most amino acid concentrations with height which at harvest reached 50 to 100% difference between plain and plateau. The different amino acid concentrations additionally have been higher in the cooler year.

According to Carbonneau et al. (1992) the importance of amino acids for grapes quality is underestimated, but the dependence from climate and weather is not well elaborated apart from a certain temperature and radiation dependence. As amino acids are transferred to the
berries rather late during ripening, the water supply is very important for nitrogen uptake by the grapevine (Löhnertz, 1998). Esteban et al. (1999) have reported of a significantly higher titratable acidity at harvest after irrigation. Correlations of meteorological factors with alcohol content and with must acidity in the Champagne region have been found to behave inversely and traced back to August of the previous year (Payen, 1990).

In a Free Air Carbon dioxide Enrichment (FACE) experiment Bindi et al. (2000a, 2001) have measured an 8% to 9% increase in the maximum acid content in August and 13% to 14% increase in sugar content two weeks later, but after ripening the differences to the control plants had completely vanished, although leaf area and fruit dry weight increases by CO₂ have been significant.

1.4 Quality component mineral content

The mineral concentration of grapes (mainly in the skin and seeds) is governed by potassium (K), followed by calcium (Ca), magnesium (Mg), sodium (Na) and nitrogen (N). The K content in grapes largely affects the acid characteristics by neutralizing the tartaric and malic acids (Esteban et al., 1999). High mineral content in must is linked with well wetted vegetation periods (Schwab, 2001) and gives quality to the wines. Nitrogen content will be handled in the chapter about aroma. The storage (i.e. increase) of K content has been time-delayed in the altitude experiment (plain, slope, plateau) of Schrader et al. (1976b), but dependent on the cultivar the coolest microclimate did not affect always the lowest K content. During ripening the Ca and Mg content decreased. In 1973 (as the warmer year compared with 1972) the mineral content of harvested berries was about 10% higher, showing a slight but not large influence by meteorological parameters. Smart (1984, 1985) and other authors have stated increased potassium content in musts from shaded winegrapes compared with sun-exposed ones, whereas Crippen & Morrison (1986a) have found no significant differences between these on a concentration or per berry basis. Under irrigated conditions in Spain Esteban et al. (1999) have measured equal or lower mineral contents in the must of irrigated grapevine. Schwab & Peternel (1997) have stated lower K contents in must of grass cover vineyards compared with bare soil, reflecting not only the changed soil water regime.

1.5 Quality component pH value

The pH value of must is more or less the real acidity the consumer tastes and is coupled to the mineral content and to the tartaric acids. Both, titratable acids and pH value are important for must stability (Esteban et al., 1999). The pH value of grapes can be important, as levels above 3.6 in wines may increase the activity of certain microorganisms, may lower the colour intensity of red wines and via sulphur dioxide binding may shorten the ageing ability of the wine (Jackson & Lombard, 1993). These authors attribute night temperatures above 15°C at ripening to high pH values and below 15°C to low pH values. High pH values are attributable to wet years (in Germany) (Schwab, 2001). A lower pH level has been measured by Kliewer & Lider (1970) under low day temperatures (20° compared with 30°C) and under lower light conditions, whereas Smart (1984, 1985) has reported of increased pH values by shading. At Mallorca a moderate irrigation/drought experiment during veraison and maturation has shown no difference in pH content between treatments (Escalona et al., 1999).
1.6 Quality components polyphenols and aroma

In the ripening period the development of e.g. anthocyanins and tannins as polyphenols in berry skins (or seeds) is positively influenced by a certain stress by dryness and high maximum and minimum temperatures (Carbonneau, 1992; Carbonneau et al., 1992). These authors have found for the difficult field of the aroma development in berries similar demands as for polyphenols, but nevertheless a slowly maturation rate which relativates the high temperature effect. Jackson & Lombard (1993) present in their environmental effects table:

- high polyphenols content is induced during ripening by night temperatures between 5°C and 15°C, mean temperatures between 9°C and 29°C or high radiation level, or soil moisture deficits, and

- low polyphenols content is induced during ripening by night temperatures above 15°C, mean temperatures above 20°C, or cloudiness, or excessive soil moisture. They have reported of very similar conditions for the aroma.

A cool and temperate climate is needed for the aromatic potential of many varieties (Riou, 1994). For the flavour and some aromas Gladstone (1992) has estimated mean temperatures of 20°C to 22°C during the ripening period as optimal and has attributed the highest levels of these qualities to the smallest range of daily temperature amplitudes. Tonietto & Carbonneau (1998) have considered the minimum air temperature during the veraison to harvest period as the discriminating factor for colour and flavour characteristics of Muscat du Ventoux in different zones in Vaucluse/France. Zenarola et al. (2000) have tried to follow the new concepts for determining ripeness other than normal technological parameters. They have assessed phenolic maturity (anthocyanin and phenols concentration) and cellular maturity (cell wall degradation, correlated with the extractability of pigments) and have found no uniform behaviour for several places in Slovenia, which may be the result of a strong impact of a lot of environmental variables. In their shade and sun-exposed experiment Crippen & Morrison (1986b) have determined no significant differences at harvest in total soluble phenols, anthocyanins and polymerized phenols, but during ripening some of these compounds have been higher (in concentration or per berry) for the sun-exposed portion. Enclosing berries in black bags during the ripening stage Giorgessi & di Leo (1985) have detected a greater influence on decreased anthocyanin pigments than on sugar and acid concentrations which reflects the role of radiation versus temperature. Razungles et al. (1996) have stated that sun-exposed berries before veraison contained more carotenoids than shaded ones. Experimenting with different soil reflectivity Robin et al. (2000) have found red light positively influencing the aroma and colouration. It appears that here the quality of radiation plays a greater role than the quantity of total radiation received by the berries.

Irrigation under Australian conditions has caused a decrease in the per berry terpene concentration, but due to higher yield the terpene content per vine has been significantly increased (McCarthy & Coombe, 1985). In their irrigation / drought experiment in Mallorca Escllona et al. (1999) have determined a higher aroma potential after irrigation during ripening, where the development of aroma potential has behaved differently according to the cultivar. Total polyphenol development has not been affected by irrigation, while the anthocyanin content has shown higher or lower values under irrigation compared with the drought treatment. As aroma development (via amino acids) depends upon nitrogen supply, a well adapted water supply in the end of the ripening period would be optimal for this quality aspect (Löhnerzt, 1998; Schwab, 2001). Irrigation effects on anthocyanin composition can change according to the year and development stage, but mostly have been higher for irrigated grapes at Madrid (Esteban et al., 2001). Schwab & Peternel (2001) have drawn the conclusion from their experi-
ments in Bavaria that all weather factors delaying ripeness (dry periods during the ripening stage) negatively influence the must contents and consequently undesired aromatic components. At least partly, undesired aromatic components in the wine are attributed to UV radiation, an influence beginning at early shoot development (Hühn et al., 1999). In another experiment Schultz (2000) has found UV-B affecting grape aroma development, especially concentrations of amino acids and carotenoids in the berry skin. Total polyphenols, flavonoids and anthocyanins have increased with CO2 enrichment in the two-years FACE experiment at Siena/I (Bindi et al., 2001).

1.7 Empirical quality scales

Jones (1999) has developed an empirical ranking for quality from 1 (very low quality) to 7 (very high quality vintage). It is not clearly separated between the chemical composition of the harvested berries and that of the resulting wine, but of course the composition of wines are dependent on musts. Schwab (2001) has proposed a quality index as the ratio of mean value of quality content to yield (in hectolitres/hectare), where sugar and acid content, pH value, mineral content and amino acids are to be combined in the numerator.

1.8 Quality trends and forecast models

Gerbier and Rémois (1977) surely have not been the first who correlated climatic variables with quality of grapes in order to make forecasts. They have calculated regional statistical equations considering climatic analysis of temperatures, radiation and precipitation for the months of July, August and September. These different prognostic tools have been developed for a number of cultivars in Champagne and have given the best results for calculating the harvest alcohol content from the August values. Chudyk et al. (1979) have developed regression equations for the harvest sugar content (in °Brix) using corn heat units and sunshine hours summation based on anthesis as starting day. Achieving a forecast for acidity Gerbier and Rémois (1977) have published a regional set of statistical equations taking in account grape varieties and meteorological parameters of the 6 pentads up to 31st of July, up to 31st of August and up to 30th of September. Their best parameters change: different temperature parameters, radiation and precipitation, and calculations of 31st of August often have yielded the best results. Turmanidze (1992) has proposed a regression equation for the sugar content on a daily basis by using a temperature sum for the maturation period, the daily temperature range and precipitation. Gladstones (1992) has developed a biologically effective temperature summation with 10°C and 19°C as lower and upper limits to predict the maturity date. For the Bordeaux/France region Jones & Davis (2000) have investigated in a 1952-1997 climatology and have found that trends for increasing quality in the last two decades can be described by the increase of warm day numbers (from flowering to beginning of ripening) and by the increase in precipitation (during maturation).

Models of vine development have shifted from pure yield models (Folwell et al., 1992) to plant models (Bindi et al., 1997) and to models incorporating phenology, microclimate, nutrient transports and berry quality (Gaudillère, 1998, Quereix et al., 2000). For three European climate zones Rieu (1998) has developed a model of statistical equations for the sugar content and for a maturation index incorporating bioclimatic variables as a water balance and a helio-thermic index between 1st of April and 30th of September. Hoppmann (1994) has given an overview 100 years of must weights and a prudent outlook for a 1K increase in temperature in the Rheingau region/Germany, which would result in a 5°Oe rise of must weight. Bindi et al. (2000b) use climate change scenarios for Tuscany/Italy to model the effect on regional grapevine productivity. Together with a shortening of phenological stages they evaluate a general
increase in acid and sugar contents with noticeable geographic gradients and depending on the scenario chosen. Schultz (2000), too, gives an outlook on viticulture and grape composition under climate change with special reference to UV radiation.

1.9 Quality and wine

For a long time many scientists in viticulture and enology relate wine quality, which is narrowly resembling the quality of the harvested grapes, to the weather history, and they distinguish between e.g. good and bad wine years. It is not within the scope of this review to deal with wine quality in detail. Mostly the relations are qualitative, as e.g. Primault (1971) has stated for Switzerland (Kanton Waadt) that a good quality wine results especially from a September with above normal temperatures and bad quality wine from a September with low temperatures and poor insolation. Fregoni & Pezzutto (2000) have reported of the bioclimatic Fregoni index for wine quality successfully used in Italy, especially for the aroma, taking in account the temperatures lower than 10°C and the number of these days in the month before harvest. Significant correlations have been found between wine quality and December and May temperatures and April precipitation in Portugal and even for the Southern Oscillation Index (Esteves & Orgaz, 2001).

1.10 Storage capacity of grapes

It is evident that producers and trade want a long and good keeping quality of table grapes, as well as consumers prefer a product of excellent inner and outer quality. This storage capacity or longevity depends on several meteorological factors. Wet harvesting is to be avoided, as wet berries tend to rot earlier than dry ones. The storage conditions, mainly temperature and air humidity, should be held in an optimum. Storage of fruit according to Green (1963) is terminated by rotting by fungi, physiological diseases or senescent breakdown. But not only the storage conditions (temperature, relative humidity) are relevant for the length of good health storage, but also the time of harvest, the pre-harvest treatments and harvest weather. The most important direct weather effects shortly before harvest are radiation with high temperature and rain. Not only quality itself, but longevity, too, is affected by sunburn and heat injuries (fine cracks in the skin where moisture loss or fungal infection can take place). Prolonged rains without berries drying up before harvest cause loose berries and breaks in the skin with a consecutive earlier decay in storage. Because of the moisture loss through the stalks, lenticels and stomata the berries should be cooled down for storage to 0° or 1°C within 6 hours after harvest (Berry & Aked, 1996). Additionally the authors refer to plastic bags (and modified atmosphere packaging) as useful for avoiding water loss from table grapes. Luini & Antonacci (1998) have given a graph about the hourly water loss up to 12 hours for different storing temperatures. Ballinger & McClure (1983) have reported of 24h shelf life after one week storage at 0°C for four ripeness classes. The least ripe grapes survived even 3d shelf life, and 1d after 5 weeks at 0°C storage. Grape berries need a certain equilibrium in acids and sugars for a longer storage, which means that nearly unripe and nearly overripe berries will decay earlier. This refers to the weather conditions during ripening. Green (1963) has cited results of cold storage experiments, where an air humidity of 85% turned out to be the optimum preventing a too early shrivelling or mould growth. A successful storage for three months is reported by Mukailov (1992) due to increasing CO₂ and O₂ in the cooling room resulting in an increase from 10 to 26% of essential amino acids compared with normal atmosphere. The number of loose berries in cold storage has been lower after a soil irrigation during the stages from budburst to start of ripening (van Rooyen et al. 1980). Apart from moisture stress also high temperatures at harvest could be a reason for berry drop (Berry & Aked, 1996).
Postharvest handling of grapes for juice production is described by Morris (1998), as he has stated that berry temperature at harvest mainly influenced shortterm grape storage and that grape temperature did not rise for 72 hours in pallet boxes. Fumigation with acetic acid at 0°C has led to a reduction of rotted berries from 94% to only 2% after 74 days in an experiment of Moyls et al. (1996). Also berry shatter can be widely avoided by acetic acid fumigation at 0°C storage.

2 Quality and storage capacity of spring barley

As with all cereals spring barley in its development is very susceptible to weather. For yield formation the basis is laid very early, but for quality formation later in plant development. Spring barley of high quality mostly serves as brewing barley, and grown for animal feeding it requires only well-filled and minimum contaminated kernels (Russell, 1990). A high starch content of feeding barley provides an excellent nutritional value for pig production as it is well digestible. The feeding value rises with a higher lysin content in the protein and with a low raw fibre content (Reiner et al., 1984) changing from year to year. Meteorological effects are not always distinctly elaborated. Fuchs (1984) has found that above all other meteorological parameters daily mean temperatures of July (east Germany) influence brewing barley quality. Northern regions affected by deteriorating weather during harvest like Scotland tend to earlier ripening cultivars in the last years to overcome quality problems (Cranstoun, 1996). Other meteorological variables like windspeed are not treated individually in literature, as any yield or quality effect cannot be separated from that of more important variables. Nevertheless windspeed plays an important role for the microclimate of a barley field, transporting off moisture or drying the ears. So its impacts can be seen in the evapotranspiration rates and following in the translocation rates in the plants. Additional usage of barley as raw material is made for industrial starch and ethanol production. Also certain elements of the yield level belong to quality as follows.

2.1 Quality components (thousand) grain weight, size grading and further outer traits

Volumetric weight of barley is greatly influenced by temperature and water budget. Mukula & Rantanen (1989) have reported on the often insufficient temperature sums in the northern agricultural areas of Finland for harvesting industrially acceptable volumetric weight (limit 51kg/hl). Savin & Nicolas (1996) have found temperature and water stress combined cause larger grain weight reductions than heat stress alone. Grain dry matter decrease at higher temperatures is due to reduced starch synthesis (MacLeod & Duffus, 1988b). Barley, similar to wheat, responds with optimum kernel dry weight to day/night temperatures of 15°C/10°C compared with lower or higher temperature combinations (Chowdhury & Wardlaw, 1978). Tester et al. (1991) have stated in their 10°, 15° and 20°C chambers experiment that the highest thousand grain weight was reached at 10°C, not being sure about the temperature effect alone or changed length of grain filling period, too.

In their shading experiment at Wageningen/NL Grashoff & d’Antuono (1997) have found for barley mean grain weight:

- inconsistent deviations from control plot after radiation reduction (by 40%) from start of tillering to start of culm elongation and from start of culm elongation to start of grain filling,
- considerable decrease after radiation reduction from start to end of grain filling.
In their climatological-statistical study Chmielewski & Köhn (1999) have investigated for a 35 year period at Berlin that the spring barley kernel weight is not much influenced by weather variables before July, but in July (main grain filling period) temperature and saturation deficit clearly affect kernel weight. For two-rowed barley Spennemann (1966) has reported on the relationship between higher grain proportion of size >2.8mm and low protein content which reflects the influence of a wet and cool season from May to hard dough stage. But this weather influence on grain size does not hold true for every cultivar. For breweries a high proportion of kernels greater than 2.5mm is essential, additionally fineness of the spelts allowing for a high malting extract (Reiner et al., 1984). Grain size was reduced in the drought and heat experiments after temperature and water stress beginning 17 and 27 days after anthesis (Macnicol et al., 1993). Bonnifet et al. (1996) consider the period between the stages 2 nodes and anthesis as most sensitive to a water deficit concerning grain size. Repeated rain wetting and drying may lead to a certain level of cracked casings of the grains and result in a higher percentage of broken kernels during milling (Smith & Gough, 1990).

2.2 Quality components dormancy level, germinative capacity and water susceptibility

Spring barley possesses a distinct genetical dormancy. Harvested barley can hardly be induced to germinate above 10° or 15°C (Corbineau & Côme, 1996). On the other hand malting industry wants for an unproblematic production a brewing barley with a germinative capacity of about 98% shortly after harvest. Beer and whisky industry sometimes have difficulties with dormancy, different from cultivar to cultivar and from year to year, as they need barley readily and uniformly germinating. Auranen (1995) gives a definition: “... a viable seed is dormant if, when hydrated, it will not germinate under favourable environmental condition of temperature, water and oxygen”, and he demands for a model for the dormancy level to predict the optimum harvest time for the farmers. Dormancy of barley can last for some weeks or months after maturation. The grade of dormancy is measured by germinative capacity assessments about 3 weeks after harvest. So, it is an aim for the producers to shorten the dormancy period. Furthermore it is interesting for malting industry to receive a forecast about the length of barley grain dormancy. Hough (1990a) has reported of dormancy problems with malting barley in one year in England which seemed to be associated with cool weather, and of no problems after next year’s hot, dry season.

Reiner et al. (1984) have learnt from harvest years with very strong and very weak dormancy that there exist two important temperature sensitive phases in spring barley development:

- during the 12th to 16th day after ear emergence low temperatures promote a short dormancy,
- during the 30th to 41st day after ear emergence high temperatures promote a short dormancy.

Cochrane (1993) has drawn the conclusion that environment (and cultivar) has a dominant effect on dormancy. He has found 360 days after anthesis that grains recovered badly when had been transferred plants in their development from 12° to 20°C, and vice versa. The intensity and duration of dormancy highly depends on the temperature experienced in the ripening period (Hagemann & Ciha, 1987), especially the milk ripeness stage is most sensitive to weather (Hradilík et al., 2000). Grains ripened at lower temperatures tend to lose their dormancy earlier. Reiner et al. (1984) have stressed that cool weather during the 3rd to the 6th pentad after ear emergence affects positively assimilation and kernel filling. But the last 20 days before harvest should be dry and warm for a good ripening and for a short period of dormancy. In a study of 17 years in Southern Germany Reiner & Loch (1976) have found a temperature sensitive period between 12 and 16 days after ear emergence (where low temperatures reduce post harvest dormancy) and another period between 30 and 41 days after ear emergence (where high temperatures reduce dormancy). For further treatment of dormancy see chapter on longevity in storage.
below. Malting barley should have a high germination rate. But normally dormancy of the grains is high at harvest (exception: certain weather conditions) and is low after several weeks. For brewing industry dormancy should be as low as possible after harvest (Henry, 1990). A quick and high water uptake of the brewing barley grains is a quality trait for a good malting success. Breweries have problems when the barley grains are very sensitive to long-time soaking due to their germinative capacity not yet fully reached. Water susceptibility of harvested brewing barley is closely connected with dormancy.

2.3 Quality components sprouting and water content

The grain moisture content is essential for farmers and taking mills and depends upon a lot of meteorological parameters during the ripening period. Precipitation represents an important factor influencing the barley via soil moisture and plant water status. Water stress of course decreases the yield and parallelly changes internal quality parameters. Dry conditions impact on cell growing and synthesis of cell-wall substance and on protein development during the vegetative as well as during the reproductive growth. After anthesis the kernel quality can be reduced by shortage of water: the malting characteristics are negatively influenced by a lower number of volume and number of endosperm cells (Nicolas et al. 1984).

There seems to be no significant influence by a surplus of water (during vegetative and early ripening stages) on quality measures, although phenological stages are prolonged compared with normal soil moistures in barley. During the late ripening stages (after the beginning of dough ripeness) repeated wetting by rain and high relative humidities (and relatively high temperatures in northern countries) can lead to sprouting and thus to a decrease in enzymatic quality of the grain. This visible or invisible germination process causes detrimental damage, as the grain is no more usable for malting purposes, because the germinative capacity of sprouted kernels is reduced. Such material fails in the malting process, as the enzymatic changes have already taken place. The time of brewing barley harvest may play an important role concerning water content and quality. Harvesting is advisable at full ripeness or dead ripeness. No further yield increase is possible after full ripeness, but quality still can increase then, if the kernels loose water. After harvest the stored product is normally so dry that it has no large respiration losses (Reiner et al., 1984). A barley crop standing too long in dead ripeness may suffer of course from sprouting when wet conditions occur.

2.4 Quality components protein and starch content

Proteins consist of amino acids synthesized by the plant. Both biochemical components, protein and starch, are negatively correlated, as the starch dilutes the protein content (Henry, 1990). For the brewing industry a high starch content (low protein content) is required because of a high malt extract. These barley components strongly depend directly on weather, and indirectly by duration of phenological stages, too. The most important time for quality development is the kernel filling period when the strongest assimilate and nitrogen transports happen under the influence of environmental factors. One quality characteristics important for farmers and breweries is the protein content which has to meet a range between 9.5 (or 10.5) and 11.5%. Too high contents, e.g. by overdosed N-fertilizing, are unsuited for good brewing barley and normally are only used as feeding barley. But too high protein content is inappropriate as well for feeding barley, a trait Molina-Cano et al. (1997) in their genotype / environment interaction study have found to behave similar in brewing and feeding cultivars.

Feeding barley quality depends on grain protein concentration which requires nitrogen for synthesis (Bulman & Smith, 1994). The barley plant should experience an adjusted fertiliza-
tion, so that the nitrogen transport rate in the stages of late stem extension, heading and grain filling is as low as possible (Russell, 1990). This can be best achieved by cool weather and normal supply of soil water. For each percent increase in raw protein content the malting extract content decreases linearly by 0.6% (Reiner et al., 1984). Additionally the brewing quality is reduced because of cold tarnishing, lower beer quality, higher expense for cooling, filtration difficulties and intense wort colouring. Protein levels start to develop rather early, before anthesis, in barley plant growth (Le Bail, 1995). Spennemann (1966) has found a low protein content after a wet and cool season from May to hard dough stage when the rain was evenly distributed. Experiments with induced drought stress after tillering in spring barley have shown a 22% decrease in protein yield of mature grain (Leinhos & Bergmann, 1995). Dependent on the phenological timing favourable weather (adequate rain amounts and high temperature during dough stage) as well as hot and dry spells after anthesis may result in a high grain protein content (Henry, 1990), the latter due to shrivelling of the kernels and thus increasing concentration. Several days with maximum temperatures of more than 32°C end of June in Loiret/France have led to protein contents higher than 13% (Payen, 1990). In their study of environmental, genotype and fertilizing effects on brewing barley quality Therrien et al. (1994) have calculated 38.4% of total variation of grain protein content explained by environment, much more than by other factors. Spanish grown barley in an experiment of Swanston et al. (1997) has reached a very high protein content compared with Scottish one due to the dryer and warmer climate. There exist influences on protein content from before anthesis, but they are not distinct and very hard to quantify. In the early and late sowing experiments of Conry (1995) grain nitrogen content results have been different according to weather until harvest with a strong tendency to lower protein content after early (February) sowing in Ireland (Conry, 1994) or even autumn sowing (Ward et al., 1994). Protein and starch transport up to the ears are differently influenced by temperature. During kernel filling the protein contents rise with increasing temperature, mostly due to lower dry weight (Wallwork et al. 1995, Savin et al. 1996, Savin & Nicolas 1996, Savin et al. 1997). Schelling (2000) has stated that a mean daily temperature of 14° to 18°C between ear emergence and hard dough stage is optimal for yield, and higher temperatures produce high level protein content and lower screening percentages.

For Swedish conditions Bertholdsson (1999) postulates a breeding for a cultivar with low and stable grain protein content, which should have a prolonged vegetative period to minimize environmental effects. For the sometimes semiarid conditions at Yugoslavia Przulj et al. (1998) have found that variability in malt protein content is far more affected by the genotype than by the year (i.e. climate). Higher temperatures reduce the kernel filling period and often compensate for higher translocation rates. The thresholds for damaging heat stress are reached at 32 to 35°C (Savin et al. 1997a,b, Wallwork et al. 1998). After Stone & Nicolas (1995) a quick temperature increase is more reducing yield than slow temperature changes. The structure of the endosperm changes with elevated temperatures during kernel filling. After radiation reduction especially during grain filling unacceptable (for malting purposes), higher protein contents have been stated (Grashoff & d’Antuono, 1997). The interaction of factors under field conditions makes it difficult to separate the effects (Gonzales Ponce et al. 1993, De Ruiter & Brooking 1996), and further the combination of impacts can have more distinct effect than the impact of one variable alone (Savin & Nicolas 1996). The protein content as influenced by water stress is discussed differently and inconsistently. There seem to be interferences with several agronomic factors and a dependence on the spring barley cultivar (Gonzales Ponce et al. 1993, DeRuiter & Brooking 1996, Dalal et al. 1997, Fathi et al. 1997). The latter have shown that grain protein concentration is distinctly increased in high nitrogen level and moderately increased in low nitrogen level experiments after post-anthesis water stress. For malting barley under French conditions Bonnifet et al. (1996) have found the stages before anthesis to be sensible to a water deficit and thus influencing the protein level.
Increased nitrogen fertilization normally will raise the grain protein content and thus the diastatic power, but will decrease the malt extract which should be high (Eagles et al., 1995). The malt fine extract and grain beta-glucan level decreases with drought stress and additionally is directly proportional to the seasonal transpiration (Coles et al., 1991, Macnicol et al., 1993). But heat stress alone does not influence these parameters. Beta-glucan is an undesired polymer for malting and chicken feeding purposes. Malting extract has increased after the 17 days (27 days) post-anthesis drought and heat experiments of Macnicol et al. (1993). A malting extract loss of 3 to 7% is reported by Savin et al. (1996) after short periods of high temperature (>35°C) exposure.

MacLeod & Duffus (1988a) and Wallwork et al. (1998) have stressed that certain enzymes which synthesize starch in the grain, are very sensitive to high temperatures, so that less starch is converted from sucrose. In their elevated temperature experiment MacLeod & Duffus (1988b) have found out that the lower starch level after 25/30°C controlled environment (beginning two days before anthesis) was due to the reduced number of starch granules and due to reduced volume available for starch accumulation. According to Palmer (1989) most barley samples of a high protein content (12-16%) have a low starch content of about 50 to 60%, whereas samples of a low protein content (9-11%) contain a higher (61-65%) starch content. For malting purposes grain filling periods (starch biosynthesis) at 10°C prove to be better than those at 20°C because of a higher endosperm proportion and better conversion to alcohol (Tester, 1997 and Tester et al., 1991). Wallwork et al. (1995) have measured a 26% decrease in starch synthesis in heat-treated (16/21°C, 25/35°C) barley grain during grain filling, resulting in a lower dry weight. Mylläri et al. (1998) have studied two-rowed barley in Finland in cold and a normal summer. The composition and starch granule composition and gelatinization behaviour has been influenced by normal or higher growth temperatures with a distinctly higher starch lipid content, and this starch required higher gelatinization temperatures as compared with low temperatures. High moisture levels at harvest are liable to reduce the starch content, e.g. in Finland (Arvola, 1995).

2.5 Quality component nitrogen content

The nitrogen concentration is strongly related to malt quality. For UK conditions brewing barley should not contain more than 1.7% of nitrogen. Maximum uptake of nitrogen has been reached at anthesis in the fertilizer experiments of McTaggart & Smith (1995). Fertilizer splitting and paying attention to controlled water management is recommended. In the drought experiments of Coles et al. (1991) the lowest grain nitrogen content and the best malt quality have been attained after no drought conditions. Soil moisture indirectly influences the N content of barley by reducing crop assimilation (de Ruiter & Brooking, 1996). The last years’ milder winters in Great Britain have lead to experiments of earlier (up to December) sowing of spring barley to avoid summer dryness and thus receiving a low grain N content (Froment et al., 1993). Grashoff & d’Antuono (1997, p. 292) may be cited from their conclusions drawn from their Wageningen barley experiment: “... optimum quality and yield require the, partly contradictory, combinations: (a) high and stable radiation levels, and (b) moderate temperature levels and nitrogen dressings (and ample water supply).”

2.6 Quality component lignin content

For feeding purposes of spring barley a low content of lignin in the cell walls of plants is favourable. Leinhos & Bergmann (1995) have detected a higher lignin content in the shoots before anthesis in their drought stress experiment.
2.7 Further quality components

It would lead too far referring to brewing barley quality features beyond those mentioned above. Fuchs (1984) has presented 17 quality traits for malting purposes, which all varied, partly greatly, with the weather patterns, without being able to define the way of dependence or even the responsible environmental variable. Also Therrien et al. (1994) have worked on alpha-amylase level, its activity (diastatic power) and percent malt extract, but did not split up single meteorological effects. These characteristics have been found all highly weather-dependent, the last two traits show 41.8% and 33.8% explanation of the total variation (the other effects were genotype and fertilizer treatment).

2.8 Quality forecasts

Concerning grain protein concentration Hector et al. (1996) have presented a barley crop growth model extended by quality characteristics incorporating soil nitrogen levels, fertilizing and especially the precipitation. It appears that the exact timing and degree of water stress are determining grain N level. Chmielewski & Köhn (1999) have given an outlook to the influence on future barley yield components (e.g. grain weight) along with climate change, insofar as they suppose a reduction with higher temperatures and stronger saturation deficits, especially during grain filling.

Forecasting dormancy or germination capacity has been tried already by Reiner & Loch (1976) - for recent developments cf. to the next chapter. There exist not only models to simulate the grain water content on an hourly basis, but also to forecast it with considerable quality (Atzema, 1998; Löpmeier & Friesland, 1998). Recent research deals with remote sensing methods for assessing yield and quality of brewing barley (Dockter et al., 1997, Schelling 2000). GIS is propagated for assessing the yield by the phenological development (ear emergence, hard dough stage) and relative humidity and to derive thus the protein content and screening percentage, while the remotely sensed soil water is difficult to assess.

2.9 Storage capacity of spring barley

Grains show a pronounced longevity in storage compared with the very perishable fruits or grapes. Due to respiration grains reduce carbohydrates with release of CO₂, water and heat. So, brewing barley has to be treated with correct ventilation and drying if necessary, which avoids metabolic heating of grains. Temperature and humidity are to be kept at levels positive for the brewing barley quality. This holds true especially for dormancy and water susceptibility of spring barley. A cooling down in storage is also important in warmer climates and if the stored grains contain too much internal water leading to high respiration activity. But such a drying causes a loss of substance and may damage the endosperm. On the other hand warm storage helps in breaking dormancy of malting barley.

Brunner (1995) considers grain moisture and storing temperature as the most important variables to conserve barley quality in storage. For the viability of seeds Smith & Gough (1990) consider a low grain moisture content more important than storage temperature. Under East Mediterranean conditions Varnava et al. (1995) have stored dry barley in a 4018 t bulk (7m peak height) open air but with PVC overliner for 34 months. There have been definite temperature gradients between 30cm, 100cm and 300cm grain depth and distinct seasonal amplitudes near the surface reflecting the outer conditions, which have led to a moisture migration from below to the top parts of the bulk. Nevertheless the grain moisture at 100cm and below has been nearly the same (about 9%) after 900 days and only in the end has risen to about 12%. Mould
development has been small and only in the upper, moister layers, while the germination level after 19 months storage has been at 94 to 98 % and after 34 months at about 88%. For British conditions 11-12% moisture content is optimal for longer storage, and the cooling and ventilation are to prevent hot spots in the barley where the germinative power of the grains would be damaged (Palmer, 1989). In storage dormancy is controlled by grain moisture, and together with elevated temperatures high moisture will lead to high respiration rates and sprouting (Smith & Gough, 1990). For food grains they report of an equilibrium between 13% to 15% grain moisture and about 70% air humidity.

Without losing quality brewing barley of 15% grain moisture can be held at 25°C for 30 days, but at 10°C for 180 days. Moreover Brunner (1995) concerning relative humidity of cooling air states the rules: never blow (too) moist air on dry grain and never blow (too) warm air on cooler grains, as this would lead to water adsorption of the stored barley. After one year storage White et al. (1999) have found no relevant seed germination deterioration at 35% rel. humidity and storage temperatures from 10° to 30°C, but for higher humidities like 50% or 65% germination percentage went down even at lower temperatures. Poor germination has been shown for dormant barley (and only slow recovery from dormancy) after low temperature storage, and recovery was better at 12% than at 16% moisture content (Baxter et al., 1991). On the other hand non-dormant barleys have shown no effect in germination when stored at low temperatures for 5 months. After a drying down to 12% grain moisture Briggs & Woods (1993) have stored barley batches at 15°, 25° and 38°C, and the germinabilities turned out as:

- faster dormancy decline under higher temperature (irrespective of any drying regime),
- very slow recovery of dormancy under storage at 15°C (some batches > 1 y) and
- faster loss of viability at higher temperatures.

In another experiment of drying down to different moisture contents between 9.4 and 14.5% Briggs & Woods (1993) have stated that grains stored under the lowest moisture and 38°C for 15 weeks or more gave very good results of viability and did not impair the break of dormancy. Briggs et al. (1994) have reported of deeply dormant barley which was hardly recoverable at 15°C, but showed a drastic fall in germinability, when dormancy was broken at 38°C. Newer findings of Armitage & Woods (1997) show a rise of germinative energy from 10 to 95% after 24 days treatment at 30°C with 12% grain moisture, and at lower temperature it takes much longer. Artificial drying means a forced ventilation with heated air while aeration is unheated. A too rapid or overdosed drying, can lead to an unwished hardening of the grain casings (Smith & Gough, 1990). According to Reiner et al. (1984) water–sensitive brewing barley in storage should be operated at those temperatures which missed during the sensible ripening phase between the 30th and 41st day after ear emergence. Marecek & Sychara (2001) and Marecek et al. (2001) report of a long-term storage (two years) of malting barley after a ventilation at the beginning, which yielded good results in germination energy, but a decreasing enzyme activity deteriorating malt extract quality.

For reducing the dormancy level Palmer (1989) has described a warm storage for barley grain at 25 to 40°C after which it was moved to storage bins for up to four weeks before use in breweries. Buitendag (1989) has experimented with storing temperatures of 25° to 40°C for several weeks, then returned to 25°C long-term storage and has found that germination energy was reduced by 30° to 40°C treatment for malting barley. For Scotch whisky production Batchgate (1989) describes the handling of harvested barley. For storage it should be dried down to 12% moisture content, which e.g. in Scotland is done in malt kilns at drying temperatures of 40 to 48°C for about 12 hours, also leading to a faster recovery of the grains from dormancy. A later cooling down to 10°C makes the grain ready for a longer storage.
For a cylindrical bin of grain Yaciuk et al. (1975) have presented a heat transfer model to calculate the grain temperature to help preventing quality losses. Briggs & Woods (1993) have developed a model for predicting the rate of recovery from dormancy in malting barley, while Bason et al. (1993) use storing temperature and relative humidity for their model to calculate acceptable storage life of brewing barley (e.g. 95% germinative capacity). Sun & Woods (1994) present a moisture transfer simulation model for barley to calculate the drying rates. A probit model indicating the maximum warm storage time to reach a certain break of dormancy is published by Woods & McCallum (2000). They have stated that a ‘second dormancy’ due to a rapid cooling after warm storage cannot be induced. Further research in the quality of stored malting barley with the aim of a decision support system is underway in a running EC project (Fleurat-Lessard, 2000).

3 Quality and storage capacity of potatoes

Potatoes of very different varieties are one of the most widely grown crops from northern to southern Europe. It is a cool season crop, and in warmer climates nevertheless two or three harvests are possible, avoiding the hottest and driest months (WMO, 1988). In the last decades two opposite trends in usage have been obvious: consumers are eating less potatoes, whereas industrial production of chips and other nutrition, as well as production of starch, ethanol and alcohol has increased. Further growing is done for livestock feeding (high starch and rather low protein and raw fibre content for pigs and cattle) and as seed potatoes. In potatoes about 200 different substances are found of which some proteins are very valuable for nutrition. A lot of outer and inner quality characteristics depend on weather. Again the numerous plant diseases and deficiency symptoms, though mostly weather-dependent, are not enclosed in this review. Potatoes as a ground crop in its development strongly depend on radiation and subsequently on soil temperature. As this culture prefers lighter soils and has a small rooting depth, water supply, i.e. precipitation, is a further important meteorological variable for crop development, yield and quality formation (Hough, 1990). The meteorological interrelations are numerous. Kolbe (1997b) gives a treatise of them, where principally rain, temperature and sunshine duration are involved. Nevertheless especially the inner quality characteristics, mainly chemical composition, are not easy to measure and can largely vary according to variety, environment, culture and fertilizing methods, maturity and age of the tubers (Wedler & Overbeck, 1993). In line with the different potato usage and products the quality characteristics are numerous. The potato storage can be extended for months but is not so easily done without quality losses as it may seem at first sight.

3.1 Visible quality

The texture and colour of the tuber skin has to be undamaged and without faults. Generally harvesting at soil temperatures below 10°C (i.e. tuber temperature) raises the percentage of damaged tubers (Schuhmann, 1998). These are unacceptable for consumers and industry and of course for storage. The rate of damaged tubers at 5°C is double compared with the rate of harvesting at 15°C (Putz, 1989). Bouman (2000) recommends at least 12°C tuber temperature, better 15° to 18°C for harvesting and postharvest handling. Especially after dry seasons mature tubers react sensible to pushing at low temperatures with blue or black spots under the skin, which spoil the visible quality as well as industrial use. This blackspot susceptibility of tubers is increased by higher rain amounts in the vegetation period (Kolbe & Haase, 1997). In addition high soil moisture at harvest interferes with a quick drying of the tubers. Well-dried potatoes have skin a more resistant to damages by pushing and falling and to wound infections (Schuhmann, 1998).
High water supply after a dry period will lead to cracked skin and loose tuber skin (Schuhmann & Krumbiegel, 2001). The firmness of tuber skin normally reaches its optimum at after-ripening, i.e. about three weeks after topkill (Putz, 1989). People have learnt rather early about the green, toxic parts of insolated tubers. As these contain solanin they are unsuited for consumers, and farming production techniques like correct ridging are used to provide sufficient soil on the tubers to prevent a washing off by rain. So, the rain regime in the last weeks before harvest can decide about the proportion of green tubers. Predefined by the variety the potatoes have a certain shape and internal colour making them useful as ware or industry product (Lindhauer et al., 1998). Potatoes for chips (French fries) need a certain volume and oblong dimension. Round shaped tubers (40-65 mm diam.) are preferred for crisps, <35 mm for wet-canned ware, and oval tubers (>55 mm diam.) are used for chips production. Undersized tubers develop under water stress, whereas unacceptable forms like attached secondary tubers develop after a too late irrigation or due to a late excessive rain after a dry period (Putz, 1989). Abnormal tubers from secondary growth are also related to high temperatures (WMO, 1988). According to Hough (1990b) the size distribution of tubers is changed after drought in the way that the proportion of 55 mm size grade is reduced, but often within grades the tuber length is increased relative to its breadth.

3.2 Quality components tuber weight, specific gravity and dry matter content

Tuber weight distribution represents an important characteristics not only for the yield but for its quality. A certain volume has to be attained by adequate water supply and by waiting for correct ripeness. Specific gravity represents an important quality trait for the potato chip industry. High dry matter content means higher rate of yield for the finishing industry by lower energy input. Of course weather during plant development plays the most important role for tuber weight. As potatoes consist of water to an high extent (75%, dry matter: 25%), the available soil water is decisive. Low precipitation rates during tuber growth are effecting smaller potatoes. This has been proved in irrigation experiments, where only water given after the end of anthesis linearly increased the mean tuber weight (Schmidt & Vetter, 1985). When there exist distinct temperature differences due to the daily amplitude, tuber growth is enforced by a high assimilate surplus (Struik et al., 1989). Putz (1997) considers elevated temperatures and sunshine duration as more effective for a high tuber weight than precipitation. In their experiment with simulated hail Orr & Jardanan (1991) have shown a reduction in tuber weight and in numbers by the partly destroyed leaves and subsequent deranged photosynthesis. In the same trial the average specific gravity has fallen from 1.096 to 1.085. The percentage of dry substance greatly affects the characteristics of crisps and other snack products (Putz, 1989). In temperature experiments Struik et al. (1989) have found that increased air temperatures reduce the tuber dry-matter content, but this quality trait can still be upgraded by low soil temperatures around roots and stolons. Generally, warmer and above all dryer years stand for a higher dry matter content (Kolbe, 1995). Rain and high soil moisture during potato development increase the water uptake of the tubers, decrease the potassium content and thus increase the dry substance. Putz (1997) stresses the sunshine duration as the prominent factor for a high dry matter content. Hough (1990b) has reported of an increase up to 22% to 24% dry matter concentration in well watered potatoes. This contradiction is confirmed by Kolbe & Haase (1997), as with increasing precipitation the K content of tubers is lowered, so that dry matter content is increased.

3.3 Quality component mineral content

The potato tuber is nearly famous for its K content as nutritional value. The weather (mean temperature and water status) during the vegetation period highly influences the storage of K, Mg, P and Ca in the tubers. Potassium (K) content of the tubers is reduced with an in-

101
creasing precipitation sum of the vegetation period (Kolbe & Haase, 1997). The coincidence of low calcium input with high temperatures can induce (non-virus) iron spots inside the tubers (Pawelzik, 2000). Putz (1997) attributes high phosphorus content to high precipitation and moderately high temperatures, high potassium content to elevated temperatures, but lower sunshine duration and rain, and magnesium to higher temperatures with no effect of precipitation.

3.4 Quality components protein and starch content

In the mean the potato dry matter contains about 75% of starch. The taste of potatoes is largely determined by the ratio of protein and starch. The taste, though important for consumers, is hard to assess and to relate to climatic factors. For technological purposes starch is the main raw material and has to fit in certain margins. Though rather low in content the potato tuber proteins are of a high nutritive value. Higher raw protein content in potatoes means a harder consistence for industrial processing and is induced by higher nitrogen dressing (Kolbe et al., 1995). The effects of the latter of course is variegated by the rainfall distribution. According to Putz (1997) raw protein content is positively influenced by elevated temperatures, whereas a high net protein content results from high sunshine duration with lower temperatures, but both are negatively affected by increasing rain amounts. Net protein content of food potatoes has been positively increased by high summer temperatures in the experiments of Kolbe et al. (1995). If not too extreme, high temperatures from May to August lead to a distinctly higher raw protein content, but a lower net protein content in tubers (Kolbe, 1996b). Higher precipitation amounts than 50mm/month reduce the nitrogen availability by a washout effect and thus effect a lower protein content. Starch formation and increase lasts until the end of tuber maturity and depends on weather at the end of the vegetation period, may it be natural or by topkill. Generally, extremes of temperatures and radiation negatively influence the starch content, as photosynthesis deviates from its optimum during very hot and very cool, less sunny periods (maximum photosynthetic rate at 15° to 15.5°C mean temp.) (Kolbe, 1995). Higher starch contents result from relatively cool but sunny weather (Putz, 1997). Reust (1998) has found different starch developments in the years 1992-1995: a steady increase until tuber ripeness and from July a decrease of more than 18% of starch content for the warm years 1994 and 1995. In addition to the higher respiration the rain regime and irrigation timing of 1994 could have influenced this starch decrease. Also Reust & Keller (1999) report of a reduction in starch content after an irrigation (together with N supply) very shortly before tuber formation. For changes of starch components in storage cf. chapter 3.10.

3.5 Quality component sugar content

Potato tubers contain different sugars, the polysaccharid saccharose and the monosaccharids glucose and fructose, which belong to the carbohydrates as well as starch and are influenced by temperature during plant growth and harvest. This quality trait should be at a low level. A too high glucose and fructose content causes processing problems under frying temperatures, as these sugars then effect a browning and a bitter taste of chips, crisps, etc. In the experiments of Kolbe et al. (1995) higher sugar contents (saccharose) have been measured in warm and dry summers (Germany) and vice versa. For the reducing sugars glucose and fructose the temperature dependence is inverse: cool weather increases the content of these sugars (Kolbe, 1996a, Putz, 1997). Cold or too late harvested tubers react by a rather quick sugar formation (Keller, 1999) and so have to be stored longer (warm treatment for recovery, see chapter on storage). Normally precipitation does not affect the tuber sugar content. But high rain amounts indirectly increase the overall sugar content in tubers by a reduction of nitrogen availability and an increase in phosphorus availability (Kolbe, 1996a).
3.6 Quality component nitrate and vitamin content

Generally, potatoes contain a rather low amount of nitrate - a quality trait which should be as low as possible for the consumer (below 100ppm). Nitrate is stored in tubers at very changeable levels and normally is reduced again until harvest, unless there is an error in fertilizing (Bodin, 1984). Higher insolation during the vegetation period effects lower nitrate content due to the intensive photosynthesis and high nitrate level in tubers are found after low radiation inputs (Putz, 1997). High water availability after a dry spell causes high nitrogen uptake as well as high nitrate levels in tubers, whereas higher than normal monthly rain amounts lead to N dislocation in the soil and to a lower nitrate content (Kolbe, 1996c).

Potatoes store ascorbic acid to a rather high extent. In fertilizing experiments Rogozinska (2000) has found the vitamin C content in tubers very dependent on magnesium and potassium application, and high or low rain (or irrigation) amounts have lowered the vitamin C content. Kolbe (1997a) has found that temperature alone has no specific effect on ascorbic acid content, but the latter is increased by a high amount of incoming radiation. Sometimes higher vitamin C content is a stress effect of a pronounced water deficit. Putz (1997) relates an increased ascorbic acid content to high sunshine duration with smaller influences of low temperature and no effect of the rain regime. In storage until the end of winter about 30 to 60% of the vitamin C content is reduced. All vitamins suffer from high temperature occurrence or treatment (Bodin, 1984).

3.7 Quality component seed viability

A certain proportion of potatoes is planted for seed purposes which of course have to fulfill certain conditions. E.g. germinative properties depend rather strongly on temperature, as Hofferbert (1986) stresses that cool vegetation periods produce the more viable seeds. Tubers of warm summers tend to sprout too early and loose a proportion of their germinative energy before the growers want them to germinate. In this connection refer to the last chapter about storage and dormancy, too.

3.8 Quality component of postharvest products

For potato industry an important characteristics is the potato and chip colour. The tendency to raw discolouration negatively influences the post-processing value of potatoes for industry. Tubers harvested late under temperatures below 10°C tend to react by enzymatic discolouring of the raw product (Kolbe & Haase, 1997). In their water stress experiments Pawelzik and Delgado (1999) have found that the tendency to a later enzymatic discolouration of the raw material was higher after normal water supply in the vegetation period than after a low one. High sunshine duration is considered as the main factor (coupled to ascorbic acid content) for a low tendency to raw discolouration by Putz (1997). Baking products from potatoes tend to be browner with a higher content of the sugars fructose and glucose, which is dependent on temperature and water supply during tuber development and ripening (Putz, 1989, Winiger, 1999). Potato chip colour has been hardly influenced by leaf damages, e.g. by the hail experiments of Orr & Jarnadan (1991).
3.9 Quality forecasts

For the farmer the date of potato harvest has to include actual weather, ripeness, days since topkill and needs of the market. As we have seen in chapter 3.1 too low soil temperatures increase the risk of tuber damages, so agrometeorology is called to indicate the risk of damaged tubers by calculation and prediction of soil temperatures, as it is described by Löpmeier & Friesland (1998). Caldiz et al. (2001) have developed a physiological age index (PAI) for estimating the performance of seed tubers. The number of models simulating the development of other outer quality traits than harvest damage or inner quality characteristics under consideration of meteorological data is very limited, as the interrelations of plant (cultivar differences) and environment are very difficult in potatoes.

3.10 Storage capacity of potatoes

As people have to rely upon potato availability out of the season, they have had to store them since early times, e.g. in frost-protected potato clamps. Until now outside storage with automatic aeration to avoid heating and moistening of the tubers plays a role (Cordes, 1999). Generally, the potato quality in storage is to be held against the influences of evaporation, transpiration, respiration and germination which all are highly governed by the environment. During the first days after harvest the tubers lose about 2% of their water, and 4 weeks after harvest 3% of water have been respirated. A very important issue of potato storage is to avoid this water loss in order to maintain the tuber weight and the firmness of the skin (Bodin, 1984). At 10% water loss already considerable visible quality losses begin (Specht, 1999). In the first days after harvest the ventilation should be done by dry air of 2K to 4K lower than the tubers to be most effective (Putz, 1989). In the beginning of storage temperature above 10°C with good ventilation shall promote good drying of the tubers, and 12°C to 15°C for up to 2 weeks are recommended for wound healing (Hough 1990b, Langerfeld & Leppack 1992). Thereafter a rapid cooling to longterm storage temperatures of 3°C to 5°C (table potatoes) or 7°C to 9°C (warm storage, processing potatoes) with 2 hours daily ventilation has to take place. Storage in high stacks of cases may require a directed and intermittent cooling and drying with incorporation of cool outdoor air, as a temperature gradient of up to 4K between bottom and topmost cases can develop (Leppack, 2000). The ventilating air in the store should be 2K cooler than the tuber temperature in order to reach an equilibrium with metabolic processes (Specht, 1999). Considerable damages occur at temperatures >35°C (when ventilation fails) or due to frosts below –1°C to –2°C.

To preserve quality and avoid mechanical damage the tubers are to be warmed before any greater moving, rolling or transport (Langerfeld & Leppack, 1992). According to Bouman (2000) higher damage rates occur during storing and handling than at the harvest process itself, which can be decreased by suitably high tuber temperatures. In storage some of the large amount of potato starch is respirated to sugars, these again transformed to CO₂ + heat + water. Under low temperatures (especially frost) sugars still are metabolised, but CO₂ production stops, so that the unwished sugar formation, to a certain extent reversible, can spoil the taste (Putz, 1989). The lowest respiration takes place at 3°C, so that lower temperatures become critical. When potatoes have been harvested too cold, a too high sugar production takes place. This can be reversed by considerable time of storage at temperatures >8°C in order to metabolise the sugar again. A normal procedure in this case is a short-term heat treatment of 15°C to 20°C for reconditioning, which bears the danger of inducing germination (Putz, 1989). Potatoes waiting for food industry are to be held at 6°C to 10°C in storage, to suppress a too high unwished sugar production (Kolbe & Haase, 1997). Wet potato products need a deep cooling to avoid any discolouring. The increase of sugar content (mostly saccharose) due to age and sprouting disposition is temperature-independent and irreversible (Bodin, 1984).
Relative humidity has to meet the optimum range of 95 to 98%, because then (together with optimum temperature) the respiration losses amount only to 0.8 to 1% per month (Putz, 1989). A little lower range of 92 to 95% is postulated by Specht (1999) in order to avoid any free water on the tubers (risk of fungal or bacterial infections). The storage temperature influences the starch properties of tubers compared with the properties before storage. In his 12 weeks storage at 20°, 8°, 4°, 0° and –15°C (with intermediate thawing) Golachowski (1985) has found that the range of 8° to 4°C shows the least differences to the properties before storage, whereas at the high and low temperature the starch chemical composition and physical properties mostly decrease in quality. Abdel-Rahman et al. (1999) have described the quality change of potatoes stored in plastic bags and in woven material as more depending on the cultivar and storing temperature than on the type of bag. The different number of holes in the plastic bags partly have lead to higher germination rate in bags with the most holes. Ascorbic acid has been strongly reduced up to 30 days or only up to 150 days of storage and was independent from the bag material, but reduction was least at 4°C compared with 10° or 16°C. The highest reduction in starch content has been measured within the first two months at 4°C and, too, was hardly influenced by the type of bag.

The dormancy of tubers varies with environmental conditions during growth. So, after a warm and dry summer dormancy generally is shorter (Hofferbert, 1986). Additionally dormancy shows a development and normally vanishes in winter. Tuber germination in storage is of course unacceptable for food and industry potatoes. After a cool vegetation period potatoes tend to germinate later (about February) and after a warm summer as early as at the end of November (Reust, 1994). He has found that saccharose and citric and malic acid contents are likewise influenced and from their development in storage indicate the dormancy status of the tubers. Another issue is to maintain the germinative power of stored seed potatoes. The optimum temperature levels to be held at 2° to 4°C (Bodin, 1984) or variegate between 3° and 7°C, depending on the cultivar. Lower temperatures than 2°C (but above 0°C) can nevertheless cause a heavy loss in germination success. Before sowing a certain number of week of elevated temperature treatment is required to induce a pre-germination as it is mostly done by potato growers. Shelf-life expectancy by modelling physiological processes is asked for by De Baerdmaeker (1997).
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SUMMARIZING CROP GROWTH SIMULATION MODELS IN EUROPE WITH POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS

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Introduction

Agriculture, like most business, is a decision-making enterprise. Farmers and policy makers are constantly faced with the task of matching and allocating time and resources to efforts that are likely to produce desired outcomes. Agriculture involves biological factors for which, in many cases, the interactions with the environment are unknown. Deviations from expected outcomes are often caused by random environmental variables over which the decision maker has little or no control. Year-to-year variations in weather cause large variations in crop yields. Uncertainty in weather creates a risky environment for agricultural production. Thus chance, and therefore risk, enters the decision-making process, and farmers and policy makers are unwillingly forced to gamble with nature.

During the last decades the application of simulation and system analysis in agricultural research has increased considerably. The simulation model is one of the most complex methods among the approaches used to describe the soil-plant-atmosphere system. Models that use weather data and soil and plant data in simulating crop yields have the potential for being used to assess the risk of producing a given crop in a particular soil-climate regime and for assisting in management decisions that minimize the risk of crop production (e.g. Tsuji et al., 1998). Models, in general, are a mathematical representation of a real-world system (e.g. Mize and Cox, 1968). In reality, it is impossible to include all the interactions between the environment and the modeled system in a computer model. In most cases, a model is a simplification of a real-world system (e.g. Hoogenboom, 2000). A model might include many assumptions, especially when information that describes the interactions of the system is inadequate or does not exist. Depending on the scientific discipline, there are different types of models, ranging from very simple models that are based on one equation to extremely advanced models, that include thousands of equations (e.g. Hoogenboom, 2000). Crop models, in general, integrate current knowledge from various disciplines, including meteorology, soil physics, soil chemistry, crop physiology, plant breeding, and agronomy, into a set of mathematical equations to predict growth, development and yield (e.g. Hoogenboom, 2000).

Simulation models are robust tools to guide our understanding of how a system responds to a given set of conditions. Crop simulation models are increasingly being used in agriculture to estimate production potentials, design plant ideotypes, transfer agrotechnologies, assist strategic and tactical decisions, forecast real time yields and establish research priorities (e.g. Bannayan and Crout, 1999; Penning de Vries and Teng, 1993; Uehara and Tsuji, 1993). Numerous crop growth and yield models have been developed for a wide range of purposes in recent years (e.g. Casanova et al., 2000; Hoogenboom, 2000). These models range in complexity from the most sophisticated simulators of plant growth, primarily intended for research into...
Plant physiological interactions, to multiple regression models using only a few monthly weather variables to forecast regional crop yields. Generally, plant-process yield models have been developed to predict yield at the level of an average plant in a specified field. Thus the input data required by these models include plant parameters specific to the variety or hybrid planted in some field and soils parameters describing the soil in that field. The prediction of crop development is an important aspect of crop growth modelling.

One use of the crop models developed in recent years is to simulate the effects of cultural practices and climatic scenarios on crop growth and yield. However, their use for predicting yields over large areas is limited by the difficulty in obtaining information about local conditions or crop characteristics at any given point. Some crop or soil features may be considered to be constant for a group of genotypes in a given region, but others depend on changes in local conditions (e.g. Guerif and Duke, 1998). Testing over a range of environmental conditions is required to establish confidence in applying models (e.g. Goudriaan and Van Laar, 1994). Crop models are available for almost all economically important crops and on many occasions they have been successfully used in research. In the future, models may be useful for improving the efficiency of agricultural systems and could be a tool for farmers trying to improve the profitability of their farms (e.g. Jacobson et al., 1995). Nevertheless, before this is possible, models must be calibrated and evaluated for each climatic region where they are intended for use in decision making (e.g. Sau et al. 1999).

Crop simulation models permit the summary of scientific knowledge on the biological processes that regulate plant growth. They integrate the work of experts in different fields and place it all at the disposal of any agronomist. As such, these models appear as very powerful tools. Low cost and time saving are their two major advantages over field experimentation. These models simulate final variables of the crop cycle, such as grain yield, but also simulate the evolution of some intermediate variables. They are generally built with an analytical purpose. Yet, these models are sometimes used as a predictive tool (e.g. Trousland-Kerdiles and Grondona, 1997).

Large area yield forecasting prior to harvest is of interest to government agencies, commodity firms and producers. Early information on yield and production volume may support these institutions in planning transport activities, marketing of agricultural products or planning food imports. Moreover, at world scale, agricultural market prices are affected by information on the supply or consumption of foodstuffs. Market price adjustments or change in agricultural supplies in one area of the world often causes price adjustments in other areas far distant (Supit and van der Goot, 2002).

It is no longer necessary nowadays to demonstrate the usefulness of simulation models to explain and predict crop yields or changes in the environment at various scales of agricultural production (e.g. Boote et al., 1996). The value of exploring agronomic situations not tried experimentally (or difficult to try out experimentally) is all the greater when the model can simulate several crops arranged in succession, and when as many cropping techniques and environmental limiting factors as possible are included (e.g. Cabelguenne et al., 1999). Crop models can also be used to generate input data for models for technical/economic optimisation, notably in the context of the analysis of European or national policies for competitiveness and environmental protection (e.g. Fließmann, 1995; van Ittersum and Rabbinge, 1997). In an economic context in which techniques and regulations are rapidly evolving, or where the objectives and limitations applied to cropping systems are also very diverse, long-term experiments cannot provide answers quickly enough for action to be taken. Models are called upon more and more to contribute to the formulation of innovative cropping systems. Clearly, the credibility of the conclusions from long-term exploratory simulations rests heavily on the reliability of the models, and
especially on a good prediction of the yields of crops subjected to various water and thermal stresses (e.g. Cabelguenne et al. 1999).

2. Goal, working tasks and material

The major goal of this work was to summarize current status of crop growth simulation models in Europe, with potential for operational assessment of crop status and yield prognosis. In order to achieve the above goal the following working tasks were executed:

1. Reviewing previous WMO (World Meteorological Organization) reports, papers and books on crop growth simulation models, applied in Europe;
2. Development and dissemination of a questionnaire on crop growth simulation models, currently used in Europe;
3. Contacting the members of the WMO RA VI Working Group (WG) on Agricultural Meteorology and seeking help, information, and also appropriate names and addresses, related to crop growth simulation models, used nowadays in Europe;
4. Contacting members of electronic (e-mail) conferences and seeking updated information on crop growth models, run in Europe;
5. Contacting and collecting information directly from crop model developers;
6. Contacting researchers applying crop models in Europe;
7. Searching literature and information on crop models in standard and electronic libraries;
8. Summarizing information on the status of crop growth simulation models, used in Europe.

Previous WMO reports (e.g. Baier, 1977; CAgM, 1988; Haun, 1983; Plaisier, 1986; Robertson, 1983, 1984; Sirotenko, 1983; WMO, 1985) were reviewed in order to obtain impression about the structure, methodology, etc. of similar studies. A questionnaire on the use of crop growth simulation models in Europe with potential for operational assessment of crop status and yield prognosis was developed (Table 1) and disseminated mainly by e-mail together with a request for assistance to most meteorological services in Europe, members of WMO. The questionnaire was sent also to:
- all members of the WMO RA VI WG on Agricultural Meteorology who have some experience and at least knowledge about crop growth models, used in their countries.
- a wide auditorium on agricultural models around the world, available through the AGMODELS (agmodels-L@crcvms.unl.edu), DSSAT (DSSAT@listserv.uga.edu) as well as AGROMET (agmet-L@mailserv.fao) electronic/e-mail conferences.
- model developers such as Dr. O. Sirotenko (Russia), Dr. C. van Diepen (The Netherlands), etc.
- researchers on crop model applications such as Dr. A. Iglesias (Spain), Dr. M. Semenov (United Kingdom), etc.
- most national delegates of Action COST 718 “Meteorological applications for Agriculture” (http://agromet-cost.istea.bo.enr.it/meetings.html)

Current journal papers (e.g. Casanova et al., 2000; Saarikko, 2000), books (e.g. Vossen and Rijks, 1995) and conference (e.g. International Symposia on Modelling Cropping Systems, Lleieda, Spain, 1999 and Florence, Italy, 2001) proceedings (e.g. ESA, 1999, 2001) were reviewed in respect of crop modeling and its applications in Europe. Another opportunity for accumulating information in the field was to search (for a limited period) journal articles on crop modelling via the Internet electronic library Science@direct, where many journal papers are available on line. Information on crop models was also obtained via crop model registers on the web: CAMASE (http://www.bib.wau.nl/camase/) and REM (http://eco.wiz.uni-kassel.de/ecobas.html).
Table 1. Questionnaire on crop growth simulation models in Europe with potential for operational assessment of crop status and yield prognosis.

<table>
<thead>
<tr>
<th>No.</th>
<th>Questions</th>
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<tbody>
<tr>
<td>1</td>
<td>MODEL NAME (including acronym and version)</td>
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<tr>
<td>2</td>
<td>MODEL DEVELOPER(S) (name(s), address(es))</td>
</tr>
<tr>
<td>3</td>
<td>OPERATIONAL SYSTEM (used for model runs)</td>
</tr>
<tr>
<td>4</td>
<td>MODEL SCALE (e.g., field, farm, regional, etc.)</td>
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<tr>
<td>5</td>
<td>ABSTRACT (model description, including inputs)</td>
</tr>
<tr>
<td>6</td>
<td>MODEL OUTPUTS</td>
</tr>
<tr>
<td>7</td>
<td>MODEL APPLICATIONS IN EUROPE (e.g. model evaluation, testing irrigation strategies, climate change impact studies, etc.)</td>
</tr>
<tr>
<td>8</td>
<td>MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS</td>
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<td>9</td>
<td>ADDITIONAL MODEL INFORMATION</td>
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<tr>
<td>10</td>
<td>CONTACT NAME AND ADDRESS</td>
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<tr>
<td>11</td>
<td>REFERENCES (if possible, reprints/PDF copies should be mailed/attached)</td>
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</table>

It is necessary to emphasize that the author of this report is aware of the limited information obtained and consequently summarized/posted here. It was difficult/impossible to have an access to all available literature in the field; time for preparing this report was also limited. The received replies to the questionnaire on crop models in Europe were also below the expected ones.

3. Summarizing results

3.1. Previous crop model summarizing

Baier (1977) discusses general principles of crop growth simulation and gives typical examples, including the ELCROS and SPAM models. According to the author a crop-growth simulation model may be defined as a simplified representation of the physical, chemical and physiology mechanisms underlying plant and crop growth processes. Baier also explains the nature of crop-weather analysis models as a research tool for analyzing crop responses to weather and climate when climatological data only are available. The prediction system of spring wheat yields from temperature and precipitation data, as proposed by Haun (Baier, 1977) is determined to belong in this category of crop-weather analysis models.

One of the tasks of the AgRISTARS project (Motha, 1980) was to review the literature regarding crop yield models. Crop yield models are evaluated based on established criteria to identify candidate models for application testing in the AgRISTARS program. There are numerous types of models requiring varying scale of input data. The Motha’s reviews (1980) do not attempt to classify models into such categories as statistically-based, physiological, etc., but indicate the basic approach used in model development. Most attention is given to those modes requiring monthly meteorological data during the first phase. The format of the reviews is described as follows: author/title/source, abstract, area, model design, critique, author’s comments (Motha, 1980).

Haun (1983) presents a summary on mathematical models in agrometeorology, which seems to sound partly valid also nowadays. This author specifies the literature on plant-environment modeling had expanded greatly in previous years. Most of the models are academic exercises that have no immediate “practical” use. Many of them are in the research stage.
and are limited in value because of incomplete theoretical basis and/or insufficient database. Simulation procedures have many potential uses in modeling. However models are, like chains, no better than their weakest links. Efforts to aggregate as many separate plant processes as possible into large models are limited by the tentative or “approximate” nature of many submodels and insufficient knowledge of interactions among submodels (Haun, 1983).

Sirotenko (1983) provides an analysis of development trends in crop-yield-weather models. Difficulties in the mathematical modeling of this system are considered. The questions of modeling the processes of energy and mass exchange in connection with agrometeorological problems are also described in his work (Sirotenko, 1983). It is shown that large simulation models are necessary for the development of a theoretical basis for agrometeorology, in which they will play the same role as global numerical models of the general atmospheric circulation in the development of climate theory. Questions connected with modeling the important live in plants are also concerned. Models of these processes are the foundation of dynamic models of the agroecosystem productivity. An analysis of the dynamic models of productivity, available to the author, is also comprised. Particular attention is given to the dynamic-statistical crop-yield-weather models. The main directions for using these models are considered as well as means and ways for their further development (Sirotenko, 1983).

Robertson (1983) reports that several models have been developed in many countries for determining yields for the most important agricultural crops. Within the chapter on crop monitoring and yield forecasting the problem area, objective, model description, computer requirements, scale, data requirements, validation and application, limitations and remarks as well as references are specified for the following: relative assessment (developed in USA) of potential food production, multiple regression models for yield estimates (Germany), the Champagne model (France), FAO model for crop monitoring and yield forecasting (FAO, Italy), soil moisture evaluation programme (SMEP, Canada), weather-soil yield projection model (Canada), the productivity of agroecosystems by a dynamic model (USSR), simulator of seasonal forage yield (SIMFOY, Canada) (Robertson, 1983). Robertson (1984) reports also the crop models have a wide range of applications in agricultural activities. These include crop zoning, land-use planning, management and operation of the production and processing of perishable crops, characterizing genotype response to the environment and use as a biological time-scale sub-model in weather-based systems for monitoring crop conditions and forecasting crop yield and production.

The WMO/UNEP/ICSU-SCOPE expert meeting (WMO, 1985) on the reliability of crop-climate models for assessing the impacts of climatic change and variability (held in Geneva, Switzerland, 1984) summarized the existing crop-climate models range from purely statistical to complex process-based simulation models. Each type has its strength and weaknesses, but, on balance, the process-based models are more appropriate for CO2-related impact studies. It should be borne in mind, however, that the use of any crop-climate model alone represents only a beginning step. Eventually, full analysis of components of agricultural systems, including plant growth, pests, disease and management models (WMO, 1985).

The WMO report prepared by Plaisier (1986) contains a description of crop-climate models with potential to evaluate climate change. Details such as objectives, description of the model, time scale, input data requirements, validation, application and limitations, computer requirements and tape specifications, references and contacts are included for each model. Though the objectives of all models included within the report are yield related, the description and specification vary considerably. Some general goals of these models are: predicting final yield from weather data and crop characteristics; establishing relationships between a single or a number of weather factors and yield or yield components; predicting the dates of some impor-
tant phenological characteristics in order to improve the quality of agricultural planning; integrating knowledge in order to increase insight into physiology and ecology of the crop and to provide a research tool for further development (Plaisier, 1986). The wheat crop has greatly attracted modellers and that models for this crop exist in all continents. Models developed for this crop also have been applied successfully in regions other than where it has been developed. Maize is the other crop which has received considerably attention by modellers (Plaisier, 1986).

The WMO RA VI Working Group on Agricultural Meteorology pointed out in 1988 (CAgM, 1988) that dynamic models of crop production make it possible to simulate effects of agrometeorological conditions on main aspects of photosynthetic of the potato and to appraise the extent of such impact. The same models are used to describe photosynthesis, respiration and growth. The WMO RA VI Working Group reviewed also multilevel explanatory models for potato had appeared in the literature, the ELCROS model and its modification BACROS developed by the Wageningen Scholl, the POMOD 1 model, the POTATO model and the SWACRO model (CAgM, 1988).

Perhaps the most current and comprehensive overview on crop models is given by Hoogenboom (1999, 2000). According to him, current literature reviews show that there are at least 100 different simulation models. The largest number of models can be found for wheat, as it is one of the most important food crops. A limited number of models exist for the other grain cereals, grain legumes, root and tuber crops, and specialty crops such as vegetables and fruits. However, there are many other crops for which no crop simulation models have been developed, either due to lack of resources or interest (Hoogenboom, 1999). Hoogenboom (1999, 2000) acknowledges the ‘School of De Wit’ (e.g. de Wit and Goudriaan, 1974; Bouman et al., 1996) which defines four different levels or facets with respect to the evolution of plant growth models (e.g. Penning de Vries and van Laar, 1982; Penning de Vries et al., 1989).

According to Hoogenboom (2000) crop simulation models can play an important role at different levels of applications, ranging from decision support for crop management at a farm level to advancing understanding of sciences at a research level. The main goal of most applications is to predict final yield in the form of either grain yield, fruit yield, root or tuber yield, biomass yield for fodder, or any other harvestable product. In some cases, associated variables, such as resource use or the impact of pollution on the environment, might also be of interest. Certain applications link the price of the harvestable product with the cost of inputs and production to determine economic returns. One application is the use of crop simulation models for policy management. Hoogenboom (2000) defines the management applications of crop simulation models can be defined as strategic applications, tactical applications, and forecasting applications. In strategic applications, the crop models are run prior to planting of a crop to evaluate alternative management strategies. In tactical applications, the crop models are run before planting or during the actual growing season. Both strategic and tactical applications provide information for decision making by either a farmer, consultant, policy maker, or other person involved directly with agricultural management and production. Forecasting applications can be conducted either prior to planting of a crop or during the growing season. The main objective is to predict yield; this information can be used at a farm-level for marketing decisions or at a government level for policy issues and food security decisions. Crop simulation models can play a critical role in crop yield forecasting applications if accurate weather information is available, both with respect to observed conditions as well as weather forecasts (Abawi et al., 1995; Hoogenboom, 2000; Nichols, 1991).

Hunkar (2000) points out the history of agrometeorological models shows that only well and widely organized huge projects can lead to success. Encouraging to establish this kind of teams, PhD programs may help from both side. Another question is model dissemination. For
example, there are some valuable crop growth models used only by the developers. The reason may be that a model developer often feels that something is missing from the completed model version, therefore the model is not appropriate for application. It is more or less true according to Hunkar (2000). Another problem she rises is the required model input data - different according to the individual models. Agricultural field experiments, which are not planned for the special model building work, do not contain all of required input model data. It causes difficulties in model adaptation. Furthermore some of required input model data are not available on network basis which also make constraints in practical use. From a practical point of view Hunkar (2000) emphasizes that simplicity is a great advantage in model application and adaptation.

3.2 Crop model registers on the web: CAMASE and ECOBASE

The Internet capabilities and especially users have been considerably growing during the last years. Many crop growth models were registered and posted on the web through the CAMASE project (CAMASE, 2002). CAMASE was a Concerted Action for the development and testing of quantitative Methods for research on Agricultural Systems and the Environment. The objectives of CAMASE were to advance quantitative research on agricultural systems and their environment in the EU-countries, by improving systems research in participating institutes through exchange and standardization of concepts, approaches, knowledge, computer programs and data. One of the specific objectives was to produce a register of models. CAMASE started in November 1993, and was funded for three years. Marja Plentinger and Frits Penning de Vries coordinated the project. The CAMASE Register of Agroecosystems Models was last updated in June, 1996 and contain a list of 211 agroecosystems models (most of them are listed in Table 2).

There is another web server for ecological modelling, which updates frequently its register of ecological models (REM, 2002). The Register of Ecological Models (REM, http://eco.wiz.uni-kassel.de/ecobas.html) is a meta-database for existing mathematical models in ecology. REM is a cooperative service of the University of Kassel and the GSF - National research center for Environment and Health, Germany. In REM, models can be searched either by: name or with regard the content; keywords, main subject, main medium, mathematical type of the model; free text search. The REM status shows 632 registered ecological models by 29 November 2001. In Table 3 the search models results (applying a free-text-search – in this case the word “crop”) are shown. There are near 200 ecological models containing the world “crop” within the particular model description. Some of the models listed in Table 3 are the same as ones posted in the previous Table 2.
Table 2. CAMASE register of agroecosystems models *(CAMAS, 2002)*

<table>
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<tr>
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<td>SAWAH 2.0</td>
<td>SWAGMAN</td>
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Table 3. Search models (by free-text-search). REM result of query: list of words: crop; 199 models found *REM, 2002*

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3.3. Crop models applied in Europe – the ESA International Symposiums on Modeling Cropping Systems, held in Spain (1999) and Italy (2001)

The 1st ESA (European Society for Agronomy) International Symposium on Modelling Cropping Systems was held during June 1999 in Lleida, Spain where aspects related to options in process simulation, applications, scale of application and software development were discussed by scientists coming from all over the world (ESA, 1999). Table 4 represents most of the crop models/model systems discussed during the Symposium and contributed by European researchers. 2nd Symposium on Modelling Cropping Systems was held in July, 2001 in Florence Italy. The Symposium was aimed at presenting and discussing approaches for process simulation in cropping systems modelling. A critical analysis of the research activity during the last decade was done. Special emphasis was given to the integration and comparison of such approaches, and to the techniques to develop and maintain cropping systems models (ESA, 2001). Table 5 gives an impression of crop models/model systems applied in Europe during the last few years. However, it should be emphasized that both Tables 4 and 5 do not represent many crop models applied in Europe, especially in east European countries.

3.4. Examples of current crop model applications in Europe

The SVAT model DAISY was modified in Belgium to be able to utilize remote sensing (RS) data in order to improve prediction of evapotranspiration and photosynthesis at plot scale. The link between RS data and the DAISY model is the development of the minimum, unstressed, canopy resistance during the growing season. Energy balance processes were simulated by applying resistance networks and a two-source model. Modeled data was validated against measurements performed for a winter wheat plot (van der Keur et al., 2001)

Different method for aggregating simulated county and national crop yields for winter wheat in Denmark were tested using a crop simulation model (CLIMCROP), which was run with and without irrigation for a range of soil types and climatic conditions. The aggregated county or national yield was calculated by summing simulated yield of each category multiplied by the area, they represent. Ten different combinations of scales of climate and soil data were used. The simulated results were compared with Danish county and national yield statistics for winter wheat from the period 1971–1997. There was, in general, a poor relationship between simulated and observed yields when the observed yields had been detrended to remove the technology effect. A larger fraction of the inter-annual variability was captured by the model on the loamy soils compared with the sandy soils. The model was able to capture most of the spatial variation in observed yields, except at the coarsest resolutions of the soil data. The finest resolution of soil and climate data gave a better fit of simulated to observed spatial autocorrelation in yield. The results indicate that upscaling of simulated productivity of crops for Danish conditions requires a spatial resolution of soil data of 10 x 10 km or finer (Olesen et al., 2000).

A method of upscaling a site-based crop model to obtain regional and national results on spring wheat productivity under changing climate was presented in Finland. The model, CERES-Wheat, was calibrated and validated first at sites, and in the upscaling phase it was run across a regular 10 x 10 km grid over Finland. In the grid the model was run both for the present-day (1961–1996) climate and scenarios of future climate for 2050. Regional averages were computed for the years 1981–1996 to be comparable to yield observations in the farm yield statistics.
Table 4. Models in Europe, discussed during the 1st International Symposium on Modeling Cropping Systems, Lleida, Catalonia, Spain, 1999 (*ESA, 1999*).

<table>
<thead>
<tr>
<th>Model (developed/ applied)</th>
<th>Authors of the contribution</th>
<th>European country involved</th>
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<tbody>
<tr>
<td>AFRCWHEAT2-O3</td>
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<td>Hamos and Kovács</td>
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<td>CROPSIM, SUCROS2</td>
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<td>CGMS</td>
<td>Buffet et al.</td>
<td>Belgium</td>
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</tr>
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<td>Hungary</td>
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<td>Bulgaria</td>
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<td>CERES</td>
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<td>Spain, France</td>
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<td>CERES</td>
<td>Quemada et al.</td>
<td>Spain</td>
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<td>Zalud, Dubrovska and Stastna</td>
<td>Czech Republic</td>
</tr>
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<td>France, Spain, Italy, Germany</td>
</tr>
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</tr>
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<td>Spain</td>
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<td>Italy</td>
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</tr>
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</tr>
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<td></td>
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<td>CSS</td>
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<td>Berntsen et al.</td>
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<td>Israel*</td>
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<td>Germany</td>
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<td>Italy</td>
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<td>model of sorghum</td>
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<td>France</td>
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* Israel is a member of RA VI*
CERES-Wheat does not consider crop stress caused by poor soil aeration under wet conditions; however, this was found to be crucial to obtain satisfactory simulation results at sites. The model was modified accordingly, and the new version labelled ‘CERES-Wet-Wheat’. The results indicate that CERES-Wet-Wheat was able to detect both at the site and regional scale yield variations dependent on climate, even though the approach did not consider variations in crop management, pests and diseases and soil dependent differences in initial conditions (Saarikko, 2000).

The plant module of the EPIC model (Erosion Productivity Impact Calculator) has been modified in France to simulate the effects of water and nitrogen (N) stress on biomass production and grain yield, taking account of the sensitivity of the crops to water and N stress during the course of their developmental cycle. This French version of the model, EPICphase, was validated with maize, sunflower, sorghum, soybean and winter wheat over 9 years, using experimental data from a long-term cropping system experiment carried out at three levels of cropping intensity. The results have been compared with those from a normal version of EPIC. The results show that EPIC overestimates crop production by comparison with the measured data, notably under conditions of severe moisture stress. The additional crop parameters introduced into EPICphase concern the water extraction capacities peculiar to each crop, the division of the growth period into four phases, with adjustments to the conversion efficiency of intercepted radiation into biomass, and the drought adaptation of sunflower and soybean (Cabelguenne et al., 1999).

ORYZA1 is an explanatory model to simulate rice growth, development and leaf area index (LAI) under potential production. Casanova et al. (2000) conducted a study testing the performance of ORYZA1 for Mediterranean conditions for fully irrigated direct-seeded rice. ORYZA1 was calibrated and validated with field data of two cultivars, a short-grain (Tebre) and a long-grain cultivar (L-202), grown in various years in the Ebro Delta of Spain. Phenological development of the rice crop, daily dry matter production and leaf area development were calibrated. The model simulated rice growth very accurately until flowering. After flowering, however, divergences appeared and increased especially at the yellow ripe stage. From then on the crop did not grow much more, whereas it continued in the simulation. This reduction of growth rate was usually accompanied by an increase in the relative death rate of leaves and the drying of the grains. The main source of error may be a limited understanding of the ripening and sink limitation processes.

Soil characteristics are some of the most important inputs in crop simulation models like CERES-Maize and MACROS models under field conditions. A sensitivity analysis of these models was carried out in Czech Republic (Stastna and Zalud, 1999) for 1995 and 1996 by incorporating changes of the measured values of three basic soil input parameters: wilting point, saturated soil water content and field capacity. For this purpose, eight soil profile layers were chosen for CERES-Maize and three for the MACROS model. The MACROS model was found to have a higher degree of sensitivity to changes in the relevant soil parameters than the CERES-Maize model, especially for wilting point. Alteration of the model's remaining parameters showed a negligible influence on yields for both the models.

A sensitivity analysis and analysis of the structure of the SIRIUS wheat model has resulted in the development of a simpler meta-model (Brooks et al., 2001), which produced very similar yield predictions to SIRIUS of potential and water-limited yields at two locations in the UK, Rothamsted and Edinburgh. The analysis showed that the response of wheat crops to climate could be explained using a few simple relationships. The meta-model aggregates the three main SIRIUS components, the calculation of leaf area index, the soil water balance model and the evapotranspiration calculations, into simpler equations.

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</table>
This results in a requirement for calibration of fewer model parameters and means that weather variables can be provided on a monthly rather than a daily time-step, because the meta-model can use cumulative values of weather variables. Consequently the meta-model is a valuable tool for regional impact assessments when detailed input data are usually not available.

Wheat models such as CERES-wheat, AFRCWHEAT2 and SIRIUS predict grain yield and have been widely used, in particular to assess possible effects of climate change. Observed yields from well-managed and documented UK agricultural experiments were used by Landau et al., (1998) for a large-scale study of these models’ grain yield predictions. None of the models accurately predicted historical grain yields between 1976 and 1993. Substantial disagreement was found between the models' predictions of both yield and yield loss due to water limitation. A regression of observed yields on monthly climatic variables indicated that indirect climatic effects play a considerable role in UK well-managed yields. The study shows that more work is needed before such yield predictions can be used with confidence in decision support or climate change assessment in the UK.

An adaptation of the CERES model for winter wheat and spring barley, the CROPGRO model for soybean as well as the WOFOST v.7.1 model for winter wheat and spring barley in selected agricultural regions in Austria have been initiated by Alexandrov et al. (2001a, 2002). Both three models adequately simulated the growth stages duration as influenced by cultivar and planting date (day-length, temperature). The difference between simulated and observed dates of anthesis and physiological maturity varies between zero and seven days. Simulated grain yields were in most cases in accordance with the measured data, with predicted yield results mainly within limits of ± 17% of measured yields. The obtained results indicated a satisfactory performance of the CERES, CROPGRO and WOFOST simulation models for winter wheat, spring barley and soybean in a fully defined environment in Austria. These three models were also applied to assess the potential climate change impact on the above crops in the country (e.g. Alexandrov and Eitzinger, 2001; Alexandrov et al., 2000; 2001b,c; 2002; Cajic et al., 2000).

In the context of the COST718 Working Group on Remote Sensing (http://agromet-cost.istea.bo.cnr.it/) the SWAP (Soil, Water, Atmosphere and Plant) model has been adopted as reference for describing the meteorological input requirements of the model, and the possibilities to obtain such input with the use of remote sensing (e.g. de Wit et al., 2001). SWAP’s history of development and redesign starts in 1978. The current SWAP model version 2.0 is the fruit of a longstanding cooperation by the Alterra-institute and the Water Resources department, both belonging to the Wageningen University and Research Centre, The Netherlands. The SWAP model is suitable to select viable water management options, to perform regional studies employing geographical information systems, and to illustrate transport processes for education and extension. In recent years SWAP has been employed to explore alternative flow and transport concepts, to analyze laboratory and field experiments, and to evaluate management options with respect to field scale water and solute movement. Typical examples of applications where SWAP has been applied, were published by van Dam (2000).

Crop models are useful for monitoring crop production on a local scale. Their application to a larger area, such as a region, is hampered by the difficulty in determining the value of some of their parameters, which may differ greatly between fields. The use of optical remote sensing helps to overcome this problem. Coupling a radiation transfer model to a crop model makes it possible to simulate reflectance for those times in crop growth for which remote sensing data are available. The inversion of the combined model on these data then makes it possible to estimate new values for certain sensitive parameters of the crop model. In France, Guerif and Duke (1998) described the use of such a method on a local scale, for sugar beet, focusing on the
parameters describing emergence and early crop growth. These processes vary greatly depending on the soil, climate and seedbed preparation, and affect yield significantly. The SUCROS crop model and the SAIL reflectance model were combined. The resulting model was calibrated under standard conditions and then evaluated under test conditions to which the emergence and early growth parameters of the SUCROS model were adjusted. Application of this method on a regional scale, for yield prediction or agronomic diagnosis, should be of great value (Guerif and Duke, 1998).

An investigation carried out by Bannayan and Crout (1999) evaluated the utility of the SUCROS model for site-specific real-time crop biomass and grain-yield forecasting. A stochastic forecasting approach was used combining generated weather data with observed data for model updating. The forecast procedure was tested with field data collected at four sites in the UK over two growing seasons. The results showed that across all site-years, the model is able to forecast the final biomass and grain yield with <10% bias. There was no significant difference between observed and forecasted biomass and grain yield for forecasts made at anthesis or milky grain stage although earlier forecasts did show significant differences. The ranking of the observed and forecast biomass and grain yield were also highly correlated for the later forecasts.

3.5. Summarizing the submitted questionnaires on crop growth simulation models in Europe with potential for operational assessment of crop status and yield prognosis

Twenty-six filled in questionnaires were received from eighteen European (RA VI) countries. The models described within the questionnaires are shown in Table 6. All questionnaires are presented in an Appendix at the end of this report. All of them were reformatted (for the purpose of this report), however, in most cases the submitted information is presented 1:1. It is considered that the contact persons listed within the filled in questionnaires would take the responsibilities for the respective model information. Here, only a short summary of the model potential for operational assessment of crop status and yield is presented below:

WOFOST v.6.0 was developed under the Contract study “Models for yield forecasting” issued by the Joint Research Centre (JRC) of the EC at Ispra, Italy, in the framework of Action 3 of the Agriculture Project, also called MARS project (Monitoring Agriculture with Remote Sensing). The objective of this study was to generate crop growth indicators for the quality of the current agricultural season over European countries regions as compared to the quality of historic seasons, and to use these indicators for quantitative yield prediction per region or per country (Kazandjiev, 2001).

CGMS (Crop Growth Monitoring System) including the WOFOST 6.0 model is run operationally and the results are used within the JRC and DG-Agriculture Outlook group to support real-time analysis of the agricultural campaign in course and outlook analysis to support Common Agriculture Policy decisions. A report called the MARS bulletin, containing several results of CGMS, is published regularly (http://mars.aris.sai.jrc.it/mars/stats/bulletin) (Genovese and Orlandi, 2001). CGMS is described in 3.6.3.

The STICS model has been used at the agricultural plot scale to make agronomic or environmental diagnoses or to evaluate crop management schedules (Brisson, 2001). It is also being used at the intra-plot scale in a precision farming framework. However, at this intra-plot scale, one could question whether the model's sensitivity to its input variables is sufficient to reproduce the spatial variability studied. At the regional scale, STICS is used to estimate the
potential of the environment or to make agronomic diagnoses on a large scale using remote sensing. It is also used in association with a hydrological model to estimate nitrate leaching at the scale of a watershed or a region. As part of the ISOP programme, STICS gives estimations of forage production in real time for the whole French territory. Some studies base themselves on the STICS model to test the effects of climatic changes on cash crops, on the flowering of fruit trees and on forage calendars in mountainous areas. It can also contribute significantly to socio-economic studies (Brisson, 2001).

Table 6. Crop models in Europe, described within the filled in questionnaires and source (countries) of information

<table>
<thead>
<tr>
<th>Model</th>
<th>Source of information</th>
</tr>
</thead>
<tbody>
<tr>
<td>AGROSIM <em>(AGROecosystem SIMulation)</em> – Agroecosystem model family, v. 1.95</td>
<td>GERMANY</td>
</tr>
<tr>
<td>CERES (Crop Estimation through Resource and Environment Synthesis) – Wheat, v. 2.1 and later</td>
<td>FINLAND</td>
</tr>
<tr>
<td>CERES-Maize v. 2.1</td>
<td>HUNGARY</td>
</tr>
<tr>
<td>CERES-Wheat, CERES-Maize, CERES-Rice, SOYGRO, CROPWAT</td>
<td>SPAIN</td>
</tr>
<tr>
<td>CGMS – Crop Growth Monitoring System, v. 2.0a</td>
<td>ITALY (JRC)</td>
</tr>
<tr>
<td>CLIMATE – SOIL – YIELD</td>
<td>RUSSIA</td>
</tr>
<tr>
<td>CROPSYST (Cropping Systems Simulation Model)</td>
<td>ITALY</td>
</tr>
<tr>
<td>CROPWAT7</td>
<td>TURKEY</td>
</tr>
<tr>
<td>Growth and Development of Barley</td>
<td>CYPRUS</td>
</tr>
<tr>
<td>GVM (Growth Verhulst Model)</td>
<td>BULGARIA</td>
</tr>
<tr>
<td>HERMES</td>
<td>GERMANY</td>
</tr>
<tr>
<td>ImpelERO: nn expert system/neural network model for evaluating soil erosion, impact on crop productivity and management practices accommodation</td>
<td>SPAIN</td>
</tr>
<tr>
<td>IRRFIB-3 (Irrigation forecast model)</td>
<td>SLOVENIA</td>
</tr>
<tr>
<td>IRRIS</td>
<td>TURKEY</td>
</tr>
<tr>
<td>(a) Johnstown Castle Grass Growth Model</td>
<td>IRELAND</td>
</tr>
<tr>
<td>(b) Met Eireann Potato Blight Warnings</td>
<td></td>
</tr>
<tr>
<td>LAPS (Land Air Parameterization Scheme)</td>
<td>YUGOSLAVIA</td>
</tr>
<tr>
<td>PASIM (Pasture Simulation Model)</td>
<td>SWITZERLAND</td>
</tr>
<tr>
<td>POTATO 2</td>
<td>PORTUGAL</td>
</tr>
<tr>
<td>PROMET-V (Process oriented Modular Environment and Vegetation model)</td>
<td>GERMANY/USA</td>
</tr>
<tr>
<td>Semi-empirical mathematical model of tea-bush shoot formation</td>
<td>GEORGIA</td>
</tr>
<tr>
<td>Simplified dynamic model of tea crop</td>
<td>GEORGIA</td>
</tr>
<tr>
<td>STICS (Simulateur multiTidisciplinaire pour les Cultures Standard) v. 4.0</td>
<td>FRANCE</td>
</tr>
<tr>
<td>a) SUCROS</td>
<td>THE NETHERLANDS</td>
</tr>
<tr>
<td>b) A-gs model</td>
<td></td>
</tr>
<tr>
<td>VGSM (Vine Growth Simulation Model), v. 2.01</td>
<td>GEORGIA</td>
</tr>
<tr>
<td>WDM (Wheat Disease Manager)</td>
<td>UNITED KINGDOM</td>
</tr>
<tr>
<td>WOOP (wheat development and growth object-oriented programmed)</td>
<td>GERMANY</td>
</tr>
<tr>
<td>WOFOST v.6.0 (World Food Study)</td>
<td>BULGARIA</td>
</tr>
</tbody>
</table>

The geoinformation system CLIMATE-SOIL-YIELD consists of: 1.) WEATHER-CLIMATE simulation dynamic models of agroecosystem productivity; 2.) a model of energo-mass-exchange in plant-soil-atmosphere system; 3.) stochastic models permitting generation of annual series of daily weather elements corresponding to specified climate norms; 4.) a database including hydrometeorological data over 100 year period, scenarios of possible climate changes and data about physical and agrochemical soil properties (Sirotenko, 2001). Different versions of the WEATHER-CLIMATE model were tested for a wide variety of climatic, soil and agro-
technical conditions of different regions in Russia as well as other countries (mainly eastern European countries). Tested crops include, for example, spring wheat and pea (Moldavia), spring barley (Slovakia, Poland), tomato (Ukraine), etc. The model has been used as a practical instrument for operational assessment of crop in Russia and yield prognosis since 1998 (Sirotenko, 2001).

A 3-year experiment was carried out near Modena, Italy in order to estimate the environmental impact of urea and pig slurry applied to a maize crop (Marchetti et al., 1999). Each fertilizer was applied to give 0, 75, 150 or 225 kg N/ha, in factorial combinations. A considerable spatial and temporal variability of maize yield was observed for the same treatment in an apparently uniform field. The possibility of predicting such variability by analysing the available information about soil properties and climatic conditions, using both statistical methods and simulation models, was investigated. The significance of the treatment effects was spatially dependent. Yield variability could be explained by differences in soil NO₃ content at the beginning of the growing season, and by spatial differences in soil C and N content. Yield variability was simulated with the CROPSYST model, and it is suggested that the complementary use of statistical analysis and model simulation may constitute an effective (Marchetti et al., 1999).

According to Iglesias (2001) the CERES, SOYGRO, and CROPWAT models are already widely used in operational mode. The Research Institute of Rural Services in Ankara, Turkey (Ozalp, 2001) submitted an information the CROPWAT7 model estimates relative yield reductions. The VGSM vine model can be used for testing irrigation strategies as well as climate change impact on vine production, etc. (Shelia, 2001). The AGROSIM models exist for a scientific use, not for a use within decision support or prognosis systems up to now. An integration in such systems is possible, but on the source level only. For a successful yield prognosis reliable weather forecast data are necessary (Mirschel, 2001).

The WOOP model simulates yield and yield components very good. The new description of plant stages allows the calculation of the developments stages at least at the places mentioned above, where the program has been validated. The phyllochron for the location should be known (Haeckel, 2001). The HERMES model can be used to predict relevant crop development stages for nitrogen fertilization and yield formation using site specific weather scenarios (Kersebaum, 2001). PROMET-V has a very high potential for operational use, but have been not tested yet. Integration of model, remote sensing and GIS are particularly useful for decision support (Schneider, 2001).

The irrigation forecast IRRFIB-3 model generates the crop-soil-water balance ranging from one day to whole vegetation period. Data obtained can be given as tables including time increments or entire vegetation period or graphically presented curves of soil water content for irrigated and non irrigated crops. Different degrees of plant water stress for crops can be observed when crops are not irrigated. An additional curve of irrigation water applications is generated when for a specific crop the maximum application rate of water for the predefined irrigation system is given. The model gives the near future irrigation needs up to seven days, when including forecasted weather parameters. In the case of weather forecast with precipitation sufficient to replenish the soil water reservoir throughout the crop rooting depth the irrigation can be canceled (Matajc, 2001).

The Growth and Development of Barley model potential for operational assessment of crop status and yield prognosis is related to: 1.) production land use systems; 2.) testing sowing date; 3.) effect of water stress conditions on crop yield (Pashiardis and Michaelides, 2001). The pasture simulation model PASIM can be driven by hourly weather scenarios provided by cli-
mate models and downscaled to site of interest. There is a potential to use medium-range weather forecast for seasonal yield predictions (Fuhrer, 2001). The IRSIS model potential for operational assessment of crop status and yield are related to model estimates of relative yield and yield reductions (Ozalp, 2001). The Johnstown Castle Grass Growth Model shows very good potential and there is ongoing research for its use (Holden, 2001). Milne (2001) gives two answers on the WDM model potential for operational assessment of crop status and prognosis: 1.) Yes, if the limiting factor is foliar and ear diseases; 2.) No, if NPK, irrigation, take-all, weeds, etc.

A logistic nature of growth processes, as well as a specific character of agrotechnical measures change tea crop dynamics substantially during vegetation. Without consideration of the given effect, it is impossible to make correct assessment of tea plantation state, the impact of other factors upon its productivity and that is most important, it is impossible to make forecast of harvest (Gudusha, 2001). By means of the mathematical model of shoot formation, it is managed to make the quantitative assessment of the impact of biological peculiarities of tea-bushes, allowing to describe the dependence of tea crop upon weather factors in a "clean way". Simultaneous consideration of impacts of age and biology of tea bushes, as well as weather, allowed to model over 90% of a whole information on time dynamics of tea crop (Gudusha, 2001).

On the basis of the dynamic model of tea crop, a scheme of long-range forecasting the tea crop has been built up, the parameter of which is a prognostic value of air temperature sums accumulated for a vegetation period (Gudusha, 2001). The forecast of the sums of mean daily air temperatures are made by a known method of Davitaya. On the basis of the forecast of rhythmic dynamics of tea crop during the picking season, a commercial activity and technical works may be planned. By means of the model, the approach of tea shoots to picking for a harvest season may be regulated changing the duration of the period between pickings depending upon the possibilities of farms to conduct agrotechnical and technological works, connected with pick up and processing of tea leaves (Gudusha, 2001).

The GVM model potentialities are focused on the managing of the different agricultural treatments, first of all irrigation (Valkov, 2001). The model capabilities are connected with the form of the main growth model. The model is based on a system of ordinary differential equations. This fact gives a possibility to use mathematical managing with respect of optimal expenses with given yield or optimal yield with given expenses. The problem of crop managing needs a huge computer resource and it is very important to use a compact and reliable growth model. GVM is constructed especially for the purpose of the yield managing. This is a reason of the simplified form of the growth model - the main parameters are the growth from one side and external parameters - air temperature and soil moisture from the other side. There is a possibility to enlarge the number of parameters in case of special needs.

3.6. Case studies of crop simulation models in Europe with potential for assessment of crop status and yield prediction

Crop simulation models are receiving increasing use in agriculture and are recommended as multipurpose tools in research and farm management. Simulation models have been developed for many crops (e.g. Ritchie, 1994). These models can be used as research tools to help improve understanding of the physiology of crop growth and development, and as decision-support tools to help the optimize crop and soil management strategies. Of one particular interest to crop growers is the possibility of applying crop models for real-time yield forecasting.
Timely and accurate crop yield forecasting and prediction on regional, national and international scales is increasingly becoming important in both developing and developed countries (e.g. Bouman et al., 1995).

3.6.1. Predicting national wheat yields using a crop simulation and trend models

The European Union's Directorate General for Agriculture requires timely and accurate estimates of the total wheat yield at national level. In a study carried out by Supit (1997), four simple prediction models were tested to assess their operational usefulness. These models consist of a trend function and a function, which accounts for weather influences. Two of them first predict the national yield per hectare, which is then multiplied by an area estimate, the other two predict the national yield directly. Input variables are crop growth simulation results, planted area and a trend function. As trend functions, a linear time trend and a trend based on the nitrogen fertilizer application per hectare are tested. Total national wheat yield for twelve European countries for 10 years were predicted. The results were evaluated against observed official national yield and yield statistics, using as criterion the relative root mean square error (RRMSE) and the root mean square error (RMSE). Area and nitrogen application estimates come available a few months after the end of the growing season. Therefore, the models were also tested using estimated area and nitrogen application values available as input. Crop growth simulation results proved to be more useful for predicting national yield volumes than national yield, suggesting that both area and crop growth simulation results account for the annual variation of the yield volume (Supit, 1997).

3.6.2. Crop Growth Monitoring System (CGMS)

The Directorate General for Agriculture (DG AGRI) of the EU (European Union) is responsible for implementation and control of the various EU policies on agriculture. To manage these policies DG AGRI requires detailed information on planted area, crop yield and production volume (Supit and van der Goot, 2002). To support DG AGRI in executing its tasks, in 1988 the Monitoring Agriculture with Remote Sensing (MARS) project was initiated with the objective to generate monthly information on land use, land use changes, exceptional growing conditions such as water stress and expected yields. This information had to be provided for various crops for all member states of the EU. To realize this objective, the MARS project used field surveys, high and low resolution satellite data and a crop growth simulation model (Dallemand and Vossen, 1995; Supit and van der Goot, 2002).

In order to estimate the expected yields, a crop growth simulation model was combined with a detailed soil map, parameters for the various crops and spatial crop information to create the Crop Growth Monitoring System (CGMS) (Supit and van der Goot, 2002; Vossen and Rijks, 1995). CGMS uses daily meteorological observations to estimate crop status (i.e. water stress, biomass production, etc.) in the course of the growing season and crop yield at the end of the season.

The WOFOST crop growth simulation model was selected and combined with a GIS and a yield prediction routine to form CGMS. The WOFOST (WOrld FOod STudies) explanatory and dynamic crop model (e.g. Supit et al., 1994; Supit and van der Goot, 2002; van Diepen et al., 1989) was developed by the DLO-Winand Staring Centre and Research Institute for Agrobiology and Soil Fertility in Wageningen (e.g. Boogaard et al. 1998). WOFOST is a member of the family of models developed in Wageningen, The Netherlands. It simulates the growth
and development of annual field crops during the growing season, from sowing to maturity or harvest. The main processes taken into account are phenological development, assimilation, respiration and evapotranspiration. The model calculates this per cropping system, defined by crop, weather conditions, and soil parameters. WOFOST also calculates the soil water balance. Outside the crop growing period the soil water balance can be calculated for bare soil conditions. In WOFOST three different soil water sub-models are distinguished. The first and most simple water balance applies to the potential production situation. The second method for estimating water balance in the case of water-limited production applies to a freely draining soil, where groundwater is so deep that it cannot influence the soil moisture content in the rooting zone. This soil water balance is based on the cascade principle. The third water balance is used for water-limited production on soils with groundwater impact in the rooting zone.

![Diagram of Crop Growth Monitoring System (CGMS)](image)

Fig. 1. Schematic overview of the Crop Growth Monitoring System (CGMS) (Supit and van der Goot, 2002).

For each of the crops included in CGMS, standard values for crop parameters were collected representing region specific crop growth characteristics. Figure 1 presents a schematic overview of CGMS; three levels can be distinguished (Supit and van der Goot, 2002). The first level is the weather system. Historical and actual weather data are collected, corrected and subsequently interpolated to the grid centre. The CGMS system as used by the European Commission is based on a 50 x 50 km grid. Other CGMS systems may use a different grid size. Historical, actual and interpolated meteorological data are stored in a database. The interpolated data are subsequently introduced in WOFOST. At the second level, crop growth simulation takes place. In addition to the interpolated data obtained at Level 1, crop characteristics and soil information are needed as input for WOFOST (Supit and van der Goot, 2002).

The objective of the MARS project is to predict production volumes of the major crops at national level and possibly at regional level for all EU member states. Production volume is divided in a yield and a planted area component, which are estimated separately and subse
Production volume predictions are refined in the course of the year, from an early indicator value through provisional data to final results. A panel of analysts performs these predictions on a monthly basis, from March till September. Every ten days, they also assess crop growth conditions, such as occurrences of droughts, excess rain, etc. It is assumed that changes in crop growth and development as a result of, for example, stress situations, can be detected by CGMS and on remote sensing images, obtained in consecutive ten-day periods. The first predictions are based on extrapolated yield and planted area time series. In the course of the season, information provided by various sources is analyzed and combined – Fig. 2 (Supit and van der Goot, 2002).

Fig. 2. MARS yield forecasting system (Supit and van der Goot, 2002)

Where possible, information of each source is compared to information of preceding years obtained in the same 10-day period and to information obtained in the 10-day period in which the crops reached a similar simulated development stage. CGMS results included in the analysis consist of cartographic material, representing the simulation results per grid cell obtained at Levels 1, 2 and 3 (e.g. maps of temperature sums, maps of development stage, etc.) To gain insight into how current year’s crop growth and development compare to those of previous seasons, current year’s simulation results are also compared to the long time average simulation results and to results obtained from simulations performed with average meteorological input values. The simulation results used in this analysis are: total weight of aboveground biomass, total weight of storage organs, leaf area index, crop growth development stage, water use and soil moisture content. Furthermore, information on occurrence of pests, diseases, droughts and yield indications in individual EU member states, is retrieved from agricultural magazines and included in the analysis. Based on the analysis, the panel of analysts decides on magnitude of the production volume. Experts in various member states are requested to comment on these predictions (Supit and van der Goot, 2002).

Prediction results obtained at Level 3 (i.e. the prediction model), indicate how crops may have reacted to weather influences. The analysts adapt these results when, in their opinion,
other factors should be accounted for or when the predicted value is deemed to be incorrect. For prediction, one of the following simulation results is selected: potential yield, potential biomass, water-limited yield and water-limited biomass (Supit and van der Goot, 2002). A report called the MARS bulletin, containing several results of CGMS, is published regularly on http://mars.aris.sai.jrc.it/stats/bulletin/ – Fig. 3. Several web and FTP addresses on the MARS project and CGMS are listed within the filled in questionnaire (see the Appendix), kindly provided by G. Genovese and S. Orlandi (JRC-EC, IPSC/MARS).

Fig. 3. MARS bulletin - http://mars.aris.sai.jrc.it/stats/bulletin/

3.6.3. Operationally running software/models/systems in France

METEO-France organized a workshop in agrometeorology at the end of October, 2001 (Perarnaud, 2001). Several institutes dialing with agrometeorological service for farmers participated. The working group on the knowledge transfer from research to applications obtained several technical descriptions of operationally running decision support systems and crop growth models. Short outputs of the workshop are presented below:

An AGRO CLIM SYSTEM was developed. It was designed to advice on irrigation scheduling. Agronomic (including soil, crop, irrigation) and weather data are necessary inputs. The results are presented in the form of traditional curves of soil water content showing the temporal evolution of the soil water reserves and the risk of water stress. These curves are readjusted depending on the soil type. They are also compared with tensiometric curves for the same soils. From these curves, one can consult on the irrigation scheduling and water amount to be used. The consultation is then synthesized in a weekly form and can also be recorded on answering phone machine.

The COGIT0 software was described. It estimates the soil water content and crop water requirements and is based on the STICS crop growth model (see a detailed description on it within the Appendix). The STICS model developed by INRA (Avignon, Montfavet, France) can be considered as a reference regarding the operational aspect of crop model using (e.g. Maihol, 2001). This model is widely used in France to analyze the impact of fertilization practices on the environment. The STICS water and nitrogen transfers are based on reservoir concept (multi-
layers) whereas the growing module is based on more physical concepts. It works at daily time steps. Model inputs are: soil characterization, agrotechnology (sowing date and density, crop cultivar, irrigation applied - total volume and frequency), weather daily data (including air temperature, precipitation, solar radiation, etc.). The COGITO has been running on an experimental basis since 1998. It is applied for the Poitou-Charentes area with opportunity for expanding. The ISOP system is also based on the STICS model. ISOP is supplying information on the fodder regions (200) in France. The STICS model is running every 10-days in METEO-France and the respective results and assessments are monthly published as hard copies and on the web (Statistics of Ministry of Agriculture).

Researchers of INRA in Toulouse (France) have recently developed the MODERATO simulation tool coupling a biophysical model and a decision model. MODERATO is related to irrigation scheduling at a farm level. The concepts of the biophysical model is very similar to these ones of the STICS model - the difference is due to the fact that MODERATO uses decision rules specially for maize (e.g., Maihol, 2001). The MODERATO irrigation decision rules may be divided into a series of elementary rules dealing with: a) germination irrigation; b) irrigation to dissolve fertilizers; c) the starting date for the main irrigation period; d) the delay between two irrigations on the same plot; e) temporary halts due to climatic conditions; f) the date for ending irrigation.

DECLIQ (Développement et Expertise en Champagne pour la Lutte Intégrée et la Qualité) is a software giving epidemiological information and plant health recommendations. A harmonization of the recommendations is made according to the soils, the outputs of respective models, with the collaboration of the official services (Protection of the plants) and the wine groupings of technicians operating on the Champagne vineyards. It is using climatological and real-time (from automatic stations) weather data from 35 sites. The output information is disseminating via Internet and is intended for the wine growers and technicians. The plant health recommendations are updated every week whereas weather data is showing every day. In 2001 approximately 700 consultations per week were counted.

The product PANORAMIX was created in 1992 and is gathering models related to ecophysiology of cereals (e.g., wheat, spring, etc.). The principal models are related to crop phenology. The models are updated every year for new crop varieties. They are also revised periodically and enriched by new modules to answer the requests of users. The PANORAMIX software takes into account possible biological measurements made on the ground. In an integral simulation mode, one can make studies of different strategies. For example - to envisage the average dates (and deciles) of some phenological stages over an area, taking into account the sowing dates and crop varieties, in order to limit the risks of freezing. After harvest, a comparison between the results for a particular year and historical records is a base of additional assessment. By means of the PANORAMIX software, knowledge of some specialists is made available and accessible to users. The results are integrated in various services or are used in collaborations with different organizations.

3.6.4. A stochastic modelling approach for real-time forecasting – exploring CERES models for operational prognosis of crop phenology and yield of winter wheat and maize in Bulgaria

Operational prognosis of expected phenological stages and final grain yield in Bulgaria, applying the CERES models for wheat and maize (e.g., Tsuji et al., 1994, 1998), was initiated in the 1990s (e.g., Alexandrov, 1995a, b; Slavov et al., 1998). In May, 1994 agrotechnological and crop data, observed daily weather data as well as different weather scenarios were applied as inputs in the CERES model in order to simulate expected phenological development and final
The weather scenarios (from May till the end of the year) were simulated by a weather generator, developed by Alexandrov and Valkov (1993).

Table 7. Forecasted and observed maturity dates of winter wheat in 1994 at the experimental variety stations in Bulgaria, using CERES model for wheat (Alexandrov, 1995a,b).

<table>
<thead>
<tr>
<th>Station/Region</th>
<th>Sowing 1993</th>
<th>Forecasted maturity dates in 1994</th>
<th>Observed dates/1994</th>
<th>Δ (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>Benkovski</td>
<td>22.X</td>
<td>10.VI</td>
<td>09.VI</td>
<td>08.VI</td>
</tr>
<tr>
<td>Burgas</td>
<td>17.X</td>
<td>21.VI</td>
<td>20.VI</td>
<td>19.VI</td>
</tr>
<tr>
<td>Pavlikeni</td>
<td>14.X</td>
<td>15.VI</td>
<td>14.VI</td>
<td>13.VI</td>
</tr>
<tr>
<td>Svetlen</td>
<td>18.X</td>
<td>27.VI</td>
<td>26.VI</td>
<td>24.VI</td>
</tr>
<tr>
<td>Selanovci</td>
<td>11.X</td>
<td>24.VI</td>
<td>22.VI</td>
<td>21.VI</td>
</tr>
<tr>
<td>Carev brod</td>
<td>14.X</td>
<td>29.VI</td>
<td>27.VI</td>
<td>26.VI</td>
</tr>
<tr>
<td>South Bulgaria</td>
<td>25.X</td>
<td>19.VI</td>
<td>18.VI</td>
<td>17.VI</td>
</tr>
<tr>
<td>Total</td>
<td>28.X</td>
<td>21.VI</td>
<td>20.VI</td>
<td>18.VI</td>
</tr>
</tbody>
</table>

Legend: A - simulated maturity dates under the climatic (1961-1990) monthly air temperatures in June and July; B and C - simulated maturity dates under air monthly temperatures, higher than climatic values by 1°C and 2°C; D and E - simulated maturity dates under lower air monthly temperatures by 0.5°C and 1°C; Δ - departures of the simulated maturity dates (variant A), relative to the observed maturity dates.

They were based as follows: A) on expected monthly average air temperatures, equal to the climate norms for the period 1961 - 1990; B) and C) on expected temperatures, 1°C and 2°C higher than the climate norms, respectively; D) and E) on expected temperatures, 0.5°C and 1°C lower than the climate norms. At the same time a prognosis of crop phenological stages and expected dates of maturity was done. Such kinds of estimations are very helpful for agricultural management, especially for harvesting and grain conservation. The obtained results on wheat phenological prognosis in 1994 were good - the maturity dates of winter wheat were very close to the predicted ones for the whole territory (Table 7). In Table 8 a comparison between the forecasted and measured grain yield of winter wheat at experimental variety stations in Bulgaria is shown.
The obtained results show that under applying standard agrotechnology, the measured grain yield of winter wheat (averaged for the experimental variety stations in Bulgaria) was 5563 kg/ha in 1994, or about 87% of the predicted (variant A) one - 6397 kg/ha. A comparison to the national farm’s yield (approximately 3200 kg/ha according to the Ministry of Agriculture) leads to a conclusion that the farmers omitted the opportunity to obtain double the wheat grain yield in 1994. Moreover, the grain yield was with very low quality due to bad conditions for conservation.

Table 8. Forecasted and measured grain yield of winter wheat in 1994 at the experimental variety stations in Bulgaria, using CERES model for wheat (Alexandrov, 1995a,b).

<table>
<thead>
<tr>
<th>Station/Region</th>
<th>Sowing</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>Measured yield/1994</th>
<th>∆ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benkovski</td>
<td>22.X</td>
<td>5059</td>
<td>4992</td>
<td>4925</td>
<td>5118</td>
<td>5163</td>
<td>6850</td>
<td>-26.2</td>
</tr>
<tr>
<td>Bojanovo</td>
<td>17.X</td>
<td>6661</td>
<td>6512</td>
<td>6348</td>
<td>6773</td>
<td>6863</td>
<td>5030</td>
<td>+31.4</td>
</tr>
<tr>
<td>Brashljan</td>
<td>19.X</td>
<td>6815</td>
<td>6675</td>
<td>6545</td>
<td>6894</td>
<td>6971</td>
<td>5580</td>
<td>+22.1</td>
</tr>
<tr>
<td>Burgas</td>
<td>17.X</td>
<td>7142</td>
<td>6993</td>
<td>6857</td>
<td>7234</td>
<td>7333</td>
<td>525</td>
<td>+36.0</td>
</tr>
<tr>
<td>G. izvor</td>
<td>25.X</td>
<td>7391</td>
<td>7228</td>
<td>7061</td>
<td>7501</td>
<td>7594</td>
<td>6300</td>
<td>+17.3</td>
</tr>
<tr>
<td>Dobrich</td>
<td>15.X</td>
<td>8246</td>
<td>7975</td>
<td>7722</td>
<td>8372</td>
<td>8519</td>
<td>5350</td>
<td>+54.1</td>
</tr>
<tr>
<td>Jitnica</td>
<td>16.X</td>
<td>7046</td>
<td>6911</td>
<td>6778</td>
<td>7112</td>
<td>7206</td>
<td>6010</td>
<td>+17.2</td>
</tr>
<tr>
<td>Zimnica</td>
<td>19.X</td>
<td>6175</td>
<td>6060</td>
<td>5954</td>
<td>6259</td>
<td>6309</td>
<td>6020</td>
<td>+2.6</td>
</tr>
<tr>
<td>Kapitanovci</td>
<td>14.X</td>
<td>5509</td>
<td>5427</td>
<td>5372</td>
<td>5558</td>
<td>5606</td>
<td>5830</td>
<td>-5.5</td>
</tr>
<tr>
<td>Kojnare</td>
<td>13.X</td>
<td>6198</td>
<td>6063</td>
<td>5975</td>
<td>6247</td>
<td>6308</td>
<td>6000</td>
<td>+3.3</td>
</tr>
<tr>
<td>Kubrat</td>
<td>14.X</td>
<td>5529</td>
<td>5466</td>
<td>5403</td>
<td>5568</td>
<td>5608</td>
<td>5980</td>
<td>-7.5</td>
</tr>
<tr>
<td>Ljubimec</td>
<td>16.X</td>
<td>7420</td>
<td>7301</td>
<td>7203</td>
<td>7491</td>
<td>7552</td>
<td>6990</td>
<td>+6.2</td>
</tr>
<tr>
<td>Medkovec</td>
<td>20.X</td>
<td>5035</td>
<td>4912</td>
<td>4835</td>
<td>5091</td>
<td>5164</td>
<td>6000</td>
<td>-16.1</td>
</tr>
<tr>
<td>Ognjanivo</td>
<td>28.X</td>
<td>6458</td>
<td>6362</td>
<td>6267</td>
<td>6529</td>
<td>6598</td>
<td>7050</td>
<td>-8.4</td>
</tr>
<tr>
<td>Pavlikeni</td>
<td>14.X</td>
<td>6350</td>
<td>6257</td>
<td>6157</td>
<td>6381</td>
<td>6444</td>
<td>ND</td>
<td>-</td>
</tr>
<tr>
<td>Pordim</td>
<td>25.X</td>
<td>6486</td>
<td>6389</td>
<td>6291</td>
<td>6572</td>
<td>6638</td>
<td>2250</td>
<td>188.3</td>
</tr>
<tr>
<td>Radnevo</td>
<td>15.X</td>
<td>7234</td>
<td>7111</td>
<td>6988</td>
<td>7299</td>
<td>7360</td>
<td>4700</td>
<td>+53.9</td>
</tr>
<tr>
<td>Svetlen</td>
<td>18.X</td>
<td>6117</td>
<td>5888</td>
<td>5696</td>
<td>6234</td>
<td>6372</td>
<td>6600</td>
<td>-7.4</td>
</tr>
<tr>
<td>Selanovci</td>
<td>11.X</td>
<td>6367</td>
<td>6236</td>
<td>6132</td>
<td>6442</td>
<td>6527</td>
<td>4380</td>
<td>+45.4</td>
</tr>
<tr>
<td>Sitovo</td>
<td>19.X</td>
<td>5158</td>
<td>5075</td>
<td>5016</td>
<td>5203</td>
<td>5260</td>
<td>3480</td>
<td>+48.2</td>
</tr>
<tr>
<td>Carev brod</td>
<td>14.X</td>
<td>5945</td>
<td>5800</td>
<td>5688</td>
<td>6021</td>
<td>6111</td>
<td>5600</td>
<td>+6.2</td>
</tr>
<tr>
<td>North Bulgaria</td>
<td>11.X-25.X</td>
<td>6216</td>
<td>6083</td>
<td>5970</td>
<td>6284</td>
<td>6364</td>
<td>5255</td>
<td>+18.3</td>
</tr>
<tr>
<td>South Bulgaria</td>
<td>15.X-28.X</td>
<td>6693</td>
<td>6570</td>
<td>6450</td>
<td>6776</td>
<td>6847</td>
<td>6024</td>
<td>+11.1</td>
</tr>
<tr>
<td>Total</td>
<td>11.X-28.X</td>
<td>6397</td>
<td>6268</td>
<td>6153</td>
<td>6471</td>
<td>6548</td>
<td>5563</td>
<td>+15.0</td>
</tr>
</tbody>
</table>

Legend: A - simulated grain yield under the climatic (1961-1990) monthly air temperatures in June and July; B and C - simulated grain yield under air monthly temperatures, higher than climatic values by 1°C and 2°C; D and E - simulated grain yield under lower air monthly temperatures by 0.5°C and 1°C; Δ - departures of the simulated grain yield (variant A), relative to the measured yield.

The CERES model for maize was run at the end of June 1994, developing an operational prognosis on dates of silking and physiological maturity of widely used maize hybrids with middle-short and middle-long growing seasons (Table 9). When the silking date of maize occurred, an updated prognosis on grain yield was done. Five different prognoses were created according to the same number of scenarios, simulated by the weather generator. In general, the physiological maturity date for the whole territory of Bulgaria in 1994 occurred earlier than the mean date for the last years. The national average grain yield of maize was lower, comparing to
the data for the previous ten years. The weather conditions of 1994 presumed 4000 - 7000 kg/ha in rainfed and 8500 - 12000 kg/ha in irrigated fields. The forecasted maize grain yield was close to the average values for the last decades and a comparison to the measured yield showed a difference up to 20%. The major reason for such error was not related to the CERES model performance, but it was explained by not applying standard agrotechnological requirements in farmers’ activities.

The above method for operational prognosis of expected phenological development and final grain yield was applied also in 1995 - both for the operative agrometeorological stations and experimental variety stations across the country (Fig. 4 and 5). In the same manner, observed and generated daily meteorological values were applied as CERES model weather input. The agrometeorological prognoses were presented in the national media (newspapers, national radio and TV).

Table 9. Forecasted and observed silking and maturity dates of maize in 1994 at the experimental variety stations in Bulgaria, using CERES model for maize (Alexandrov, 1995a,b).

<table>
<thead>
<tr>
<th>Station/Region</th>
<th>Forecasted silking dates</th>
<th>Observ. dates</th>
<th>Forecasted maturity dates</th>
<th>Observ. dates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
</tr>
</tbody>
</table>

Legend: A - simulated silking and maturity dates under the climatic (1961-1990) monthly air temperatures in July, August and September; B and C - simulated silking and maturity dates under air monthly temperatures higher than climatic values by 1° and 2°C; D and E - simulated silking and maturity dates under lower air monthly temperatures by 0.5° and 1°C; Δ - departures of the simulated silking and maturity dates (variant A), relative to the observed silking and maturity dates; ND - no data.

Two forecasted variants of the simulated grain yield of winter wheat were developed depending on the expected weather in June, 1995 - the prognosis of final winter wheat yield was done a month before physiological maturity, assuming the expected monthly air temperatures and precipitation near to the respective averages. A comparison between the forecasted and observed flowering/maturity dates showed a satisfactory CERES model performance. The ob-
tained departures were in most stations up to 4 and 6 days, respectively (Fig. 4b). The departures of the simulated to measured phenological stages and grain yield of maize at the operative agrometeorological and experimental variety stations were higher, relative to the wheat results.

Nevertheless, it was assumed the CERES model for maize also appears to be appropriate for use in a large area yield forecasting program, when agrometeorological conditions are available. The model method of operational prognosis of wheat grain yield was applied again in

Fig. 4. Prognosis (a) of the expected flowering date of winter wheat and deviations (b: in days) between the forecasted and observed flowering/maturity dates, 1995 (Slavov et al., 1998).
1996, this time using data from 56 agrometeorological and phenological stations. The prognosis was developed first on 20 April, 1996 and updated on 22 May and 10 June, respectively. Generally, the forecasted grain yield of winter wheat was well fitted in the sequel to the observed one (as reported by the Ministry of Agriculture).

![Prognosis of expected grain yield of winter wheat in Bulgaria, 1995](Slavov et al., 1998)

**Fig. 5.** Prognosis (in kg/dka; 1 dka = 1.10⁻¹ ha) of the expected grain yield of winter wheat in Bulgaria, 1995 (Slavov et al., 1998).

### 3.6.5. UK crop models running on the web

The Common Gateway Interface (CGI), developed in United Kingdom, is a means by which interactive programs can be easily run by remote users of the world wide web (www) by means of special web pages (IPOL, 2002). Some CGI programs only need the user to call a page (usually by clicking a link) but others required the user to provide information on a form within an input web page. Either way, a CGI program on a www server computer will then start up, carry out its work and then send the result back to the remote user by means of an output web page. The work can be any kind of information processing such as a calculation, a database search or just a simple hit counter.

A substantial CGI system (IPOL, 2002), illustrated in Figure 6, supports a simplified version (http://www.qpais.co.uk/moda-djg/potass.htm) of a mathematical potassium (K) crop response model which simulates the growth response of 13 different crops to applications of nitrogenous fertilizers. The model is concerned with arable crops especially field-grown vegetables. The model calculates for each day the potential increase in plant weight and the increment in root length, from the current plant mass, its %K and panevaporation. It calculates the maximum amount of K that could be transported through soil to the root surfaces. It modifies this potential uptake by taking account of the “feedback” of plant K on root absorption to give the
actual uptake and a new %K in the plant. It calculates the radii of the depletion zones around 
each root increment and the interchange between the solution, exchangeable and fixed-K in 
these zones and also in the undepleted regions of soil. Routines are included for the effects of 
weather on the various processes. Differences between species are accommodated by selecting 
one of three algorithms for root growth and by adjusting the values of two crop-K parameters 
that define in a critical and a maximum possible %K with increase in plant mass per unit area 
(e.g. Greenwood and Karpinets, 1997).

The above sophisticated CGI system supports also a complex mathematical nitrogen (N) 
crop response model N_ABLE (http://www.qpais.co.uk/nable/nitrogen.htm) written in 
FORTRAN (e.g. Greenwood, 2001; Greenwood et al., 1996). The model equations include ones 
for the decline in critical %N with increase in plant mass, for the dependence of growth rate on 
sub-optimal %N, and for the development of roots systems and their ability to extract nitrate 
from soil. It requires only readily available inputs. It has been calibrated for different crops and 
its validity tested against the results of field experiments. User-friendly versions have had an 
impact on commercial practices in the UK. The Internet version of the model simulates the 
growth response of 28 different crops to applications of nitrogenous fertilizers in 134 different 
climatic regions around the world (more than 50 locations in 22 European countries are avail-
able). The installation consists of the large FORTRAN program containing the simulation 
model, a CGI program which manages the substantial weather database, a CGI shell program 
interfacing the compiled FORTRAN to the Web and a graphical output CGI program which 
generates GIF files. There is extensive on-line documentation including system diagrams, de-
scriptions of the model, an explanation of the weather data processing and a list of references.

The CGI system which supports also a detailed mathematical phosphate (P) crop re-
response model (http://www.qpais.co.uk/phosmod/phos.htm) written in 32-bit BASIC. For each 
day, the model calculates the increment in root growth and partitions it into segments between 
the regions of soil enriched with starter fertilizer, those enriched with granular fertilizer and the 
remainder of the soil. It calculates the maximum possible amount of P that can diffuse through 
soil to each root segment in each region. Using this information and the P concentration in the 
plant, total P uptake is calculated. The increment in plant weight and root growth is calculated 
from the current plant weight, plant P concentration and air temperature. Subroutines calculate 
daily soil water content, the extractable and non-extractable soil P, and diffusion coefficients in 
the P-depleted zones around each root segment and in the remainder of the soil.

Model simulations and sensitivity analyses indicate that extractable soil P and starter 
fertilizer P can lead to higher crop yields than are achieved when granular fertilizers are incor-
porated in soil, in the usual way, immediately before sowing (Greenwood, 2001a,b). The Inter-
net version of the model currently simulates the growth response of 10 different crops to appli-
cations of phosphate fertilizers – broad beans, carrots, French beans, leek, lettuce, onion, spinach, sugar beet, summer cabbage and turnip.

As an example, the simple nitrogen model input (an option for advanced input exists) is 
shown in Table 10. Weather files have been prepared to represent the daily mean, temperature, 
rainfall, and potential evaporation for different parts of Europe and other continents. To run the 
model it is first necessary to select the most appropriate weather file and make any adjustments 
to monthly rainfall. A web form to upload one’s own weather file instead of selecting one of the 
fixed weather centers can be also used. All Internet versions of the three models can be run any 
time via the web. The models’ outputs are presented in a text format as well as in tables and fig-
ures.
Fig. 6. An illustrated description of the nitrogen, phosphate and potassium web system and its users' interface (http://www.qpais.co.uk/npk/npksdia2.htm)
Conclusions

From the one side, there have been no significant advances in the development of new crop simulation models during the last decade in a global scale, including Europe. Instead, crop models have been evaluated and applied for a wide range of environmental conditions and management scenarios. Existing crop models are being improved, but at a slow pace (e.g., Hoogenboom, 2000). More efforts are needed to improve the current crop models and add the simulation of processes that are important for agricultural practices.

Table 10. Simple N_ABLE model input (http://www.qpais.co.uk/nable/s-091426.htm)

<table>
<thead>
<tr>
<th>Input description</th>
<th>Valid range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of sowing or planting the crop (day, month)</td>
<td>Months 1-12</td>
</tr>
<tr>
<td>Date of harvesting the crop (day, month)</td>
<td>Months 1-12</td>
</tr>
<tr>
<td>Date of first nitrogen application (base dressing) (day, month)</td>
<td>Months 1-12</td>
</tr>
<tr>
<td>Date of second nitrogen application (top dressing) (day, month)</td>
<td>Months 1-12</td>
</tr>
<tr>
<td>Date of incorporation of previous crop debris (day, month)</td>
<td>Months 1-12</td>
</tr>
<tr>
<td>Date of sampling soil for nitrogen analysis (day, month)</td>
<td>Months 1-12</td>
</tr>
<tr>
<td>The highest expected yield (t/ha)</td>
<td>Range 0.1-22</td>
</tr>
<tr>
<td>Analysed mineral soil nitrogen in 0-30 cm soil layer ((kg/N/ha)</td>
<td>Range 0-400</td>
</tr>
<tr>
<td>Analysed mineral soil nitrogen in 30-60 cm soil layer (kg/N/ha)</td>
<td>Range 0-400</td>
</tr>
<tr>
<td>Analysed mineral soil nitrogen in 60-90 cm soil layer (kg/N/ha)</td>
<td>Range 0-400</td>
</tr>
<tr>
<td>Estimated water content at field capacity in 0-30 cm soil layer (ml water per ml soil)</td>
<td>Range 0.16-0.5</td>
</tr>
<tr>
<td>Estimated water content at field capacity in 30-60 cm soil layer (ml water per ml soil)</td>
<td>Range 0.16-0.5</td>
</tr>
<tr>
<td>Estimated water content at field capacity in 60-90 cm soil layer (ml water per ml soil)</td>
<td>Range 0.16-0.5</td>
</tr>
</tbody>
</table>

From the second side, however, the application of crop simulation models has become more acceptable during the last few years. The crop models reviewed within this report can be used, for example, for within-year crop decisions, multi-year risk analysis for strategic planning, crop yield prediction, basic economic assessments of agricultural cereal production and definition of research needs in Europe. Several of these models have the potential for assessing the crop status and generating forecasts of environmental yields in advance of harvest or maturity, as well as at the time of harvest. In this case, online assessments of current agrometeorological conditions and expected yield can be done. Some models and/or systems are running already operationally in Europe. For example, the result of the CGMS (build around the WOFOST crop growth model) are used within the JRC (Joint Research Centre, European Commission) and DG (European Union's Directorate General for Agriculture) Agriculture Outlook group to support real-time analysis of the agricultural campaign in course and outlook analysis to support common agriculture policy decisions.

Crop status can be assessed and expected crop yields can be predicted in Europe some time before harvest by using observed and/or expected weather data. For example, stochastic forecasting approaches (e.g., Bannayan and Crout, 1999) were already tested in Europe, combining generated weather data with observed data for model updating. There is no doubt, for that application of crop models, weather data is one of the key inputs. The quality of observed weather data is very important. It is well known that in some cases the model users are applying observed weather data from weather stations, located far from the crop fields (where weather,
especially precipitation occurrence, intensity and amount, might be different). In order to account for spatial weather variability, denser weather station networks are necessary. As automated weather stations are becoming more common, it is crucial that standards are developed for weather station equipment and sensors, installation, and maintenance. Because long-range weather forecasts are not yet reliable, predicting weather is not yet very exact. However, using a range of reasonable weather patterns, a “fork” of yield expectations can be determined. Such estimates will be of value to growers seeking to sell their crops, to the transportation industry in planning to move the crop, and to national governments estimating the effects of production on future prices.

Not only weather data are important for a satisfactory crop model performance, especially for forecasting model applications. Before using a crop model for a particular production region, it is important that at least a minimum amount of crop phenological and yield data should be available to allow a prior estimation of the model performance for that region’s cultivar types and for calibration of specific model parameters.

Easy access to weather, crop and soil data, preferably through the Internet and the worldwide web, are important for the application of crop models for assessment of crop status and yield forecasting as well as decision making in Europe. It is considered that crop model applications, including crop yield forecasting, would expand in the near future as both researchers and farmers become more computerized. Via the Internet, information can be exchanged very rapidly, therefore, web-based models and decision support tools provide great benefits compared to the traditional desktop-based models (e.g. Hoogenboom, 1999). Through the web and the Internet, potential users can have access to crop models as well as the data required to run the crop models (e.g. IPOL, 2002).

Acknowledgments

Special thanks are addressed to all colleagues, who submitted filled in questionnaires on crop simulation models in Europe with potential for operational assessment of crop status and yield prognosis. The author wishes also to thank to all colleagues, who replied to his e-mail requests for assistance and provided additional information in the field.
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APPENDIX

Filled in Questionnaires

on Crop Growth Simulation Models in Europe with Potential for Operational Assessment of Crop Status and Yield Prognosis
SOURCE OF INFORMATION: BULGARIA

MODEL NAME
GVM (Growth Verhulst Model)

MODEL DEVELOPERS
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OPERATIONAL SYSTEM
DOS, WINDOWS (FORTRAN source)

MODEL SCALE
field, farm

ABSTRACT
From the mathematical point of view, the growth process is presented by a particular dynamic system, consisting of two ordinary differential equations. The calculated crop growth curves show significant smoothness, although the real growth process is usually subject to various environmental influences. A characteristic function, the first integral of the system of equations, is shown to exist, which is in good correspondence with the observed stability of the real growth process. The important feature of dynamic system is that the first integral does not depend on the function (bounded and continuous), describing the external impacts. In the hypothetical case of absence of external impacts, this model is reduced to the well-known Verhulst equation. The model has been tested using soybean field experimental data, which has shown quite acceptable results. On the basis of the above mention model is formulated the control task with the corresponding efficiency function, constraints and the method of solving. The functional, which is varied, expresses the difference between the cost of the final biomass growth and the funds invested in the control. The model-involved constraints are either constraints related with the maximum magnitude of the managing impact at a definite moment of time or technologic (external) constraints, determining the maximal funds invested during the whole managing impact period. Optimization is effected using the method based on the Pontrjagin’s Maximum Principle. The solution obtained for the optimal managing impact is continuous. The optimal task for the case of pulse control is also formulated. In the numerical experiments for five different managing impacts applied during the crop vegetation period are done, under the condition that the interval between each two successive managing impacts is at least 10 days. For both tasks, sufficiency studies are made by 1000 tests of the each soybean field experiments used within the model’s developments.

MODEL APPLICATIONS IN EUROPE
At a field study in Austria in 1995 three soybean cultivars, namely Ceresia (maturity group 00), Leopard (00) and Apache (0) were grown on a field plot (100 x 200 m), which was partially irrigated. The sowing date was 3rd May, the emergence date 14th May, and physiological maturity occurred on 19th September. A number of meteorological parameters and the soil water content were measured continuously by an automated agrometeorological station within the field.
Besides, the important plant growth parameters (e.g. dry matter production) of each cultivar were measured regularly. Some of the experimental data are used in this study, whereby all meteorological parameters were measured within the non-irrigated plot assuming the differences between the plots to be negligible. Soil water content was measured within the irrigated and non-irrigated plot, respectively. The variation of the driving parameters within the irrigated and non-irrigated plots were considered as negligible.

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS

The model potentialities are focused on the managing of the different agricultural treatments, first of all irrigation. The capabilities of the model are connected with the form of the main growth model. The model is based on the system of ordinary differential equations. This fact gives a possibility to use mathematical managing technology according to the abstract with respect of optimal expenses with given yield or optimal yield with given expenses. The problem of crop managing needs a huge computer resource and it is very important to use a compact and reliable growth model. Our model is constructed especially for the purpose of the yield managing. This is a reason of the simplified form of the growth model - the main parameters are the growth from one side and external parameters - air temperature and soil moisture from the other side. There is a possibility to enlarge the number of parameters in case of special needs.

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 SOURCE OF INFORMATION: BULGARIA

MODEL NAME
World Food Study (WOFOST v.6.0)

MODEL DEVELOPERS
This model was developed by the DLO-Winand Staring Center (SC-DLO) with the Research Institute for Agrobiology and Soil Fertility (AB-DLO) in Netherlands.
WOFOST is developed by – C.A. van Diepen, D.W.G. van Kraalingen, C. Rappoldt, G.H.J. de Koning, J. Wolf and H. van Keulen

OPERATIONAL SYSTEM
both DOS and Windows

MODEL SCALE
field, farm, regional - if necessary inputs are available

ABSTRACT
WOFOST simulation model is a tool for the quantitative analysis of the growth and production of annual field of crops. As with all tools we should know what we can do with it and what not. Like all mathematical models of agricultural production WOFOST is a simplification of reality. In practice, crop yield is a result of the interaction of ecological and social factors. In WOFOST, only ecological factors are considered. With WOFOST we can calculate potential production and the two levels of limited production: water-limited and nutrient-limited production. Production-reducing factors are not taken into account. The production levels are fully hierarchical within WOFOST. Potential production is the highest level. Water-limited production is the second level, it can't be higher than potential production. Nutrient limited production is the third level, it is never higher than water-limited production. Only nutrient limitation by the macro nutrients N (nitrogen), P (phosphorus) and K (potassium) is taken into account.

MODEL OUTPUTS
simulation of potential crop growth; simulation of water-limited crop growth – effect of drought only and effect of drought and oxygen shortage; simulation of nutrient-limited crop growth.

MODEL APPLICATIONS IN EUROPE
The WOFOST model can be used as a tool for the analysis of yield risk and inter-annual yield variability, of yield variability over soil types, or over a range of agrometeorological conditions, of differences between cultivars, or relative importance of growth determining factors, of sowing strategies, effects of climate change and climate variability and critical periods for use of agricultural machinery. The model can be used also for predictive purposes, in quantitative land evaluation, such as regional assessments of crop yield potential in the form of maximum yield levels, estimation of maximum yield benefits from irrigation or from fertilizer use, detection of adverse growing conditions by simulation monitoring the agricultural season and regional yield forecasts.

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
WOFOST v.6 was developed under the Contract study “Models for yield forecasting” issued by the Joint Research Centre (JRC) of the EC at Ispra, Italy, in the framework of Action 3 of the Agriculture Project, also called MARS project (Monitoring Agriculture with Remote Sensing). The objective of this study was to generate crop growth indicators for the quality of the current
agricultural season over European countries regions as compared to the quality of historic sea-
sons, and to use these indicators for quantitative yield prediction per region or per country.

ADDITIONAL MODEL INFORMATION
In addition to the mainstream of WOFOST version several models was elaborated. A typical
example is the SWAP v.2 model formed by linking WOFOST Crop module to the SWATRE
model (Soil Water and Transpiration). Also GIS – ARC/INFO format output files are available.

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REFERENCES
Kazandjiev V. and S. Ivanova-Petrova 2001. Growing and development of winter wheat crops
in the Climate variability conditions during last decade of XX century in Bulgaria -
Florence, Italy

of remote sensing data as inputs for the WOFOST model - paper on the COST Ac-
tion 718 Meteorological applications for Agriculture, Budapest meeting 27-28 Septem-
ber 2001, p.11.
SOURCE OF INFORMATION: CYPRUS

MODEL NAME
Growth and Development of Barley

MODEL DEVELOPERS
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OPERATIONAL SYSTEM
MS – DOS, the source code was written in BASIC

MODEL SCALE
regional

ABSTRACT
The potential production of barley in Cyprus is assessed using a simulation model, assuming non-limiting water and nitrogen supply. Parametrization of the model is based mainly on the results of various experiments obtained either from the literature or carried out in Cyprus. The basic physiological processes, included in the model, are: the CO$_2$ assimilation, maintenance and growth respiration, the development of the crop, the partitioning of the dry matter, and the leaf area growth. The developmental stages of the crop influencing the coefficients of partitioning are described in terms of accumulated temperature and are calculated from available data. The potential production model is used to estimate the optimum time of sowing using average temperature and sunshine duration. An extended version of the model, which includes appropriate subroutines to estimate the water balance, is used to assess the effect of water stress on dry matter production. Verification runs were carried out for two barley producing areas in Cyprus for which a series of experimental results is available.

MODEL OUTPUTS
Potential and water-limited grain yield

MODEL APPLICATIONS IN EUROPE
Testing water effects on crop yield

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
Production land use systems. Testing sowing date. Effect of water stress conditions on crop yield

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REFERENCES
SOURCE OF INFORMATION: FINLAND

MODEL NAME
CERES (Crop Estimation through Resource and Environment Synthesis) - Wheat (v. 2.1 and later) for the latest version of the CERES-Wheat model refer to DSSAT (Decision Support System for Agrotechnology Transfer)
web-site: http://www.icasanet.org/ or http://agrss.sherman.hawaii.edu/dssat/dssat/info.htm

MODEL DEVELOPER
Ritchie et al.

OPERATIONAL SYSTEM
Windows and UNIX

MODEL SCALE
Field parcel (yield kg/ha)

ABSTRACT
In the CERES-wheat model (Ritchie & Otter 1985; Hodges 1991) the plant phenological development and biomass and yield production is controlled with calibrated genetic coefficients for winter and spring sown wheat cultivars. The CERES-wheat model is divided into subroutines simulating the plant phenological growth development, tiller and leaf initiation, and senescence. The phenology subroutine (PHENOL) describes plant physiological processes controlling vernalization, photoperiodism and yield components. Other model subroutines simulate photosynthesis, transpiration, root growth and dry matter accumulation and translocation to plant organs during growing period (Otter-Nacke et al. 1986, Ritchie & Otter 1985).

The CERES-wheat model contains 9 growth stages and the growth stage classification is similar with Feeke’s (Large 1954) and Zadok’s (Zadoks et al. 1974) growing scales. In vegetative phase the phases (TBASE threshold temperatures [°C] are given in brackets) are planting to germination (1.0), germination to emergence (2.0), emergence to floral initiation (0.0). In generative phase the phases are from floral initiation to begin of ear growth (terminal spikelet, double ridge phase) (0.0), from begin of ear growth to anthesis (0.0), anthesis to begin of grain fill (0.0), grain filling period (1.0) and full maturity (+7 °C from yellow ripening stage) (1.0). In the CERES-wheat model growth stages are driven by accumulation of daily thermal time (DTT) units (driving variable). DTT units are calculated from base threshold temperature (TBASE) and then accumulated with daily increments. The cumulative thermal time is specified by the genetic constant P5 (Duration of grain filling period) for each genotype (Ritchie & Otter 1985). The thermal time requirement is modified by photoperiodical sensitivity (P1D) and vernalization sensitivity genetic coefficients (P1V). The genetic coefficients P1V controls sensitivity to vernalization, P1D controls sensitivity to photoperiod and PHINT (the size of phyllochron interval) defines the thermal time sum (TT) (modified by the vernalization and photoperiod factors) needed for the development stages. The vernalization effect (i.e., the ability of genotype to develop terminal spikelet and double ridge in generative phase) is modeled by vernalization units (CUMVD), which are accumulated daily during stages 9-1. The vernalization requirement is low with spring wheat genotypes currently cultivated in Finland (Kivi, 1983). The photoperiodical effect and the effect of day-length on wheat phenological development is modeled by the P1D coefficient assuming daylengths shorter than 20 hours/day can delay phasic development in stage 1. The photoperiodical effect on phase’s development varies between wheat genotypes, however a threshold daylength of 18 hours has been identified for genotypes adapted to Finnish long day growing conditions (Kivi 1983). Daylengths below
threshold delay vegetative phase from sowing to heading. In generative phase (from heading to full maturity) the cumulative temperature sum controls the phenological development (Kivi 1983, Kontturi 1995).

MODEL APPLICATIONS IN EUROPE
The CERES-wheat crop model (Crop Estimation through Resource and Environment Synthesis) (Ritchie & Otter, 1985) was used to estimate the changes in phenological development and biomass and yield production of a spring wheat variety (Triticum aestivum L., cv. Polkka, Svalöf Sweden) under different temperature, precipitation and atmospheric CO₂ growing conditions. The effects of mean elevated diurnal temperature levels of +3°C - +4°C and CO₂ concentration of 700 ppm. (parts per million) on phenology and crop production were simulated because of the potential growing conditions assumed to prevail ca. year 2100 in Finland during climate change. The model recalibration procedure for Finnish long day growing conditions involved optimization of genetic coefficients, which govern phenological development and yield capacity. Genetic coefficients for cv. Polkka governing the phenological development and the genotype yielding capacity and corresponding yield components were calibrated by using the measured yield levels and recorded anthesis and maturity dates of cv. Polkka from the Finnish official variety test results 1985-1990 (Agricultural Research Centre of Finland). Measurements from open top chamber experiments (Finnish Climate Change program, SILMU 1992-1995) conducted both in ambient and elevated levels of temperatures and CO₂ under potential, non-stressed, growing conditions were used in validation procedure of the model.

The modeling results with optimized genetic coefficients for cv. Polkka indicate, that by maintaining the current sowing date and simulating both non-stressed potential and non-potential growing conditions, the elevated temperature (+3 °C) accelerates the phenological development between sowing and anthesis and between anthesis and full maturity. According to the model estimations, the yield of cv. Polkka decreased on average to 65.7 % with the CERES-wheat potential model (68.8% with non-potential model simulating water and nitrogen deficiencies) with elevated temperature level (+3 °C) from the reference yield level (100%, with ambient diurnal mean temperature and CO₂ (350 ppm.) conditions). Simulated mean yield levels at 15 % moisture content in ambient temperature and CO₂ conditions were 6.16 tn/ha for potential model, 4.49 tn/ha for non-potential and 5.97 tn/ha for the observed SILMU average yield (1992-1994) in ambient conditions in open top chamber experiments (Hakala 1998). At doubled CO₂ level (700 ppm.) the yield of cv. Polkka increased to 142 % with potential model (167 % with non-potential) on average from the reference yield level (100%). When modeling the elevated temperature (+3 °C) and CO₂ (700 ppm.) interaction, the increase in yield level due to elevated CO₂ levels, was reduced by the elevated temperature effect giving an average of 106% increase in yield with potential model (122 % with non-potential) from the reference yield level. When simulating the effects of earlier sowing dates on yield potential, the cv. Polkka yield level increased with potential model to 136 % (+15 days earlier sowing, 700 ppm. CO₂, +3 °C) from the reference level (15.5 as sowing date, ambient CO₂ and temperature levels).

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SOURCE OF INFORMATION: FRANCE

MODEL NAME
STICS (Simulateur mulTidisciplinaire pour les Cultures Standard) ver. 4.0 and soon version 5.0

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OPERATIONAL SYSTEM
The STICS model is written in FORTRAN 77 and operates with a standard PC-compatible microcomputer in a user-friendly Windows environment.

MODEL SCALE
field and regional if regional inputs to run the model are available (Ruget et al., 2002)

ABSTRACT
STICS is a daily time-step crop model with input variables relating to climate, soil and the crop system. Its output variables relate to yield (quantity and quality), the environment and the evolution of soil characteristics affected by the crop. The simulated object is the crop situation for which a physical medium and a crop management schedule can be determined. The main simulated processes are crop growth and development as well as the water and nitrogen balances. The formalisations chosen are based mostly on known analogies or on simplifying more complex formalisations.

From a conceptual point of view, STICS is made up of a number of original parts but most of the remaining parts are based on conventional formalisms or have been taken from existing models. Its strong points are the following:
- its generality: adaptability to various crops (wheat, maize, soybean, sorghum, flax, grassland, tomato, beetroot, sunflower, pea, rapeseed, banana, sugarcane, carrot, lettuce, etc.)
- its robustness: ability to simulate various soil-climate conditions without generating any considerable bias, which can sometimes jeopardise accuracy on a local level.
- its "conceptual" modularity: possibility of adding new modules (e.g.: ammonia volatilisation, symbiotic nitrogen fixation, plant mulch, stony soils, many organic residues, etc.). The purpose of such modularity is to facilitate subsequent developments.
- the context of internal and external communication that it generates and that drives the way in which the model evolves, put into practice by the successive versions of the software.

MODEL APPLICATIONS IN EUROPE
Validation
The validation consists of comparing the experimental reality with the results of the simulations, defined as being the final variables of agronomic and environmental interest. In the case of STICS, this involves:
- certain key phenological stages (flowering, physiological maturity)
- yield and its components
- above-ground biomass
- the amount of nitrogen in the plant and in the harvested organs
- variations in the amounts of water and mineral nitrogen in the soil (for the whole rooting depth) during the cultivation period and bare soil period.
Obviously, the model uses secondary state variables, such as leaf area index or water content in the top few cm of soil. As a result of the simplicity of the STICS formalisms, associated with the model's objectives, these secondary variables are essential for calculating the main variables but do not meet the same validation criteria as the main variables (Brisson et al., 2002). By forcing certain state variables it is possible to partially validate the model. In the case of STICS, it is possible to force the developmental stages independently of each other and the leaf area index. In the case of the leaf area index, the measurement points are interpolated on the basis of a dual less-exponential logistic function according to the sum of degree-days since the beginning of the cycle (Ripoche et al., 2001).

Application

Until now, the STICS model has been used at the agricultural plot scale to make agronomic or environmental diagnoses (e.g.: influence of soil tillage and irrigation on the cultivation of the banana tree, Brisson et al., 1998b) or to evaluate crop management schedules (irrigation calendars for a maize crop, Levrault et al., 2000; optimisation of intermediate crop management, Justes et al., 2001). It is also being used at the intra-plot scale in a precision farming framework (Bruckler et al, 2000). However, at this intra-plot scale, one could question whether the model's sensitivity to its input variables is sufficient to reproduce the spatial variability studied. At the regional scale, STICS is used to estimate the potential of the environment (e.g. classification of soils in a region according to their mineralisation potential) or to make agronomic diagnoses on a large scale using remote sensing (assimilation of remotely-sensed data into the STICS model coupled with a model of the radiation response of plant canopies: Weiss et al., 2001). It is also used in association with a hydrological model to estimate nitrate leaching at the scale of a watershed or a region (Beaujouan et al. 2001). As part of the ISOP (Prairies Information and Objectives Survey: Ruget, 2002) programme, STICS gives estimations of forage production in real time for the whole French territory. Some studies base themselves on the STICS model to test the effects of climatic changes (addition of a CO₂ compartment not described in this information) on cash crops (Bellia, 1999), on the flowering of fruit trees (Domergue, 2001) and on forage calendars in mountainous areas (Juin, 2001). It can also contribute significantly to socio-economic studies (Affholder, 2001).

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS

See above

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REFERENCES


Juin, S. 2001 Impact du réchauffement climatique sur la répartition géographique et les calendriers de production de trois systèmes fourragers.. Diplôme Agronomie Approfondie ENSA Montpellier,


SOURCE OF INFORMATION: GEORGIA

MODEL NAME
Semi-empirical mathematical model of tea-bush shoot formation

MODEL DEVELOPER
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INTRODUCTION
Mathematical model of tea-bush shoot formation has been elaborated on the basis of the results of the investigations on the regularities of the growth and ripening of tea shoots.

a) as a result of processing and analysis of experimental data, the values of the function of starting the visual growth \( \varphi(t) \) (after picking up shoots of a previous order) and the readiness for picking \( \psi(t) \) (after starting the visual growth) have been determined. The process of formation of one-order shoots to picking, is well approximated by a logistic curve \( F_t \).

The picking of ripe fleshes artificially disturbs existing balance between the masses of surface and underground parts of a vegetating plant. This additional disturbance is compensated by the formation of shoots of the following order, which is described also by the functions \( \varphi(t) \) and \( \psi(t) \). Since the shoots, ready to be picked are time after time gathered during vegetation, mentioned functions recur, laying on each other, that finally gives a wave dynamics of the readiness of the shoots to pick.

b) except rhythmic supply of shoots for picking, general lowering of shoot formation strength of a tea-bush \( \beta(t) \) has been observed under Georgian conditions, which is resulted from the complications of the system of a bush branching and the change of correlation between its vegetation and generating activities (useful for the latter).

A mathematical approach has been worked out, allowing the description of a wave type process of tea shoot supply for picking by the functions \( \varphi(t) \), \( \psi(t) \) and \( F_t \) during the picking season.

MODEL SCALE
The elaborated mathematical model of tea shoot supply for picking up during the picking may be used in any tea growing region for those tea plantations, where picking is conducted according to agricultural rules, i.e. fresh, two and three leaf fleshes are picked.

The wave-type dynamics of the harvest during the vegetation period induced with biological characteristics of the crop and periodical picking of ripe green fleshes.

The wave type character of the supply of shoots for picking is conditioned by a logistic character of the processes of a plant growth, so, this phenomenon does not have a local character – it is observed in all tea growing countries of the world.

ABSTRACT
In the first version of the model, the dynamics of one-order shoots, supplied for picking (it is conducted daily) during the picking season by means of the functions \( \varphi(t) \) and \( \psi(t) \), is presented as separate waves. Total number of ripe shoots \( N(t) \) is obtained by means of summarizing the values of separate waves at the \( t \) moment, after which it is multiplied by a corresponding value.
of $\beta(t)$ function. Finally, the number of picked shoots $S_t$ from the start of the picking $t_0$ up to $t^{th}$ pentade is expressed as follows:

$$S_t = \int_{t_0}^{t} N(t) \beta(t)dt.$$  

The dynamics of a total number of shoots ready for picking, is quite well approximated by the curve of fading fluctuation

$$\hat{N}(t) = A_0 e^{\alpha t} \sin(\omega t + \varphi_0) + A_0,$$

where: $N(t)$ is an approximation $N(t)$; $t$-time (in pentades); $A_0$, $\alpha$, $\omega$, $\varphi_0$ - empirical parameters.

In the second version of the model, by means of approximation of a logistic curve of shoot ripening $F_t$, separate waves of the supply of shoots for picking are estimated according to dates of picking, which are conducted in any periodicity (not necessary in each five days).

In the third version of the model the dynamics of a general increase of tea shoots, the number of growing and not growing shoots during the picking period have been estimated.

To conduct the estimations on three versions of the model, the functions $\varphi(t)$, $\psi(t)$ and $F_t$ (expressed in %), also $\beta(t)$ are used, which are presented in shares from a unit.

MODEL OUTPUTS

The output parameters of a developed model are the number of ripe shoots (ready to be picked up) $N(t)$, $S_t$, average increase of a tea shoot $P(t)$, the number of growing $N^g(t)$ and not growing $N^0(t)$ shoots.

MODEL APPLICATIONS IN EUROPE

Suggested method gives the possibility to assess the impact of the age and biological peculiarities of a tea plant upon its productivity and also to build up a real statistical scheme of the connection of harvest with other factors. It may be used also in the investigations of agrometeorological processes of the formation of the crop of other perennial agricultural plants. As to a model of tea shoot formation, itself, it may be used also for the description of grass formation process, since their increase dynamics during vegetation has also a wave type nature. (Brereten A.J., Danielov S.A. and Scott D. WMO Tech. Note, No. 197, WMO, 1996, pp.22-31).

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS

A logistic nature of growth processes, as well as a specific character of agrotechnical measures (periodical picking) change tea crop dynamics substantially during vegetation. Without consideration of the given effect, it is impossible to make correct assessment of tea plantation state, the impact of other factors (weather, fertilizers, etc.) upon its productivity and that is most important, it is impossible to make forecast of harvest. By means of the mathematical model of shoot formation, we managed to make the quantitative assessment of the impact of biological peculiarities of tea-bushes, allowing to describe the dependence of tea crop upon weather factors in a "clean way". Simultaneous consideration of impacts of age and biology of tea bushes, as well as the weather, allowed to model over 90% of a whole information on time dynamics of tea crop.

ADDITIONAL MODEL INFORMATION

The model, elaborated on the basis of the analysis of special biometric observations, permitted to determine the presence of a rhythmic dynamics of shoot formation of tea bushes and reveal its mechanism: a wave type dynamics of crop during the picking period is stipulated by a logistic character of a plant growth processes and also by periodical pick up of ripe green fleshes.
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REFERENCES
SOURCE OF INFORMATION: GEORGIA

MODEL NAME
Simplified dynamic model of tea crop

MODEL DEVELOPER
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MODEL SCALE
The model has been elaborated under conditions of Ingiri tea growing region (Zugdidi district) and at present may be used on tea growing farms.

ABSTRACT
Process of tea crop formation is presented in the dependence upon temperature conditions, - the dynamic parameter of the model is the sum of average daily air temperatures $T$. The crop is estimated by the following logistic curve:

$$F(t) = \frac{a}{a + e^{-bT}},$$

where: $T$ is the sum of average daily air temperature from the start of the first harvest until the given moment; $a$ and $b$ are the parameters; $a > 0$, $b > 0$ (under Georgian conditions $a = 0.033$, $b = 0.9471$, $F(t) \leq 1$, $F(-\infty) = 0$, $F(+\infty) = 1$). In the dynamic model, the tea crop is estimated on separate waves (under Georgian conditions four waves are observed) and then these waves are summarized in the dependence upon the sums of mean daily temperatures, accumulated until the given picking. Duration of the period between the pickings is not limited. If the values, estimated by the dynamic model of an n order $F_n(T)$ are noted through $\tilde{F}_n(T)$ and $S_n(T)$ = $\exp \{np-q[T-(n-1)\Delta T]\}$, where $p=lna$ and $q=b$, the final formulas of tea crop approach on waves will be written as follows

$$\tilde{F}_1(T) = \frac{1}{S_1(T) + 1},$$

$$\tilde{F}_2(T) = \frac{0.06}{S_2(T) + 0.1765} + \frac{0.32}{S_2(T) + 1} + \frac{1.927}{S_2(T) + 5.667},$$

$$\tilde{F}_3(T) = \frac{0.0036}{S_3(T) + 0.031} + \frac{0.0384}{S_3(T) + 0.1765} + \frac{0.3336}{S_3(T) + 1} + \frac{1.2333}{S_3(T) + 5.667} + \frac{3.7133}{S_3(T) + 32.111},$$

$$\tilde{F}_4(T) = \frac{0.0002}{S_4(T) + 0.0055} + \frac{0.0035}{S_4(T) + 0.031} + \frac{0.0392}{S_4(T) + 0.1765} + \frac{0.2548}{S_4(T) + 1} + \frac{1.2603}{S_4(T) + 5.667} + \frac{3.5648}{S_4(T) + 32.111} + \frac{7.1556}{S_4(T) + 181.973},$$

where: $S_1(T) = \exp(3.41-0.9471T)$; $S_2(T) = \exp(11.555-0.9471T)$; $S_3(T) = \exp(19.70-0.9471T)$; $S_4(T) = \exp(27.847-0.9471T)$. 
MODEL OUTPUTS
The output parameters of the model are: tea crop on separate waves and total harvest in dependence upon accumulated mean daily air temperatures.

MODEL APPLICATIONS IN EUROPE
The simplified tea crop dynamic model may be used on tea farms for the estimation of harvest in dependence upon accumulated mean daily air temperatures, as well as for making forecasts of tea crop by predicted values of the sums of mean daily air temperatures.
A similar model may be worked out for grasses, since the dynamics of grass increase during the vegetation also has a wave type character (Brereten A.J., Danielov S.A. and Scott D. WMO Tech. Note, No. 197, WMO, 1996, pp.22-31) and the model may be successfully used on cattle breeding farms of many European countries.

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
On the basis of the dynamic model, a scheme of long-range forecasting the tea crop has been built up, the parameter of which is a prognostic value of air temperature sums accumulated for a vegetation period. The forecast of the sums of mean daily air temperatures are made by a known method of F.F. Davitaya (Прогноз обеспеченности теплом и некоторые проблемы сезонного развития природы. М., Гидрометеоиздат, 1964, 131с.). On the basis of the forecast of rhythmic dynamics of tea crop during the picking season, a commercial activity and technical works may be planned. By means of the model, the approach of tea shoots to picking for a harvest season may be regulated changing the duration of the period between pickings depending upon the possibilities of farms to conduct agrotechnical and technological works, connected with pick up and processing of tea leaves.

ADDITIONAL MODEL INFORMATION
In the semi-empirical mathematical model of tea plantation shoot formation, the parameter is time t. In this connection, the given model restores the process of shoot formation of tea plantation for mean weather conditions. The simplified dynamic model of tea crop presents the process of shoot formation depending upon temperature conditions. Therefore, a dynamic parameter in it is represented by the sum of mean daily air temperatures T instead of time.

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REFERENCES
SOURCE OF INFORMATION: GEORGIA

MODEL NAME
VGSM (Vine Growth Simulation Model), ver.2.01

MODEL DEVELOPER
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OPERATIONAL SYSTEM
Windows 95/98 (also there is a model version for DOS 3.0 )
Model source code is written on C/C++

MODEL SCALE
Field, Farm

ABSTRACT
Crop-Weather Model for grapevine consists from the different blocks that describes following processes taking place in vineyard:
- Daily increase of grapevine biomass and its distribution between plant’s different organ: leaf, stem and grape. Daily growth of the LAI, average length of stems and height of trellis;
- Radiation balance of trellis canopy;
- Water balance in Plant-Soil complex: soil moisture dynamic in different elementary soil layers, water absorption by roots and transpiration;
- Weather conditions.
Model inputs:
Daily meteorological data: max and min air temperature, min relative air humidity, cloudiness or sunshine duration, average wind speed, total rainfall;
Initial soil moisture distribution in depth (0-60 cm), root surface distribution in soil (0-60 cm).

MODEL OUTPUTS
Biomass for different organ: leaf, stem and grape; Surface of leaves; Average length of stems

MODEL APPLICATIONS IN EUROPE
Model was used in UNDP and Global Ecologial Fund project:"Climate Change and Estimation of Vulnerability of Georgian Agriculture" (1997)

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
Model can be used for testing irrigation strategies, climate change impact on vine production etc.

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REFERENCES
SOURCE OF INFORMATION: GERMANY

MODEL NAME
AGROSIM (AGROecosystem SIMulation) - Agroecosystem model family for:
- winter wheat (AGROSIM-WW),
- winter barley (AGROSIM-WG),
- winter rye (AGROSIM-WR) and
- sugar beet (AGROSIM-ZR)
(version 1.95)

MODEL DEVELOPERS
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Dr. Franz Reining, Dr. Eberhard Matthäus, Dr. Helmut Förkel
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OPERATIONAL SYSTEM
Developed for IBM PC compatibles, DOS 3.11 and higher, Requires: 640K CPU-memory

MODEL SCALE
whole crop stands on field scale

ABSTRACT
All physiologically based simulation models of the AGROSIM family describe whole crop stands under field conditions for limited and unlimited water and nitrogen supply, where homogeneous crop stands are assumed. All models only need meteorological standard values as driving forces and regional available inputs and parameters. The AGROSIM models base on the same modelling philosophy, have a similar model structure on the basis of modules (meteorology, plant soil), use rate equations for describing process dynamics, calculate on a minimum time step level of one day and are weather, site and management sensitive. In all models the plant growth module actively interacts with a soil process module.

One of the most important subprocesses within AGROSIM models is the process of ontogenesis (biological time scale) which acts as a time-related control variable on other subprocesses. Other processes are initiated, stopped, accelerated or slowed down by ontogenesis. The second important subprocess within AGROSIM models is the photosynthesis which acts as the source of daily biomass production. The daily assimilation rate bases on a maximum photosynthetic rate per unit green biomass and is influenced by water and nitrogen stress. The soil processes are based on daily calculations for soil layers up to 2 meters.

Processes taken into account:
- Photosynthesis (affected by photo period, light, temperature, nitrogen and water stress, atmospheric CO₂ content and accumulated total biomass; based on existing green biomass (cereals) / leaf biomass (sugar beet)
- Respiration (maintenance and growth respiration, for winter cereals subdivided into light and dark period)
- Dry matter allocation (based on development stages and partitioning coefficients)
- Redistribution of dry matter (from green and root biomass for maintenance respiration and grain filling)
- Root growth (mass growth based on partitioning from growth to roots, depth in dependence on plant development)
- Transpiration (daily potential plant transpiration based on potential ET (PENMAN, WENDLING) and leaf area index; actual transpiration is the minimum of potential transpiration and potential soil water uptake by the soil root system and available water)
- Infiltration (difference between precipitation (plus irrigation water) and interception)
- Water redistribution (above drained upper limit; percolation in case of water content above field)
- Capacity: water uptake by plants according to soil water model by Koitzsch/Glugla)
- Nutrient processes (nitrogen balance in the rooted soil layer taking into account;N-uptake by plants, mineralization according to the FREYTAG-algorithm, fertilization , dry and wet N-deposition)
- Evapotranspiration (divided into evaporation of bare and covered soil and transpiration of plants)

Model inputs:
- Site: Longitude, latitude, altitude, actual level of atmospheric CO₂ content.
- Weather: Daily values of temperature (minimum, maximum), global radiation or sunshine duration, precipitation, humidity and wind speed
- Soil: Field capacity, permanent wilting point, bulk density for each soil layer
- Water content, N-pool, temperature for each soil layer at starting day of simulation runs
- Management: Cultivar, sowing date, sowing density, N-fertilizer amounts and dates of additions, irrigation amounts and dates of additions

MODEL OUTPUTS
daily values of all calculated weather, plant and soil variables
ontogenesis , vernalization, assimilation, transpiration, maintenance and growth respiration, green, grain, root, leaf and dead biomass, exsudation, ear number, grain number soil temperature, soil water, soil nitrogen, N-mineralization (for each soil layer).

MODEL APPLICATIONS IN EUROPE
AGROSIM-model evaluation for north-east German regions
AGROSIM-WW-model adaptations for 24 locations in France, Italy, the Netherlands, Poland, Russia, Hungary and Germany
Adaptation of the AGROSIM winter cereal models for regional yield estimation on district level
Usage of the AGROSIM winter cereal models for estimation of climate change effects on plant growth processes on arable land for the federal state of Brandenburg, Germany

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
The AGROSIM models exist for a scientific use, not for a use within DSS or prognosis systems up to now. An integration in such systems is possible, but on the source level only. For a successful yield prognosis reliable weather forecast data are necessary.

ADDITIONAL MODEL INFORMATION
Programming language: AGROSIM-WW, AGROSIM-WG, AGROSIM-WR - MS FORTRAN (V.5.0) embedded in the special simulation tool SONCHES (Simulation of Nonlinear Complex Hierarchical Ecological Systems); AGROSIM-ZR - TURBO PASCAL (V.6.0)

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REFERENCES
Posters via Internet:
http://www.zalf.de/lsad/poster/mirsch/wm_agrosim.pdf
http://www.zalf.de/lsad/poster/mirsch/wm_klimaend.pdf
SOURCE OF INFORMATION: GERMANY

MODEL NAME
WOOP (weizen, objektorientiert programmiert – wheat development and growth object-oriented programmed)

MODEL DEVELOPERS
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OPERATIONAL SYSTEM
MS – DOS and Smalltalk V286

MODEL SCALE
field (region)

ABSTRACT
WOOP simulates growth, formation of the dry-matter and yield of a wheat crop on the basis of its phenological development. In contrary to most of the other winter wheat models WOOP begins at time of harvest of the previous plant stand on the same field. So the model takes into account for the processes in the soil during the “fallow period” between harvest of the plants of the last growing period and the sowing of the new plants which development and growth are simulated further. The model simulates on a daily basis. It requires commonly available data:
- the latitude
- soil: texture and depth
- organic remains of the previous crop
- crop: cultivars, information on a few genetic properties
- management: planting date, amount of seeds, fertilizer application, tillage
- weather data: daily temperature, precipitation, radiation, humidity, wind speed

WOOP simulates water-flow and nitrogen-processes in the soil (mineralisation, nitrification, denitrification). After the sowing the model calculates germination, the root formation and the growth of the above ground parts. It distinguishes strictly between development and growth. Development means the timing of critical events in the life cycle of the plant, whereas growth refers to the increase in weight, length, volume, area of plant parts. In principle the model calculates the potential performance of plant parts and than takes into account for negative factors (respiration, high temperature adaptation index, water stress, nitrogen stress).

MODEL OUTPUTS
Duration of the stages of development, biomass performances, yield and yield components (number of ears/unit area, number of grains/ear, individual grain weight)

MODEL APPLICATIONS IN EUROPE
The model (current version) has been evaluated in Germany (Bavaria) and Austria on different farms and has been used for climate change impact studies (Maier, 1997). The former model N-Sim (Engel, 1991) is currently used for the recommendation of nitrogen fertilizing.

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
The model simulates yield and yield components very good. The new description of plant stages allows the calculation of the developments stages at least at the places mentioned above, where the program has been validated. The phyllochron for the location should be known.

ADDITIONAL MODEL INFORMATION
The model WOOP has its origins in the model CERES wheat (Ritchie and Otter, 1985). But many changes had been made during the nineties of the last century, e.g. N-processes in the soil by Engel (Engel, 1991). WOOP, wheat object-oriented programmed, is very different from the former models: compartments describing plant processes, soil processes are different organized, the description of development, growth evaporation and transpiration is much more deterministic/physical. From the very beginning one of the major aims was that the model should work on different places worldwide. That is why it is based mainly on commonly valid connections which are the result of scientific investigations. Some equations had to be founded on statistical dependencies due to lack of knowledge hoping that in the future it can be described physical after knowledge gaps will be closed by experiments.

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REFERENCES
SOURCE OF INFORMATION: GERMANY

MODEL NAME
HERMES

MODEL DEVELOPER
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OPERATIONAL SYSTEM
Ms-DOS

MODEL SCALE
field, catchment, regional

ABSTRACT
The model simulates water and nitrogen dynamics in the soil/crop/atmosphere system considering soil water balance, nitrogen mineralisation, denitrification, nitrate transport, water and nitrogen limited crop growth (cereals), crop development and N uptake by plants. Inputs required are daily meteorological data (rainfall, air temperature (2 m), vapour pressure deficit, global radiation), soil data (texture, organic matter, groundwater level) and management data (sowing and harvest date, nitrogen fertilization amounts and dates, irrigation amounts and dates). The model approaches are process-oriented, but functional (e.g. capacity water model).

MODEL OUTPUTS
soil water content, soil mineral nitrogen content, seepage, nitrate leaching, above ground biomass, yield, nitrogen fertilizer recommendation, cumulative denitrification.

MODEL APPLICATIONS IN EUROPE
Model comparison in the Netherlands and Germany. Model evaluation for fertilizer recommendations at different locations in Germany. Model based evaluation of agricultural land use in a nitrate polluted drinking water catchment and scenario analysis for improvements. Model testing for site specific nitrogen fertilization. Studies on large scale effects of changing land use and different farming systems in the federal state of Brandenburg.

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
The model can be used to predict relevant crop development stages for nitrogen fertilization and yield formation using site specific weather scenarios.

ADDITIONAL MODEL INFORMATION
Different versions of the model on the same basis modules exist for the different purposes.

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REFERENCES
SELECTED PAPERS IN CHRONOLOGICAL ORDER:


SOURCE OF INFORMATION: GERMANY/USA

MODEL NAME
PROMET-V (Process oriented Modular Environment and Vegetation model)

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OPERATIONAL SYSTEM
Windows NT

MODEL SCALE
field to regional, single plot to spatial distribution

ABSTRACT
PROMET-V models the spatial patterns and temporal course of water, carbon and nitrogen fluxes in a heterogeneous watershed. Process oriented and mechanistical model components are used to ensure that interactions and feedbacks of these coupled processes are accounted for appropriately. The hydrological component of PROMET-V uses the Penman-Monteith approach, a plant-physiological model to calculate the response of the canopy conductance upon environmental parameters, and a multi-layer soil water model to calculate the flow of water in the soil-plant-atmosphere continuum. Plant growth for different vegetation types (corn, cereals, grassland, forest) is modeled based upon various approaches described in the literature (CERES, FORGRO etc.). Canopy photosynthesis, respiration, phenology and allocation are calculated as functions of environmental parameters. Plant growth and water fluxes are directly coupled through photosynthesis and transpiration. Both are determined by the aperture of the stomata. Moreover, indirect feedbacks and interactions occur through the mutual dependence of leaf area, root development and water availability and fluxes. A nitrogen model based upon CERES (Ritchie and Godwin, 1998) and the work by Lemaire and Gastal (1997) is included to account for nitrogen fluxes and nitrogen stress upon plant growth. The kernel model is integrated in a raster GIS system. Thus all fluxes are calculated on a spatial domain. A grid cell size of 100m per pixel was selected in this study. The time step of the different submodels depends upon the time step of the process under consideration. It ranges from 1 hour for quickly changing processes (water fluxes, photosynthesis and respiration e.g.) to 1 day for slow processes (phenology, biomass allocation or land use management e.g.). Spatially distributed inputs to the model are mainly derived from remote sensing data. A landuse map is derived from a knowledge based land use classification using a Landsat TM image. Meteosat data are used to determine the temporal course and spatial patterns of shortwave radiation. Management related parameters (frequency and date of grass cutting, plant density e.g.) are derived from a time series of Landsat-NDVI images. Also, model parameters such as LAI are updated with remote sensing measurements. Remote sensing data are also used to provide data for validating model results. Examples are shown using soil moisture maps derived from ERS SAR data. The integrated GIS system in PROMET-V uses generally available standard meteorological measurements and calculates the spatial patterns of these parameters using geostatistical methods. Temporally static parameters such as soil texture and topography related parameters (elevation, height, slope) are derived
from a DEM. Model inputs include meteorological, soil, topographical, vegetation and land management parameters.

MODEL OUTPUTS
Model outputs are plant parameters (dry weight, LAI, root distribution, organ weights etc.), nitrogen parameters (content in soil and plant, leaching, immobilized, NH4, NO3, etc.), water parameters (evapotranspiration, soil water, snow water equivalent, interception etc)

MODEL APPLICATIONS IN EUROPE
The model has been used and validated in the highly heterogeneous prealpine Ammer catchment (709 km5) which is located in Upper Bavaria/Germany. Large differences in topography, soil texture, climatic conditions and management practices result in large gradients of water fluxes, plant growth and nitrogen fluxes in this catchment. Despite these large heterogeneities of the growing conditions and without local calibration of the model, the results show very good agreement with field measurements. Simulation results of land use and climate change upon fluxes of water, carbon and nitrogen are discussed.

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
Very high potential, but not tested yet. Integration of model, remote sensing and GIS particularly useful for decision support

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REFERENCES
SOURCE OF INFORMATION: HUNGARY

MODEL NAME
CERES-Maize Version 2.1

MODEL DEVELOPERS
Michigan State University and International Fertilizer Development Center
USA

OPERATIONAL SYSTEM
MS-DOS

MODEL SCALE
Field

ABSTRACT
The CERES-Maize model is a comprehensive growth simulation model of the maize plant. The model accounts for independent and interacting effects of genotype, weather, hydrology and plant nutrition. CERES-Maize is a process-oriented, management-level model of maize crop growth and development that also simulates soil water balance and nitrogen balance associated with the growth of maize. It is a daily-incrementing, user-friendly, menu-driven model written and compiled in Microsoft FORTRAN, a familiar and widely used computer language. It is adapted for use on mainframe, mini- and macrocomputers and requires minimal computation time. This maize model has been developed by an international and interdisciplinary team of scientists over a period of several years. Dr. Joe Ritchie of Michigan State University and formerly of the United States Department of Agriculture - Agricultural Research Service (USDA-ARS), Temple, Texas, has coordinated development of the model. CERES-Maize is a multi-purpose model which can be used for within-year crop decisions, multi-year risk analysis for strategic planning, large area yield forecasting and definition of research needs. The model simulates interactions between many plant growth processes and environmental factors including photosynthesis, respiration, phenology, leaf initiation and growth, root growth, soil water content and extraction, evapotranspiration, light interception, grain initiation, grain growth, solar radiation, temperature and precipitation. The nitrogen version of the model simulates interactions of the above processes and factors with applied fertilizer nitrogen, soil nitrogen, nitrogen uptake, nitrogen content of the plant and movement and transformation of nitrogen in the soil. These processes response to environmental factors and their interactions are simulated by the model on a daily basis. The CERES-Maize model requires initial data about the location, the soil type, the hybrid, and the agrotechnological practices.

MODEL OUTPUTS
Outputs from the model are written to several files containing: a copy of the output as shown on the computer screen during the simulation; a one line summary of the main development events, water and nitrogen variables and yield components; a summary of the growth balance variables over time; a summary of the soil and plant water variables over time; a summary of some of the main soil and plant carbon variables; time-series outputs as steps as small as one day or as large as specified by the user. These output files are temporary and are erased and overwritten at the start of each new simulation run.
MODEL APPLICATIONS IN EUROPE

Model evaluation, climate change impact, irrigation strategies in Hungary. Crop analysis of maize was carried out at the Agrometeorological Research Station at Keszthely and Szarvas, Hungary in the years 1976-1991 and 1988-1997 respectively. Measured and simulated data of silking date, maturity date, leaf area maximum, final biomass and grain yield were compared. The average differences between the predicted and observed plant characteristics are not more than 4% at Keszthely and 5.6% at Szarvas. The probability, that of CERES-Maize model simulated yield and biomass agreed within 15% with observed values in a given year, is 80% (Hunkár, 1994). Under the climate of Hungary precipitation is the critical factor of the agricultural crop production as it was proven earlier by statistical analysis. Simulation model CERES-Maize provides an opportunity to estimate yield with optimal moisture supply. It means that the submodel of water balance is switched off. That is the production level No.1. Simulation experiments had been carried out for Keszthely and Szarvas assuming no water stress during the vegetation season. It is called potential production. The different climate of Keszthely and Szarvas is manifested in potential production levels as well as in the frequencies of yield decrease due to water shortage. The average of the potential production is 117 q/ha with CV = 17% and 127 q/ha with CV = 20% at Keszthely and Szarvas respectively. If the actual water supply i.e. precipitation as driving force in the model is taken into account there are years when significant yield decrease occurs. Under the climate of Keszthely water shortage caused significant yield decrease in 14% of the years while in Szarvas which has a warmer and dryer climate in 50% of the years significant yield decrease occurs. The average yield on this production level No.2. 107 q/ha (CV = 29%) and 85 q/ha (CV = 54%) at Keszthely and Szarvas respectively. It has to emphasize that these results came from simulation experiments, nevertheless they fit in the empirical observations. To evaluate the model outputs in proper way some details about the plant-water relations has to be considered. To study the evapotranspiration submodel of CERES crop model a dry and a wet growing season were chosen. The growing season of maize takes from 1.April until 31. September in this relation. In the years 1975-1994 the average amounts of precipitation were 356 mm (STD: 71 mm). The season was assumed dry when the amounts of precipitation were less than AVG-STD= 285 mm and wet when the amounts of precipitation were above AVG + STD = 427 mm. Simulation experiments were run for the year 1981 as a dry and 1987 as a wet year. Potential evapotranspiration calculated by CERES was compared to the values calculated by a local empirical formula developed by Antal (1968), which is used in the Hungarian Met. Service. The actual evapotranspiration simulated by CERES was compared to the measured evapotranspiration. Measuring of evapotranspiration means that the soil moisture content was measured by thermogravimetric method about 10 day frequency, and water balance was determined for those periods: \( ET = W1 - W2 + Pr \), where \( W1, W2 \) are soil moisture content in the upper 1 m layer in mm, for time 1 and 2, \( Pr \) is the precipitation during the period. The final amounts of evapotranspiration simulated by CERES is higher than the measured one both in dry and wet years but the difference is significant only in a dry year. In wet year the measured and simulated values show a good agreement. For the purposes of a climate change study outputs from three general circulation models were used (GISS, UKMO, GFDL). Then the climate change scenarios predicted for Western Hungary were linked to maize simulation model, and the impacts on the development and yield were estimated. The results describing the growth and development of maize were then compared to the corresponding values from the past 16 years at Keszthely, the location of the study, to analyse the size and direction of the changes. The climate change scenarios resulted in silking and maturity occurring much earlier, and thus the growing season became significantly shorter for all the three different GCMs. The maize crop showed the fastest development under the 16 UKMO weather years, with maturity occurring 41 days earlier on average than under the baseline weather years. The GISS scenario resulted in a small, 8% yield increase on the average, while the GFDL resulted in a 7%, and the UKMO in a 14% average yield decrease. For all the three GCM scenarios the standard deviations of the yield are somewhat smaller than in the case of the baseline.
weather, so the yields though smaller, seem to become more stable under the changed weather, especially in the case of the GISS and the GFDL scenario. Biomass results showed similar characteristics to the yield. The average values of the maximum leaf area index increased a little for all the three GCM scenarios, while the standard deviations decreased. The above results may seem surprising, as maize, being a crop of tropical origin, was expected to utilize the increased temperature better, and produce higher yields under the changed weather, but the shortened growing season and the changed distribution of precipitation under this shorter growing season counteracted the results of the advantageous temperature patterns.

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
It was not used for operational prognosis in Hungary

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REFERENCES
Hunkar M.1987: Dynamics of biomass production depending on weather (in Hungarian:A biomassza produkcio dinamikaja az időjaras függvényében. ) Növénytermelés 36: 83-90
Hunkar M.1994: Validation of crop simulation model CERES-Maize Időjaras 98: 37-46
Bacsi Zs.-Hunkar M. 1994 Assessment of the impacts of climate change on the yields of winter wheat and maize using crop models. Időjaras 98: 119-134
SOURCE OF INFORMATION: IRELAND

MODEL NAMES
(a) Johnstown Castle Grass Growth Model
(b) Met Eireann Potato Blight Warnings

MODEL DEVELOPERS
(a) Anthony Brereton (now retired from Teagasc)
E-mail: abrereton@club-internet.fr
(b) Anon - Met Eireann Staff
http://www.met.ie

MODEL SCALES
both regional, but (a) can be used at farm scale

ABSTRACTS
(a) The model is described in Brereton, Danielov and Scott (1996). It is a static model, which was originally created as a basis for evaluating the gross effects of year-to-year differences in weather conditions on herbage production in grazing systems. It does not, and was not intended to, explain the nature of grass growth. Instead, the intention was to provide a means to understand the dynamics of a grazing management system subject to a variable feed (herbage) supply. The approach is very simple compared to the other two models but the variation between the reproductive and vegetative states of the grass crop are taken into account. Reflecting the simple empirical nature of this model the description of the system is reduced to three equations. The increase in herbage mass for a period is calculated from the radiation received at the crop surface:

\[ \Delta W = \epsilon \frac{\Delta J}{Q} \]

where: \( \Delta W \) = mean daily herbage dry matter yield increase (kg ha\(^{-1}\)); \( \Delta J \) = mean daily light received at the crop surface (J cm\(^{-2}\)); \( Q \) = the heat of formation of plant matter (18.81 MJ kg\(^{-1}\)); \( \epsilon \) = the efficiency of conversion to plant energy of the radiation received at the crop surface.

According to the above equation yield is proportional to the radiation received. However, it is assumed that the capacity of the crop to utilise light is saturated at a flux density of 144 J cm\(^{-2}\) hour\(^{-1}\). In the equation \( \Delta J \) represents light received at flux densities less than 144 J hour\(^{-1}\). \( \epsilon \) is not the same as \( E_t \) in the Dutch model, which relates growth to the amount of radiation intercepted by leaf area. The other two models describe an effect of temperature on leaf area growth and light interception. The effects of leaf area on light interception are implicit in the Irish model in the assumption that the efficiency parameter is affected by temperature. Efficiency varies with temperature in a sigmoid relationship:

\[ \epsilon = \epsilon_{\text{max}} \left[ \frac{e^{-K T}}{1 + e^{-K T}} \right] \]

where: \( T \) = mean daily temperature (\(^\circ\)C); \( \epsilon_{\text{max}} \) = the maximum efficiency at high temperatures; \( K \) = temperature at which \( \epsilon \) is half maximum (\(^\circ\)C); \( n \) = constant.

The parameters of the second equation were selected to represent a reproductive crop harvested after 28 days re-growth, fertilised with N at a rate equivalent to 600 kg N year\(^{-1}\) and adequately supplied with water and other nutrients (i.e. growth not restricted by soil nutrients or by soil
water deficit). For other conditions the daily yield increase is expressed as a multiplicative function:

$$\Delta W' = \Delta W \cdot \zeta \cdot \eta \cdot \omega \cdot \nu$$

where: $\Delta W'$ = daily herbage dry matter yield increase (kg ha$^{-1}$); $\zeta = f(\text{ontogeny})$; $\eta = f(\text{nitrogen})$; $\omega = f(\text{soil water})$; $\nu = f(\text{duration of growth period})$.

The grass crop is in the reproductive state from late Winter until June when it becomes vegetative. In the vegetative state growth rates are approximately halved compared to the reproductive crop. A sigmoid curve is used to describe the relationship between calendar date and the ontogenetic factor that represents this change:

$$\zeta = 1 - \left(\frac{1 - \beta}{1 + \beta}F^{m}\right)$$

where: $D$ = date as day number; $\beta = \text{the growth potential of the vegetative sward as a fraction of the reproductive sward}$; $F = \text{the day when the transition from reproductive to vegetative growth is half completed}$; $m = \text{a constant}$.

Nitrogen (N) fertiliser has a major effect on grassland production. To accommodate variable levels of N use the growth estimates are adjusted by $\eta$. A cubic relation between $\eta$ and N is employed. Similarly, a multiplicative factor $\omega$ is employed to adjust yield estimates for soil water deficit. $\omega$ takes the value 1.0 where the soil water deficit is less than 30mm. At greater deficits $\omega$ decreases linearly with increasing deficit. The logistic growth equation is used as the basis for modifying yield estimates according to the duration of the growth period. The logistic equation is commonly written in the form:

$$W = \frac{W_o \times W_f}{W_o + (W_f - W_o) e^{-\mu t}}$$

where: $W = \text{the herbage mass at } t \text{ days after defoliation (kg ha}^{-1}\text{)}$; $W_o = \text{the herbage mass at } t = 0 \text{ (kg ha}^{-1}\text{)}$; $W_f = \text{the ceiling herbage mass, approached as } t \text{ becomes large (kg ha}^{-1}\text{)}$; $\mu = \text{the equation parameter}$; $t = \text{time (d)}$.

Re-arrangement of the logistic equation for mass:

$$\mu = \frac{1}{t} \ln \left[ \frac{W_o(W_f - W)}{W_f - W_o} \right]$$

The 28-day yields are used to estimate $\mu$ by the two previous equations is then used to estimate the yield at the relevant growth period. The seasonal change in ceiling yield is calculated using a sine-wave approximation by equation:

$$W_f = 0.5(W_h - W_w) \sin \left[ \left( t - 60 \right) \frac{\pi}{182.5} \right] + 0.5(W_h + W_w)$$

where: $W_f = \text{ceiling yield (kg ha}^{-1}\text{)}$; $W_w = \text{the mid-winter minimum ceiling mass (3500 kg ha}^{-1}\text{)}$; $W_h = \text{the mid-summer maximum ceiling mass (7500 kg ha}^{-1}\text{)}$; $t = \text{day of year}$.

(b) In Ireland, Bourke (1953) developed a set of rules for forecasting late blight which were first used in 1952, and are known as the ‘Irish Rules’. These rules were based on experimental laboratory work carried out by Crosier in the USA (Bourke, 1955). The rules were used for the de-
development of a late blight warning service that is run by Met Éireann (the Irish meteorological service). The Met Éireann blight warning service follows the Irish Rules using data supplied regional weather stations to calculate the severity of blight spells and making use of synoptic weather charts to predict spells of blight weather and so give a spray warning. The spray warnings are issued over national television and radio as required during the growing season. The rules for forecasting late blight are as follows (Keane, 1986):
(a) A 12 h period with air temperature 10°C or greater and relative humidity not less than 90%;
(b) Suitable conditions for free moisture to remain on the leaves for a further two hours or more;
(c) Effective blight hours (EBHs) begin on the 12th successive hour as in (a) if, to satisfy condition (b), there is precipitation between the 7th and 15th hour. Otherwise accumulated EBH do not begin until the 16th hour;
(d) If two spells with blight conditions, the first as in (c) and the second as in (a), follow each other, within 5 hours or less between the ending of the first and the beginning of the next, no lead in period of 11 or 15 h need be deducted for the second spell.

MODEL OUTPUTS
(a) grass production by time period and loss due to drought effects
(b) a blight risk warning

MODEL APPLICATIONS IN EUROPE
(a) and (b) not tested for rest of Europe

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
(a) very good and ongoing research for its use
(b) poor

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(b) anon - Met Eireann Staff
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REFERENCES
Bourke, P.M.A. 1955. The forecasting from weather data of potato blight and other plant diseases and pests. WMO Technical Note 10. World Meteorological Organisation, Genèве, Switzerland
SOURCE OF INFORMATION: ITALY
(authors: G. Genovese, S. Orlandi (JRC-EC, IPSC/MARS))

MODEL NAME
CGMS - Crop Growth Monitoring System
A major new release 2.0a (26-10-2000)

MODEL DEVELOPERS
Conception: Joint Research Centre – EC (MARS Unit)
Implementation: Joint Research Centre – EC (MARS Unit) together with Alterra (ex SC-DLO, Wageningen, NL, contact name K. Van Diepen)., Main Developer Responsible in JRC: Erik van der Goot – erik.van-der-goot@jrc.it,Phone Number +39 0332 785900, Fax +39 0332 789576, JRC – IPSC, T.P. 361/122 I-21020 Ispra (VA), Italy, Currently other Public European Services are working to new releases.

OPERATIONAL SYSTEM
The system has been designed as a client/server application, with the client running on a Windows NT 4/Office 98 system (Windows 2000 / office 2000 will be supported) and the database being accessed through ODBC.
The ODBC implementations that have been tested are limited to Microsoft Access and Oracle, using the Microsoft and OpenLink Lite for Oracle 7 ODBC drivers respectively (OpenLink Lite for Oracle 8 will be supported, but for now the OpenLink 7 driver works fine with Oracle8)

MODEL SCALE
Regional scale.
EMU (Elementary Mapping Unit) Level, dimension below 50x50 km,
Grid-cell level, 50x50 km
National and Regional aggregated level
Geographically the CGMS of the JRC covers the European Continent, Turkey and Maghreb.

ABSTRACT
Full description of the system, algorithm, calculation performed and formulae used are available in (Supit, I., Hooijer, A.A., Van Diepen, C.A., Edts, 1994),(Vossen, P. Rijks, D., 1995), an updated version of the system description is available in http://www.iwan-supit.cistron.nl/~iwan-supit/contents/ (Supit and Van der Goot EDS).
Specific notes(.pdf) by Erik Van Der Goot:
On the interpolation and processing of the meteo data in CGMS can be downloaded at: http://mars.aris.sai.jrc.it/documents/stats/cgms/GridWeather.pdf
CGMS consists of three main levels:
1. Interpolation of meteorological data to a square grid
Data are collected at ground meteorological stations level (WMO GTS). More than 1000 stations are operationally supplying temperatures and rain data (less for other parameters). GR and ETP are calculated by the model at this level. The point data are interpolated according to algorithm developed in the JRC. The results are the main input for level 2 together with soil data, crop calendars and area statistics.
2. Simulation of the crop growth
Crops covered operationally: wheat, spring barley, grain maize, rape seed, sunflower, field beans, sugar beet, potato.
Crops covered at experimental stage or under development in JRC: rice, soy beans, pastures, olives and vineyards.

Crop parameters simulated and available as output for each crop:
- Version Potential Model (energy is the only limiting factor): leaf area index, development stage, weight of the above ground biomass, weight of the storage organs.
- Version Water Limited Model (water supply is also a limiting factor): leaf area index, development stage, weight of the above ground biomass, weight of the storage organs, soil moisture, water requirements.

3. Statistical forecasts and evaluation of the results

The parameters produced at level 2 are used as predictors to forecast the final yield. To fit a prediction model time series of yield are necessary at the geographic level needed. In fact the parameters simulated at aggregated level often need a re-calibration on observed data. This can be explained by the fact that the model assumes constant or not influencing biotic and a-biotic limiting factors, such as pests and diseases, micro-nutrients deficiencies. Moreover there are often trend factors in inter-annual yield variations linked to technological factors that have to be taken into account, thus a time series analysis is necessary. The quality of the re-calibration versus observed time series of yields of course becomes dependent as well on the quality of data available. The yield predictions models are fit using simple-regressions (MSE methods). An automatic algorithm based on a jack-knife technique make a choice of the best model available (thus predictor) at the moment of the forecast must be issued evaluating the prediction errors of the models. Other multivariate techniques have been developed to analyse the data and produce forecasts (factor analysis, cluster analysis to make scenarios).

All the output of the three levels are available in tabular and mapped form at the different geographic scales.

The Crop Growth Monitoring System is built around WOFOST version 6.0 (Supit, I., Hooijer, A.A., Van Diepen, C.A., Edts, 1994), a crop growth model developed by the DLO-Winand Staring Centre (SC-DLO) in conjunction with the Research Institute for Agrobiology and Soil Fertility (AB-DLO), now merged in Alterra a research institution located in Wageningen, The Netherlands. WOFOST was re-adapted to cover a larger scale in order to supply crop growth simulations at European level (Vossen, P. Rijks, D., 1995).

WOFOST is a quantitative deterministic model that can be used to simulate a number of crops, based on different sets of crop parameters. It takes account of certain soil characteristics and uses daily meteorological data for the calculation of evolution in time of the crop. WOFOST could be described as a ‘point’ model in the sense that it performs the calculations for one single point in space/time. In order to allow the application of the WOFOST model on a larger scale, there is a need for the identification of areas where the meteorological data and the soil characteristics can be assumed to be homogeneous, such that one calculation for that combination of input data is representative for the whole region. Furthermore, the output of the system should be representative for a region for which statistical yield data is available. This is necessary for the regression model used for the yield forecast.

The region for which statistical yield data is available is normally one of the administrative regions in a country or a province and is therefore easily defined. The areas for which the soil characteristics are constant are more difficult to define. Most soil maps have a smallest cartographic region, the ‘soil mapping unit’ (SMU), although often these consist of various soil types. Still, the smallest region that can be defined for the soil data is this smallest cartographic region. If necessary, further subdivisions for calculation purposes have to be made based on the distribution of soil characteristics throughout this cartographic area. This leaves the definition of the area for which the meteorological data can be assumed to be homogeneous. For this purpose, the area of interest is divided into square cells, which together form a grid system. The size of the cells is fixed for a particular implementation of CGMS, and for the production system described above, the cells measure 50x50 kilometres. Other systems have smaller cells, e.g. 20x20 or 25x25 km.
The intersection of the regions described above defines the geographic regions for which CGMS produces results, and is called Elementary Mapping Unit (EMU).

MODEL APPLICATIONS IN EUROPE
Other institutions currently elaborating CGMS:
Alterra (Wageningen, NL)
VITO (Belgium)
FUL Univ (Belgium)
Univ. of Madrid (Spain)

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
The model is run operationally and the results are used within the JRC and DG-Agriculture Outlook group to support real-time analysis of the agricultural campaign in course and outlook analysis to support Common Agriculture Policy decisions. A report called the MARS bulletin, containing several results of CGMS, is published regularly: (http://mars.aris.sai.jrc.it/mars/stats/bulletin)

ADDITIONAL MODEL INFORMATION
Executables are publicly available and downloadable from Erik van der Goot's FTP site.
ftp://aisws4.jrc.it/public/erik/CGMS/
CGMS Codes are available under written request for research purposes.
No IT assistance is given for installing and running the system.
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http://mars.aris.sai.jrc.it/stats,MARS stands for Monitoring Agriculture with Remote Sensing

REFERENCES
Updated version of the CGMS system description is available in http://www.iwan-supit.cistron.nl/~iwan-supit/contents/ (Supit and Van der Goot EDS).
Specific notes (.pdf) by Erik Van Der Goot:
On the interpolation and processing of the meteo data in CGMS can be downloaded at: http://mars.aris.sai.jrc.it/documents/stats/cgms/GridWeather.pdf
Data requirements and preparation of CGMS downloadable at:
SOURCE OF INFORMATION: ITALY

MODEL NAME
CropSyst (Cropping Systems Simulation Model)
http://bsyse.wsu.edu/cropsyst/

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OPERATIONAL SYSTEM
Win95/98/Nt/2000

MODEL SCALE
Field/Regional

ABSTRACT
CropSyst (Cropping Systems Simulation Model) is a multi-year, multi-crop, daily time step crop growth simulation model, developed with emphasis on a friendly user interface, and with a link to GIS software and a weather generator (Stockle, 1996). Link to economic and risk analysis models is under development. The model’s objective is to serve as an analytical tool to study the effect of cropping systems management on crop productivity and the environment. For this purpose, CropSyst simulates the soil water budget, soil-plant nitrogen budget, crop phenology, crop canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water, and pesticide fate. These are affected by weather, soil characteristics, crop characteristics, and cropping system management options including crop rotation, cultivar selection, irrigation, nitrogen fertilization, pesticide applications, soil and irrigation water salinity, tillage operations, and residue management.

Four input data files are required to run CropSyst: Location, Soil, Crop, and Management files. Separation of files allows for an easier link of CropSyst simulations with GIS software. A Simulation Control file combines the input files as desired to produce specific simulation runs. In addition, the Control file determines the start and ending day for the simulation, define the crop rotations to be simulated, and set the values of all parameters requiring initialization. Definitions, usage, and range of variation of all parameters required by CropSyst are given in the User’s Manual (Stockle and Nelson, 1994 and 1996), and they are also available in the Help facility of the model interface.

The Location file includes information such as latitude, weather file code name and directories, rainfall intensity parameters (for erosion prediction), freezing climate parameters (for locations where soil might freeze), and local parameters to generate daily solar radiation and vapor pressure deficit values.
The Soil file includes surface soil Cation Exchange Capacity and pH, required for ammonia volatilization, parameters for the curve number approach (runoff calculation), surface soil texture (for erosion calculation), and five parameters specified by soil layer: Layer thickness, Field Capacity, Permanent Wilting Point, Bulk Density, and Bypass Coefficient. The latter is an empirical parameter to add dispersion to solute transport, particularly when using the cascading approach for soil water redistribution.

The Management file includes automatic and scheduled management events. Automatic events (irrigation and nitrogen fertilization) are generally specified to provide optimum management for maximum growth, although irrigation can be also set for deficit irrigation. Management events can be scheduled using actual date, relative date (relative to year of planting), or using synchronization with phenological events (e.g., number of days after flowering). Scheduled events include irrigation (application date, amount, chemical or salinity content), nitrogen fertilization (application date, amount, source- organic and inorganic-, and application mode- broadcast, incorporated, injected), tillage operations (primary and secondary tillage operations, which are basically related to residue fate), and residue management (grazing, burning, chopping, etc.).

The Crop file allows users to select parameters to represent different crops and crop cultivars using a common set of parameters. This file is structured in the following sections: Phenology (thermal time requirements to reach specific growth stages, modulated by photoperiod and vernalization requirements if needed), Morphology (Maximum LAI, root depth, specific leaf area and other parameters defining canopy and root characteristics), Growth (transpiration-use efficiency normalized by VPD, light-use efficiency, stress response parameters, etc.), Residue (decomposition and shading parameters for crop residues), Nitrogen Parameters (defining crop N demand and root uptake), Harvest Index (unstressed harvest index and stress sensitivity parameters), and Salinity Tolerance.

MODEL APPLICATIONS IN EUROPE
CropSyst has been applied to several crops (corn, wheat, barley, soybean, sorghum, and lupins) and regions (Western US, Southern France, Northern and Southern Italy, Northern Syria, Northern Spain, and Western Australia), generally with good results and also a few problems (e.g. Donatelli et al., 1996), particularly for applications to conditions not simulated by the model (for example, water balance of cracking vertisols). The quality and/or level of detail of the available data is often a constraint for more thorough model evaluation. For more information on CropSyst validation the reader is referred to Stockle et al. (1994), Pala et al. (1996), Stockle et al. (1996), Stockle and Debaeke (1996), Donatelli et al., 1997, and Ferrer, (1995). Validation work was performed using data collected by the Institut National de la Recherche Agronomique (INRA) at Auzeville (near Toulouse), France (Stockle et al., 1996). These data are from long-term cropping system experiments conducted from 1983 to 1992 to evaluate crop rotations at three input levels. During the last years the model was extensively applied in Italy (Ventrella and Rinaldi, 1999; Rinaldi et al., 1999; Donatelli et al., 1997)

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
A 3-year experiment was carried out near Modena, Italy in order to estimate the environmental impact of urea and pig slurry applied to a maize crop (Marchetti et al., 1999). Each fertilizer was applied to give 0, 75, 150 or 225 kg N/ha, in factorial combinations. A considerable spatial and temporal variability of maize yield was observed for the same treatment in an apparently uniform field. The possibility of predicting such variability by analysing the available information about soil properties and climatic conditions, using both statistical methods and simulation models, was investigated. The significance of the treatment effects was spatially dependent. Yield variability could be explained by differences in soil NO₃ content at the beginning of the growing season, and by spatial differences in soil C and N content. Yield variability was simu-
lated with the CropSyst model, and it is suggested that the complementary use of statistical analysis and model simulation may constitute an effective

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REFERENCES
SOURCE OF INFORMATION: THE NETHERLANDS

MODEL NAMES
a) SUCROS
b) A-gs model

MODEL DEVELOPERS
a) Goudriaan J., and Van Laar, H.H.
b) Jacobs, C.M.J.; Ronda, R.J. et al.

ABSTRACT
See extensive description in:
b1) Jacobs, C.M.J., Direct impact of atmospheric CO₂ enrichment on regional transpiration. Thesis Wageningen University, 179 pp.

MODEL APPLICATIONS IN EUROPE
b) The model has been tested for changes in CO₂ conditions (see references)

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SOURCE OF INFORMATION: PORTUGAL

MODEL NAME
POTATO 2

MODEL DEVELOPERS
Edward Ng, Robert Loomis, Aguiar Pinto

OPERATIONAL SYSTEM
MS – DOS, FORTRAN IV adapted for FORTRAN 77

ABSTRACT
The model has a simulator of climate: precipitation, maximum and minimum temperatures, dew point, solar radiation, wind speed.

MODEL OUTPUTS
Final output: crop growth of potato

MODEL APPLICATIONS IN EUROPE
Model evaluation, testing cases

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
Personnel potential

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SOURCE OF INFORMATION: **RUSSIA**

MODEL NAME
CLIMATE -SOIL -YIELD

MODEL DEVELOPERS
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OPERATIONAL SYSTEM
MS - DOS

MODEL SCALE:
regional, national

ABSTRACT
The geoinformation system CLIMATE – SOIL – YIELD consists of:
- WEATHER – CLIMATE simulation dynamic models of agroecosystem productivity
- Model of energo-mass-exchange in plant – soil – atmosphere system
- Stochastic models permitting generation of annual series of daily meteo elements corresponding to specified climate norms.
- A database including hydrometeorological data over 100 year period, scenarios of possible climate changes and data about physical and agrochemical soil properties.

The model WEATHER – CLIMATE consists of three systems of regular differential equations with direct and reverse relations accounting for dynamic carbon, nitrogen and water in agricultural ecosystem with the daily interval ranging from seeding to maturing of the crop.
Inputs: actual daily and/or decade means of weather elements, soil fertility, GCM scenarios (e.g., GISS, GFDL, HADC).

MODEL OUTPUTS
Yield, biomass of different plant parts, leaf square, soil moisture for 10- sm. layers from surface till 1 m deep.

MODEL APPLICATIONS IN EUROPE
Different versions of model were tested for a wide variety of climatic, soil and agrotechnical conditions of Russia different regions, and other countries. Types of cultures were: spring wheat and pea (Moldavia), spring barley (Slovakia, Poland), tomato (Ukraine), and some other crops.
Model is widely used for a change impact studies in Russia and other countries with considerations for all meaningful factors: changing in climatic parameters, soil fertility, CO₂ and O₃ concentration growth.

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
Model is used as a practical instrument for operational assessment of crop in Russia and yield prognosis in 1998 – 2001 years.

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REFERENCES
Sirotenko O.D. Abashina E. Pavlova V., 1995. Sensitivity of agriculture in Russia to changes of climate, chemical structure of atmosphere, and soil fertility. Meteorology and Hydrology No. 5, pp. 107-114 (In Russian)
**SOURCE OF INFORMATION:** SLOVENIA

**MODEL NAME**
IRRIFIB-3 (Irrigation forecast model)

**MODEL DEVELOPERS**
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**MODEL SCALE** regional

**ABSTRACT**
The model IRRFIB was developed at the Hydrometeorological Institute of Slovenia in 1984. It is the computer model that gives the soil water balance and calculates the content of available water around rooting system. Together with the weather forecast parameters it estimates the soil water consumption for next three days. IRRFIB model simulates the water consumption by crops during their vegetation – growing and ripening season taking into account soil water characteristics, phenological phases of crops, rooting depth and naturally atmospheric conditions. Boundary conditions – soil water availability from saturation to defined depletion – are considered. The area covered by specific crop is limited by soil type, for surfaces containing different soil types the average of soil water characteristic is guiding the calculation of soil water balance. As the depth of ground water at irrigation fields in most cases is more than two meters, the capillary rise of it is not being computed. It would be better for more precise estimation of water uptake of the crop roots to include two soil layers instead of only one in IRRFIB model. Phenological dates and rooting depths of crops as well as crop coefficients are given in ASCII file – crop.etp, soil water characteristics – field capacity and wilting point - are ASCII file – soil.etp. Including measured daily precipitation daily water balance is obtained. Optional parameters can be included in the model: synoptic weather parameters for future 3 to 7 days (air temperature, relative air humidity, sunshine duration and wind speed); soil water depletion; type of irrigation; irrigation water requirements.

**MODEL OUTPUTS**
The model generates the crop-soil-water balance ranging from one day to whole vegetation period. Data obtained can be given as tables including time increments or entire vegetation period or graphically presented curves of soil water content for irrigated and non irrigated crops. Different degrees of plant water stress for crops can be observed on the graph when crops are not irrigated. The additional curve of irrigation water applications is generated when for a specific crop the maximum application rate of water for the predefined irrigation system is given (it depends on irrigation system applied and naturally on soil water infiltration rate). The model gives the near future irrigation needs up to seven days, when including forecasted weather parameters. In the case of weather forecast with precipitation sufficient to replenish the soil water reservoir throughout the crop rooting depth the irrigation can be cancelled. The export files can be directly used for irrigation system design and for calculations of water volumes for irrigation reservoirs, which are for fruit and vegetable producers on small plots quite common.

**MODEL APPLICATIONS IN EUROPE**
very recently in Austria and Germany

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SOURCE OF INFORMATION: SPAIN

MODEL NAME
ImpelERO: An expert system/neural network model for evaluating soil erosion, impact on crop productivity and management practices accommodation

MODEL DEVELOPERS
D. de la Rosa, F. Mayol, T. Bonson and S. Lozano

OPERATIONAL SYSTEM
MS WINDOWS

MODEL SCALE
Field or local scale

ABSTRACT
Soil erosion by water is one of today’s most important environmental problems, in great part due to changes in agricultural land use and management. This paper illustrates the formulation, calibration, sensitivity and validation analysis of a hybrid model of expert decision trees and artificial neural networks (named ImpelERO) to evaluate the soil erosion process. A total of 237 field-units were selected, which represent 34 major land resource areas for five traditional crops in the Andalusian region, southern Spain. The field-units observed cover the whole range of erosion events, from what was considered very small to extreme erosion. Seventy-six per cent of the fields suffered small, moderate or large erosion problems. However, only 14% of the fields suffered very small, and 10% of the fields suffered very large or extreme erosion problems. Because of the complexity of the soil erosion process, and the interrelationships of the parameters, ImpelERO was developed as an USLE-type model following traditional land evaluation analysis and advanced empirical modelling techniques. Using expert-decision trees, soil survey information and expert knowledge of the soil erosion process were combined through land and management qualities. An artificial neural network approach was then applied to capture the interactions between the land and management qualities and one output: vulnerability index to soil erosion. The neural network was trained using the Correlation-Cascade algorithm. The trained network estimated the output with a high degree of accuracy (maximum deviation 14%), and also has a good generalisation capacity. By means of correlation analysis, observed erosion vulnerability data were compared with predicted data using a previously developed model and using the ImpelERO model. The latter model gave more accurate results ($r = 0.91$) than the previous approach ($r = 0.66$). Along with the prediction of soil loss by water erosion, ImpelERO could be used as an optimisation tool for selecting the land use and management practices which satisfy the optimum environmental protection including reduction of soil erosion.

MODEL OUTPUTS
Vulnerability index of soil erosion, percentage of crop production reduction, and optimum agricultural management system

MODEL APPLICATIONS IN EUROPE
See the following paper: De la Rosa et al. 2000. Assessment of soil erosion vulnerability in western Europe and potential impact on crop productivity due to loss of soil depth using the ImpelERO model. Agriculture, Ecosystems and Environment 81: 179-190

ADDITIONAL MODEL INFORMATION
See previous paper, and the following website: http://leu.irnase.csic.es
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REFERENCES
See previous paper and web site
SOURCE OF INFORMATION: SPAIN

MODEL NAMES
CERES-Wheat, CERES-Maize, CERES-Rice, SOYGRO, CROPWAT

OPERATIONAL SYSTEM
MS DOS

MODEL SCALE
Field and farm

ABSTRACT
The wheat, maize, rice, and soybean models (CERES-Wheat, CERES-Maize, CERE-Rice, and SOYGRO) are process-based mechanistic models that describe daily phenological development and growth in response to environmental factors (soils, weather and management). The models have been calibrated and validated over a wide range of agro-climatic regions (Rosenzweig and Iglesias, 1998).

Iglesias et al. (2000) have developed functions for estimating yield changes related to climatic variations over wide geographic areas and used with a GIS at the grid level.

CROPWAT (CROPWAT, 1995) is a model developed by FAO to calculate crop water and irrigation requirements from climatic and crop data. The program allows planning of irrigation management alternatives for different schemes of water supplies and cropping patterns.

MODEL OUTPUTS
Mechanistic models: yield, biomass, crop season length, dates of main physiological stages, crop ET, nitrogen use, nitrogen leaching, irrigation demand.
CROPWAT: irrigation demand and schedule.

MODEL APPLICATIONS IN EUROPE


MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
Widely used already in operational mode. Please see the following key references for the use of crop models for operational assessment:


ADDITIONAL MODEL INFORMATION
http://sedac.ciesin.columbia.edu/giss_crop_study/

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REFERENCES
SOURCE OF INFORMATION: SWITZERLAND

MODEL NAME
PASIM (Pasture Simulation Model)

MODEL DEVELOPERS
Pierluigi Calanca and Juerg Fuhrer
FAL Liebefeld, CH-Switzerland

OPERATIONAL SYSTEM
ACSL

MODEL SCALE
Field

ABSTRACT
The grassland ecosystem model simulates above- and belowground dry matter production of a cut and fertilized perennial sward in relationship to fluxes of C, N, water, and energy. The model which was described in detail by Riedo et al. (1997, 1998), consists of four sub-models: (1) The plant sub-model, which was developed on the basis of the Hurley Pasture model, is used to simulate shoot and root growth in relationship to C and N uptake, energy fluxes, and soil moisture conditions; (2) the microclimate sub-model calculates canopy radiation interception and the energy balances of canopy and soil surface; (3) the soil biology sub-model calculates plant available soil C and N; (4) soil profiles of water and temperature are calculated by a sub-model for soil physics. The driving weather variables are hourly temperature (T), precipitation (P), vapour pressure (VP), radiation (G), and wind speed (U). The cutting days are determined by an algorithm which maximizes the seasonal dry matter production.

MODEL OUTPUTS
Above and below ground dry matter production, N, C and water fluxes, N and C stocks, energy balance etc.

MODEL APPLICATIONS IN EUROPE
Climate change impact studies, studies on implications of changes in grassland management

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
Model can be driven by hourly weather scenarios provided by climate models and downscaled to site of interest. Potential to use medium-range weather forecast for seasonal yield predictions.

ADDITIONAL MODEL INFORMATION
see the references below

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REFERENCES
SOURCE OF INFORMATION: TURKEY

MODEL NAME
CROPWAT7

MODEL DEVELOPER
FAO

OPERATIONAL SYSTEM
DOS

MODEL SCALE
Field, Scheme

ABSTRACT
The program calculates crop water requirements and irrigation requirements from climatic and crop data, and allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying cropping pattern.

MODEL OUTPUTS
Evapotranspiration, irrigation requirements and irrigation scheduling

MODEL APPLICATIONS IN EUROPE
Model was developed in Europe

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
Model estimates relative yield reductions

CONTACT ADDRESS
Ankara Research Institute of Rural Services
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Turkey

REFERENCES
SOURCE OF INFORMATION: TURKEY

MODEL NAME
IRSIS

MODEL DEVELOPERS
Dirk Raes, Herman Lemmens, Paul Van Aelst, Mathias Vanden Bulcke and Martin Smith

OPERATIONAL SYSTEM
DOS

MODEL SCALE
Field, Scheme

ABSTRACT
For a given climate, crop and field data, the program calculates net irrigation requirements, the optimal water distribution resulting in the highest yield under limited water conditions and yield response under rainfed agriculture, plans irrigation schedules for different operational conditions, evaluates a past irrigation schedule using historical data and forecasts irrigation actions during the operational stage according to forecasted weather information

MODEL OUTPUTS
Evapotranspiration, irrigation requirements, irrigation scheduling, water balance, yield response, application efficiency

MODEL APPLICATIONS IN EUROPE
Model was developed in Europe

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
Model estimates relative yield and yield reductions

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REFERENCES
SOURCE OF INFORMATION: UNITED KINGDOM

MODEL NAME
WDM (Wheat Disease Manager)

MODEL DEVELOPERS
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2- ADAS High Mowthorpe, Duggleby, North Yorkshire, YO17 8BP, UK
3- University of Leeds, Leeds, LS2 9JT, UK

OPERATIONAL SYSTEM
Dessac/Fortran

MODEL SCALE
Field

ABSTRACT
A canopy simulation is used in conjunction with disease growth and yield accumulation models to estimate yield loss solely due to foliar diseases, and to that end is used in a system which supports decisions on the merits of fungicide application. The focus is to produce a robust model for a defined process and to ignore factors which are not relevant to the purpose. The system is written so that it can make use of data that is available to potential users, such as daily temperature data, latitude, sowing date and more uniquely canopy observations made during the season (development stage and diseases) to modify the predictions of the simulation.

MODEL OUTPUTS
In addition to yield loss, leaf emergence and senescence dates, GAI, anthesis dates

MODEL APPLICATIONS IN EUROPE
The model is designed to be used in a DSS which will help users decide appropriate fungicide application to winter wheat in the UK.

MODEL POTENTIAL FOR OPERATIONAL ASSESSMENT OF CROP STATUS AND YIELD PROGNOSIS
Yes if your limiting factor is foliar and ear diseases, no if NPK, irrigation, take-all, weeds, etc.

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REFERENCE
Milne, A., N. Paveley, E. Audsley, P. Livermore and S. Parker. A Wheat Canopy Model For Use In Disease Management Decision Support Systems (to be submitted)
SOURCE OF INFORMATION: YUGOSLAVIA

MODEL NAME
LAPS (Land Air Parameterization Scheme)

MODEL DEVELOPER
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MODEL DESCRIPTION
A land air parameterization scheme (LAPS) developed through the joint efforts of the University in Novi Sad and University in Belgrade describes mass, energy and momentum transfer between the land surface and the atmosphere. The scheme is designed as a software package, and can be run as part of an atmospheric model or as a stand-alone model.

The LAPS scheme describes the interaction of the land surface and the atmosphere, under processes, which can be divided into three sections: subsurface thermal and hydraulic processes, bare soil transfer processes and canopy transfer processes. They are: Interaction of vegetation with radiation, evaporation from bare soil, evapotranspiration which includes transpiration and evaporation of intercepted precipitation and dew, conduction of soil water through the vegetation layer, vertical water movement in the soil, runoff, heat conduction in the soil and momentum transport. The LAPS scheme uses the morphological and physiological characteristics of the vegetation community for deriving the coefficients and resistances that govern all the fluxes between the surface and atmosphere. A single layer approach is chosen for the physical and biophysical scheme background. The scheme has seven prognostic variables: three temperature variables (the canopy vegetation, soil surface and deep soil), one interception storage variable, and three soil moisture storage variables. In the scheme upper boundary conditions are used: air temperature, water vapor pressure, wind speed, radiation and precipitation at a reference level within the atmospheric boundary layer. The sensible and latent heat are calculated using resistance representation. The evaporation from the bare soil is parameterized using an \( \alpha \) scheme.

The soil model part is designed as a three-layer model which is used to describe the vertical transfer of water in the soil. Consequently, the processes parameterized in this scheme can be divided into three sections: subsurface thermal and hydraulic processes, bare soil transfer processes and canopy transfer processes. The vegetation in the schemes treated as a block of constant density porous material sandwiched between two constant stress layers with an upper boundary (the height of canopy top) and a lower boundary (the height of canopy bottom). The design of the scheme is based on papers by Mihailovic et al. (1993), Mihailovic and Jeftic (1994), Mihailovic (1996), Mihailovic and Kallos (1997) and Mihailovic et al., (1999). In designing the scheme, a compromise has been made between an accurate description of the main physical processes and the restriction of the number of prescribed input parameters. The scheme was evaluated using micrometeorological measurements over maize, winter wheat and soya fields. The scheme accurately reproduced the observed values of the components of the surface energy balance with the parameterization which has been able to capture most of the main physical processes involved (Mihailovic et al., 1993; Mihailovic and Jeftic, 1994). In the further development of this scheme, more attention has to be devoted to two fundamental points: energy partitioning and water partitioning (Mihailovic et al. 1998). It will include reconsideration of some formulations in current parameterization of evapotranspiration and hydrology using more specific tests. At this moment the scheme can be used for practical purposes, particularly in the estimation of evaporation in agriculture. Following improvements in LAPS are in the preparation phase: approach in mixing length theory above the vegetation, turbulence inside the
canopy, calculating the surface temperature of the solid surface and some changes in hydrology (see list of references related these subjects). Detailed information dealing with the scheme are available on the site http://www.cmem.net

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REFERENCES
Arsenic, I., D.T. Mihailovic, 1998: Calculation of rocky surface temperature for use in atmospheric models. Research Activ. in Atmos. and Oceanic Modelling, Rept. No. 27, 4.1-4.3. (R52)
THE ECONOMIC CONSEQUENCE OF DROUGHT IN SPRING OF 2000 FOR THE CEREAL PRODUCTION IN SLOVAKIA

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The variability and climate change impact on the cereal production in Slovakia is connected with the time and space dissemination of precipitation and the increasing air temperature during the main growing season of both, winter and spring cereals.

The cereal production in Slovakia is previously concentrated in lowland regions. These areas were strongly influenced by the weather conditions – the time and space dissemination of precipitation and air temperature during the main growing season (from March to July) in the last decade of 20th century. The highest impact of weather on the cereal production was recorded in the year of 2000. The wet weather in March was followed by extremely hot and dry weather from the beginning of second decade of April till the last decade of June. In July the dry and hot weather changed into the wet weather which complicated the cereal harvest. These conditions ultimately determined not only the timing of phenological phases and the duration of intervals between them but also the final crop production. The mean yield of winter wheat in Slovakia was 3,1 t.ha⁻¹ and spring barley only 2,0 t.ha⁻¹ that was in some southern part of Slovakia from one third to one half of possible yield (a price of one tone of cereals was approximately 105 EURO).

On the other hand in less convenient areas for cereal growing (altitude above 300 ms) the impact of weather in the year 2000 shoved that in spite of some lack of precipitation an increasing in the air temperature positively influenced not only the winter but also the spring cereal production.

Ministry of Agriculture immediately adopted measures for to decrease the impact of weather on the crop production and to support the next year production. One of the recommendations was the reconstruction or modernisation of existing and construction of new irrigation systems for to avoid the insufficient water supply in the soil during the main growing season of crops (not only cereals) in the future.

For these reason the agrometeorological service of the Slovak Hydrometeorological Institute will plan to co-operate with special agricultural research institutes for to
test of irrigation models based on all available weather and crop data and consequently to implement them in the praxis.

It is necessary also to modify the technology of cereal growing (fertilisation, plant protection, etc.) in the less convenient areas. An increasing in the air temperature can cause an advance in timing of cereal development and a progress of some pests from lowland to basins and valleys in the highland regions of Slovakia.