MODELING OF AGRICULTURAL-ENVIRONMENTAL PROCESSES RELATED TO CROP PRODUCTION
Summary Report of the Task Force Meeting held by IIASA June 2-4, 1980

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November 1980
CP-80-32

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PREFACE

Mathematical models for impacts of agriculture on the environment are useful tools for understanding the phenomena, forecasting them or elaborating recommendations to control them. One of the objectives of REN Task 3 "Environmental Problems of Agriculture" is to collect and assess existing models describing water-related and soil-related environmental impacts of agriculture. The Task members expect to complete this undertaking by the end of 1980. Some work on the collection of models and their application to a number of case studies in the National Member Organizations has been done in-house. As part of this ongoing work, a Task Force Meeting organized by I. Shvytov was convened to discuss our progress, to study the least understood issues, to refine cooperative studies with colleagues outside IIASA, and to help them improve their collaborative efforts with one another. This paper presents a rather brief overview of the meeting before the proceedings are published.

G. Golubev
Task Leader
Environmental Problems of Agriculture

ACKNOWLEDGEMENTS

The authors would like to express their thanks to all those who contributed to this Task Force Meeting, whether by formal presentations, or through participation in the discussions. The authors are grateful to the chairmen and rapporteurs of the sessions (see Appendix), whose reports have been used to prepare this paper. We would also like to express our appreciation to Ms. Pamela Hottenstein and Ms. Caroline Goodchild for their technical and organizational help.

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INTRODUCTION

In 1978, work on mathematical modeling of environmental impacts of crop production was initiated at IIASA. The main objective of this work was to clarify the state-of-the-art with implementation of mathematical models for the assessment of crop production environmental impacts. The major emphasis was focused on the environmental consequences of dry farming. Soil erosion, nitrogen leaching, and phosphorus and pesticide losses from cropland were singled out as the most important field-scale environmental effects of dry farming which potentially can lead to large-scale environmental impacts (eutrophication, water pollution, cropland losses). The work in this field was begun by considering the hydrological and major natural biogeochemical processes which, through a chain of events, cause these environmental effects. It became apparent that there are many mathematical models describing single processes such as water percolation, runoff, nitrogen mineralization, nitrification, denitrification, phosphorus precipitation and adsorption, evapotranspiration, nutrient uptake, pesticide degradation, etc. Moreover, a few complex models (CREAMS, ARM, ACTMO, etc.) have been developed. One of these complex models, CREAMS, was transferred to IIASA and implemented by a number of NMO countries. Our experience in collecting and implementing various mathematical models convinced us not only of the necessity of refining collaborative efforts in this field, but also of the need to discuss some methodological questions. This was accomplished partly during the meetings (Planning Workshop, June 1978; Conference on Environmental Management of Agricultural Watersheds, April 1979) organized by our task, "Environmental Problems of Agriculture." The present Task Force Meeting, Modeling of Agricultural-Environmental Processes Related to Crop Production, was organized in order to summarize both our own results and collaborative efforts in the field of mathematical modeling for environmental impacts and to outline the plan for the completion of this work at IIASA.

THE OPENING SESSION

The opening session was chaired by G. Golubev. In his introductory speech, he informed the audience about the activities and major results of the IIASA Task on "Environmental Problems of Agriculture" and outlined the focal points of the meeting. Then, K. Parikh, acting leader of the Food and Agriculture Program at IIASA, stated the general issues of FAP activity. J. Hirs spoke about the major aims and approaches in studying the technology-resource-environment interactions. In closing the session, I. Shvytov discussed the reasons for choosing the subject of the Task Force Meeting by outlining the problems for the modeling of agricultural-environmental processes related to crop production, the objectives of the meeting and the expected results. In pursuing the main goal, the meeting focused on:

- discussions of the state-of-the-art of the development of mathematical models describing environmental processes related to crop production, mainly impacts of agriculture on the environment;
- improvement of the guidelines for completion of IIASA research in the field of mathematical modeling for environmental impacts of agriculture;
- refinement of collaborative efforts with other research organizations.

The second part of the opening session was based on two major papers: "A Hierarchical Approach to Agricultural Production Modeling," presented by C.T. de Wit and "The Modeling of Environmental Impacts of Crop Production," by D. Haith. Both papers provided information concerning current models and modeling bases. As a result of discussion of the first paper, it was concluded that simulation models describing natural processes of crop production systems should be combined with linear programming models of agricultural management. The simulation models should provide selected inputs, such as yield, nitrogen leaching, and nutrient and sediment losses for the LP models. Both simulation and LP models are linked to a "reclamation level," which is a key determinant for management options as well as feasible combinations of nutrient, water, and other material inputs. In general, the agricultural-environmental models should provide a means for analyzing a variety of crop production management problems, while allowing for potential environmental impacts.

The paper by D. Haith deals with mathematical models for analyzing nonpoint source water pollution from cropland. These models are mainly chemical and sediment loading models, but also include planning and management models, which encompass regional planning, watershed planning, and farm management models. Haith discusses four operational models developed at Cornell University and based on the Curve Number Runoff Equation of the U.S. Soil Conservation Service and the Universal Soil Loss Equation. It was recommended that the Watershed Loading Functions Model could be used to estimate chemical export in stream flow from agricultural watersheds. Both the Pesticide Runoff Model and Cornell Nutrient Simulation Model can be used to predict losses of pesticides and nutrients with runoff as well as nitrogen leaching from agricultural fields. The Farm Management Model is a simple linear programming model which can be used to maximize farm income allowing for constraints on nitrogen, phosphorus, and sediment losses from the farm.

THE NITROGEN LEACHING PROBLEM

The presentations on nitrate leaching indicated that this aspect of nitrogen behavior in the soil-plant system is adequately simulated. One of the presented models showed that nitrogen leaching can make a significant impact on the efficiency of nitrogen fertilizer use and therefore, on environmentally undesirable waste of the nitrate form of nitrogen. The model by T.M. Addiscott allows for the effects of soil aggregation, particularly the hold-back solutes. It was concluded that one needs to distinguish between nonmobile water which holds back solutes, and mobile water in the anion exclusion zone, which does not hold back solutes. There was discussion as to whether there is a real difference between the cascade model for leaching and a piston flow model. The participants agreed that the answer should depend on the relationship between the soil profile and the size of the rainfall input. It was also pointed out that allowance must be made for the nitrification, mineralization, immobilization, and denitrification of nitrogen. There are now models for nitrification, mineralization, immobilization, and denitrification, but these models have only partly been combined with models for the other processes significant for nitrogen leaching. At present, one of the main problems in the application of nitrogen leaching models for practical purposes is the absence of well defined criteria, indicating to what degree nitrate leaching is acceptable.

SURFACE LOSSES OF CHEMICALS FROM CROPLAND

Since hydrological phenomena in cropland areas constitute some of the main factors which lead to losses of chemicals, particular attention was paid to water balance processes. J. Balek discussed various limitations and constraints placed on various simulation models for describing the hydrological phenomena. It was pointed out that there is a lack of data bases for providing model parameter estimates as well as verification of model outputs and therefore, models should be built with this limitation in mind. At present, the extension of both existing hydrological models and experimental data from the field and watershed levels to the regional level poses a problem.

M. Holy presented a mathematical model of surface runoff from a uniform slope. The solution of this mathematical model enables calculation of the average velocity and height of the surface runoff at any point on the slope, as well as the total volume of runoff at the bottom of the slope. M. Holy suggested that the simulation of runoff in an entire catchment is possible by matching the runoff from several slopes within the modeled area.

S. Rao presented a state-of-the-art review of models for simulating pesticide behavior in agroecosystems. Very detailed and complex models as well as simple, physically-based models for retention, transformation, and losses of pesticides were discussed.

It was concluded that the central problem is not a lack of mathematical models but that of selecting an appropriate model and verifying it. The meeting pinpointed the problems of independently estimating the large number of parameters in complex models. The problem is associated with the variability of soil properties determining pesticide fate. It was recommended that rather than comparing average measured response, the confidence limits of simulation, as well as measurements, should be considered.

SIMULATION OF ECOLOGICAL ASPECTS OF CROP PRODUCTION ENVIRONMENT

Environmental aspects of crop production systems were discussed in connection with ecological processes studied with both simple and complex models. Special attention was given to the experience in applying these models when making management decisions. Two deterministic models of C. Lyons' for assessing the effects of meteorological conditions on crop production and the effects of the agricultural environment ecology were considered. This type of model is usually formulated as a series of equations describing physical, chemical, and biological processes. One of the problems of this type of model is that it consists of a collection of submodels, and although the individual submodels are verified, it may not be easy to do the same for the overall model. It was concluded that because of the complexity of these models and their large parameter requirements, they are designed more for understanding the situation than for making management predictions. It was recommended that O. Sirotenko's model possibly could be used for making detailed estimations of plant evapotranspiration, soil water content, and plant production. Moreover, this and similar types of models can also be used to predict the effects of additional irrigation or climatic changes on crop yield. This information could be used for making a management decision.

The simple model presented by B. Trenbath examined the stability of food producing systems in developing countries, with the objective of discovering how these systems could be more stabilized. The model allows decisions to be made concerning the value of different cropping practices and cropping systems.

Two papers dealt with statistical models which enable one to estimate potential resources for biological productivity in Hungary (K. Rajkai, I. Valyi). An approach presented by Valyi can be used to assess projected yields of wheat and maize based on the data derived from the knowledge of experts. The models of this type can be used for detailed analysis of the limiting effects of soil and climate on potential yield.

Special discussions were held about models for analyzing the economic aspects of management policies affecting the environment. The use of simple models to estimate the net social cost of imposing various agricultural management systems was illustrated by K. Frohberg, who compared the cost of various measures to limit soil erosion and water pollution. It was agreed that the problem of modeling trade-offs between environment and agricultural economics needs to be further elaborated.

COMPLEX MODEL DEVELOPMENT AND APPLICATIONS

A field scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS model) was considered as an example of a complex model. W. Knisel presented the basic components of the CREAMS model and emphasized that this model should be used to consider alternative management practices for nonpoint source pollution in field-size areas. The field was defined as an area with homogeneous soil, single management practice, single crop, and uniform weather conditions. An example of CREAMS application was given by W. Knisel. The model was used to compare erosion resulting from three management practices common in the Southern Piedmont land resource area of the United States.

G. Golubev and I. Shvytov presented in turn the results of IIASA work with the CREAMS model and its application to a number of countries. Application and status were given as shown in the following table:

Country	Problem	Status
Sweden	N-leaching	N-simulation
Czechoslovakia	N-leaching, erosion	N-simulation
Poland	N-leaching	N-simulation
GDR	N-leaching	Hydrology simulation
UK	Erosion	Simulation
USSR	Chemical losses	Hydrologic simulation
Hungary	Phosphorus loading	Data collection

The most extensive application has been in Sweden in the Western Skåne area. Nitrogen leaching simulation has been developed for potatoes and wheat with and without irrigation. Dr. Enderlein presented the results of the CREAMS model application for the Schaeffergraben basin in the GDR. Real potential evapotranspiration in this basin is about 30% higher than that computed with the CREAMS model.

The meeting discussed some problems of CREAMS application. It was noted that the main problem in the application of CREAMS is still in the estimation of parameter values. Very little data for soils, including a description of a curve number for the hydrological submodel, are available. In the discussion, it was pointed out that even the handbook does not provide good numerical descriptions for hydrological soil groups. It is yet more difficult to estimate the soil chemical and plant physiological parameters required by CREAMS.

A special discussion was held to clarify the matter of the development and application of complex models. As a result, it was pointed out that:

-- there are several current complex models in this field (CREAMS, ACTMO, APM, etc.) which it would be very interesting to compare;
-- simulation comparison of different mathematical models is very difficult to do; it is logical to begin with descriptive comparison;
-- special attention should be paid to complex models which do not need calibration;
-- a model should not be used for conditions outside the development objectives; this applies to CREAMS or other field-scale models as well as to watershed and basin models;
-- sensitivity analysis is very useful for complex models with large numbers of parameters;
-- the best way to apply the CREAMS model is to run it for "typical" or "representative" areas.

SUMMARY OF THE GENERAL DISCUSSION

G. Golubev, as chairman of the session, opened the general discussion by pointing out that models built for the analysis of agricultural-environmental processes related to crop production are commonly set up at the field scale level. But all practical problems arise on a larger scale, e.g., at the watershed, river basin, or even larger scale level. Following this observation, he concluded that the following three questions should first be discussed:

(1) How can field level results be aggregated to a larger scale level and what are the problems involved in doing this?
(2) Instead of aggregating field level results, would it be preferable to use different models for a large scale?

How could a subcomponent of the model for the analysis of the water quality of streams be an integral part of the whole model system?

(3) How can these simulation models be integrated into one model which investigates various policy options with regard to the economic effect of reducing the environmental stress related to crop production? This would be an important aid in the decision making process.

An answer given by C. Lyons to questions (1) and (2) won the consensus of many participants. He suggested that a hierarchical model system be set up. Many small-scale models would be run on the first level and their results be put into a model set up for a larger scale. In this way, one can avoid the aggregation problems mentioned in the first question. In modeling the larger scale level, one can draw on experience gained from working on the smaller scale. The results obtained from the smaller scale models will be used to enhance the performance of the larger model and hence produce more accurate values.

Many participants expressed doubt that the modeling of the diffusion of pollutants in waterways could be accomplished at a satisfactory level. Only a few attempts have been made to investigate this problem. However, it was recognized that in the future, this should be given more attention in research.

No consensus could be reached with regard to the third question. It was, however, agreed that this kind of work is needed and that cooperative work with economists should be initiated. C.T. de Wit enumerated the difficulties which arise in such cooperative work and stressed the importance of maintaining a flow of information between economists and natural scientists when building such economical-physical models. It is also of importance that the actor in the system be recognizable and that the results can be visualized. As an example, de Wit mentioned the joint modeling work undertaken by agronomists and soil scientists at the University of Wageningen and economists from the Centre for World Food Studies in Amsterdam. In their study, they used a linear programming approach as an interface system between the physical and economic aspects.

D. Haith stressed that IIASA's decision to establish a model bank was a very important step in the direction of enhancing interdisciplinary work. After mentioning the difficulties encountered in joint research among different disciplines, he congratulated I. Shvytov for his accomplishments in setting up this world bank, thus bridging some of the gaps among disciplines.

Several participants also pointed out the need for the establishment of a data base for testing and comparing models. Such a data set could either be based on real observations or on a synthetically generated set. IIASA would be the best place to establish this data base and carry out the testing procedure, as well as to compare the model's performance.

CONCLUSION

We define "environmental impact" of crop production as any quantitative and/or qualitative change of environmental status due to crop production activity. Of course, all these changes of environmental status may be both "negative" and "positive" as well as having both "minor" and "major" significance. In addition, each environmental impact can have different time and space scales. Therefore, to assess these changes we need well-defined criteria indicating to what degree these changes are acceptable.

There is no universal criterion, therefore we could only concentrate on environmental impacts which have well-defined criteria for their assessment (nitrate pollution of groundwater, losses of cropland and sedimentation, eutrophication of lakes and other water bodies, pesticide pollution of water sources). In order to evaluate these impacts, one would need to have a number of simulation models having these impacts as "output" and crop production activity as "model input." Unfortunately, the majority of the currently existing models (nitrogen leaching models, soil erosion and sedimentation models, nonpoint source pollution models) describe only intermediate agricultural-environmental processes which potentially can lead to these environmental impacts. Figure 1 illustrates the present situation reflecting the necessity of linking well-modeled processes with environmental impacts needing evaluation. There are two ways to accomplish this. The first way is to extend the scope of modeling in order to cover the entire chain from crop production through the agricultural-environmental processes to the environmental impacts. Another way would be to specify the criteria for assessment of the environmental hazards on a basis of calculated outputs from a field and/or a watershed. Both approaches are viable and may be realized.

We surmise that one of the central problems in modeling the environmental impacts of agriculture is to bridge the gap discussed above.

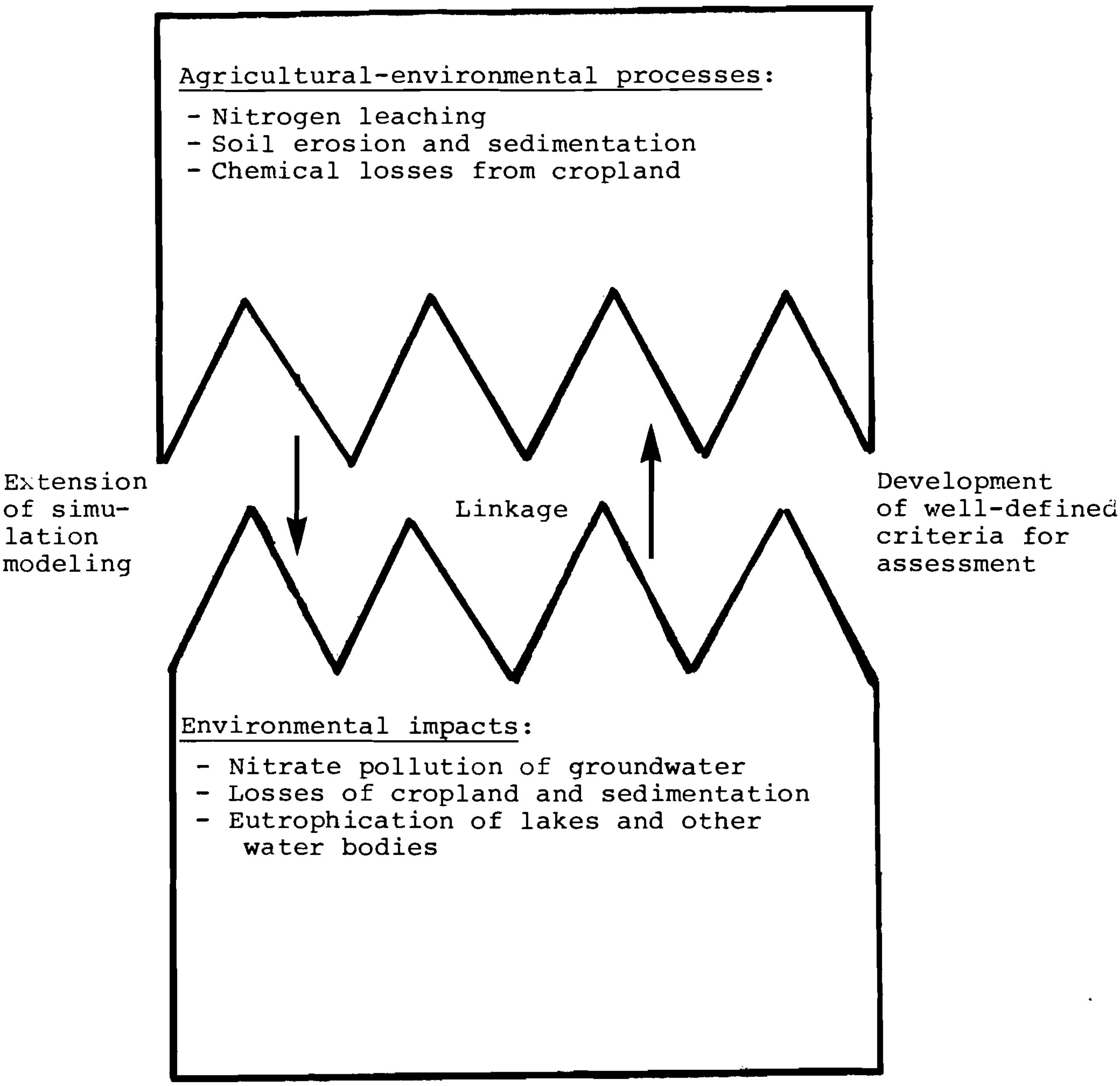

Figure 1. Linkage between environmental impacts and agricultural-environmental processes (dry farming crop production system).

APPENDIX A: AGENDA OF THE TASK FORCE MEETING (JUNE 2-4, 1980) ON MODELING OF AGRICULTURAL-ENVIRONMENTAL PROCESSES RELATED TO CROP PRODUCTION

Monday June 2

8.30 - 9.15	Registration (Conference Secretariat on First Floor)
9.15 - 10.00	Introduction (G. Golubev, Task Leader of Environmental Problems of Agriculture) (i) Opening Session (ii) General information concerning the activities and major results of the IIASA Task Environmental Problems of Agriculture
10.00 - 10.15	Aims and Approaches in Studying the Technology-Resource-Environment Interactions (J. Hirs)
10.15 - 10.45	Modeling of Environmental Impacts of Soil Fertilization (I. Shvytov) (i) Outline of the problem (ii) Objectives of the Task Force Meeting (iii) Expected results
10.45 - 11.00	COFFEE BREAK
11.00 - 11.45	A Hierarchical Approach to Agricultural Production Modeling (C.T. de Wit)
11.45 - 12.15	The Modeling of Environmental Impacts of Crop Production (D.A. Haith)
12.15 - 12.30	Discussion
12.30 - 14.00	LUNCH

THE NITROGEN LEACHING PROBLEM

14.00 - 14.30	A Critical Evaluation of a Hydrological Layer Model for Forecasting the Redistribution of Unadsorbed Anions in Cultivated Soils (I.G. Burns)
14.30 - 15.00	Review of Simulation Models for Nitrogen Behavior in Soil in Relation to Plant Uptake and Emission (M.J. Frissel & J.A. van Veen)
15.00 - 15.30	COFFEE BREAK
15.30 - 16.00	Modeling Nitrate Movement in Profiles that Contain Soil, Heavy Clay, and Chalk (T.M. Addiscott)
16.00 - 17.30	Discussion of the Nitrogen Leaching Problem

Tuesday June 3

SURFACE LOSSES OF CHEMICALS FROM CROPLAND

9.00 - 9.45	State-of-the-Art of Modeling of the Water Balance Processes in the Agricultural Field and Watershed (J. Balek)
9.45 - 10.30	Modeling of Surface Runoff Processes (M. Holy)
10.30 - 10.45	COFFEE BREAK
10.45 - 11.30	Retention, Transformation and Transport of Pesticides in Soil-Water Systems: Model Development and Evaluation (P.S.C. Rao)
11.30 - 12.30	Discussion
12.30 - 14.00	LUNCH

SIMULATION OF ECOLOGICAL ASPECTS OF CROP PRODUCTION ENVIRONMENT

14.00 - 14.45	Deterministic Models for the Ecologic Simulation of Crop Agricultural Environment (T.C. Lyons)
14.45 - 15.10	Calculations of the Relationships between Soil Factors and Crop Yields (K. Rajkai)
15.10 - 15.20	COFFEE BREAK
15.20 - 15.40	Statistical Evaluation of Experts Estimates (I. Valyi)
15.40 - 17.30	Discussion (short presentations have been made by K. Frohberg and B. Trenbath)

Wednesday June 4

COMPLEX MODEL DEVELOPMENT AND APPLICATION

9.00 - 10.00	CREAMS: A Field Scale Model for Chemical Runoff and Erosion from Agricultural Management Systems (W.G. Knisel)
10.00 - 10.30	IIASA Experience in Application of the CREAMS Model (G. Golubev & I. Shvytov)
10.30 - 10.45	COFFEE BREAK
10.45 - 12.30	Discussion of the Development of Complex Models and their Applications (short presentation by R. Enderlein)
12.30 - 14.00	LUNCH
14.00 - 15.30	Closing Session - General Discussion

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APPENDIX C: LIST OF CHAIRMEN AND RAPPORTEURS

Monday June 2

Opening Session

Morning	Chairman:	Prof. G. Golubev (IIASA)
	Rapporteur:	Prof. D. Haith (USA)

The nitrogen leaching problem

Afternoon	Chairman:	Dr. M.J. Frissel (The Netherlands)
	Rapporteur:	Dr. T.M. Addiscott (UK)

Tuesday June 3

Surface losses of chemicals from cropland

Morning	Chairman:	Prof. D. Haith (USA)
	Rapporteur:	Dr. P.S.C. Rao (USA)

Simulation of ecological aspects of crop production environment

Afternoon	Chairman:	Prof. Dr. C.T. de Wit (The Netherlands)
	Rapporteur:	Dr. I.G. Burns (UK)

Wednesday June 4

Complex model development and application

Morning	Chairman:	Dr. P.S.C. Rao (USA)
	Rapporteur:	Dr. W.G. Knisel (USA)

General discussion

Afternoon	Chairman:	Prof. G. Golubev (IIASA)
	Rapporteur:	Dr. K. Frohberg (FRG)