FAO/IAEA CONSULTANTS MEETING

on

THE USE OF NUCLEAR TECHNIQUES FOR OPTIMIZING FERTILIZER APPLICATION UNDER IRRIGATED WHEAT TO INCREASE THE EFFICIENT USE OF NITROGEN FERTILIZERS AND CONSEQUENTLY REDUCE ENVIRONMENTAL POLLUTION

29 November - 2 December 1993
Vienna, AUSTRIA

REPORT

by

Christian HIERA
Scientific Secretary
FAO/IAEA CONSULTANTS MEETING

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Christian HERA
Scientific Secretary of the Meeting

Department of Research and Isotopes
Soil Fertility, Irrigation and Crop Production Section
Joint FAO/IAEA Division
1. INTRODUCTION

A Consultants Meeting on "The Use of Nuclear Techniques for Optimizing Fertilizer Application under Irrigated Wheat to Increase the Efficient Use of Nitrogen Fertilizers and Consequently Reduce Environmental Pollution" was held in Vienna, Austria at the IAEA Headquarters from 29 November to 2 December 1993. This Consultants Meeting was devoted to establish the goals and objectives of the new Co-ordinated Research Programme on the above subject, a programme that was initiated in co-operation with CIMMYT, Mexico, and IFDC, USA. The meeting was attended by five participants from 5 Member States and staff members of the Soil Fertility, Irrigation and Crop Production Section, Joint FAO/IAEA Division and the Soil Science Unit, Seibersdorf Laboratory. The list of participants is given in ANNEX 1.

The meeting was opened by Dr. Sueo Machi, IAEA Deputy Director General and Head of the Research and Isotopes Department, who, after welcoming the participants, informed briefly on the mandate of the IAEA and objectives of the meeting. Dr. Björn Sigurbjörnsson, Director of the Joint FAO/IAEA Division, informed the participants about the Joint FAO/IAEA's Division activities, achievements in wheat breeding and on the economical implications of fluctuating grain production.

Shortages and fluctuations in crop production have a strong political impact on global economics and stability. This coupled with the fact that demand for food in developing countries is growing faster than the current ability for such countries to increase production is great cause for concern. Irrigated wheat accounts for about 40% of wheat production in developing countries but efficiency of nutrient use is thought to be quite low by international standards. Nitrogen fertilizer in particular is considered a major economic input in developing countries because it accounts for about two-thirds of all the fertilizers used. According to FAO and World Bank reports, there has been a dramatic increase in N fertilizer use for irrigated wheat production. These findings should be expected because the availability of irrigation greatly reduces the potential of crop failure cause by drought. Therefore, producers are more likely to allocate their resources of time, labor, seed and fertilizer to irrigated areas where profitability is likely to be the most stable.

The many benefits of applying N fertilizer to irrigated crops are well engrained into producers around the world. Examples set forth by developed countries clearly illustrate that the zeal for higher yields can lead to inefficient use of material inputs (water, nutrients, pesticides, etc.). Poor management of one or more of these inputs can easily reduce the effectiveness of the others. In the case of inefficient N use by crops, the unused N can harm the environment through nitrate leaching into ground water or volatile N losses to the atmosphere. In either case, loss of N represents a cost to producers. Techniques and management systems must be developed to improve nitrogen use efficiency by crops, which will help protect the environment. More judicious use of N fertilizer, especially by the new created wheat varieties, will make more funds available for better use of other nutrients.
2. JUSTIFICATION

Irrigated wheat production is the obvious crop to target for increased production to help feed the world because yields range from 3 to 8 T/ha. Past research by the Joint FAO/IAEA Division and other groups has shown how much N and other nutrients are typically required to produce given yields of wheat on medium and low fertility soils. These data are critical because they provide a reference to which current N management practices can be compared. This type of simple comparison helps identify situations where N management practices can be improved. Factors contributing to inefficient use of N fertilizer can range from something as simple as time of application, fertilizer form, method of application, and rate to very complicated interactions involving soils, climate, and crop cultivar. Much of the research to quantify the various relationships between the above factors and wheat yield has already been done and is reported in the literature. Unfortunately, much remains to be done to integrate and assemble the pertinent concepts and principles into management packages and expert systems that can effectively address the production problems of developing countries.

Allocation of precious resources in developing countries (i.e., fertile land, water, seed, fertilizer, pesticides, etc.) is difficult enough, but to be effective, these inputs must be properly managed throughout the growing season to capitalize on local production considerations (i.e., soil, climate, and labor). Simulation models are one of the most effective and universal approaches to integrate local data into management concepts and scientific principles. Access to reliable data are needed to verify that model simulations are realistic. In the case of wheat production, the CERES-Wheat model has been developed to help evaluate and compare management options. To use the model, a certain minimum data set is required, but once these needs are met, the model can quickly and easily be used to evaluate specific management practices that would otherwise require several years of field research and be very costly.

The CERES-Wheat model is a process oriented simulation tool, which tends to give it universal applicability provided the proper inputs have been identified and the various components of the simulation provide realistic estimates of crop growth, nutrient uptake, and water use. A strong attribute of the CERES-Wheat model is that it provides a dynamic assessment of factors contributing to crop growth. This is in contrast to annual input and output data that are typically used to calculate nutrient and water use efficiencies. The model makes it possible to evaluate many factors over a specific period of time, which can be very helpful when trying to identify factors limiting yields.

The key to effective use of the CERES-Wheat model, or any other model, to identify yield limiting processes, is the use $^{15}$N isotope technique to quantify the fate of N fertilizers in the soil, plant, and atmosphere. Without these techniques, it is essentially impossible to understand the dynamics of N in the soil-plant-water system. Failure to use isotopic forms of N fertilizer in model calibration research amounts to a major over-site because the $^{15}$N data provides essential insights into N mineralization, synchronization between soil N availability and crop needs, and N losses (leaching, denitrification, and volatile N losses from the crop). These N losses can be difficult to quantify, but the use of a neutron moisture gauge makes it possible to follow the movement of wetting fronts through the soil, to characterize rooting depth, to
schedule irrigation, and describe soil-water relationships. In combination, nuclear techniques to help describe water movement in soil and use of isotopic N fertilizers to trace nitrate leaching make it possible to estimate the amount of nitrate that is escaping to ground water. The only other alternative is the installation of expensive lysimeters that typically require several years before the data are reliable.

3. OBJECTIVES

The specific objectives recommended by the participants are as follows:

- to investigate various aspects on nitrogen use efficiency of the wheat crop under irrigation through an interregional research network of experimental sites in the countries with a large area of irrigated wheat;

- to use $^{15}$N techniques and neutron moisture gauges to determine the fate of applied N fertilizer and organic N as well as water movement in the soil and water use efficiency in wheat cropping systems;

- to use all results to develop further and to refine various relationships in the CERES-Wheat simulation model;

- to use the knowledge generated to validate the CERES model and produce a nitrogen recommendation expert system to refine specific management strategies with respect to fertilizer applications, expected yield and other parameters.

4. PRESENTATIONS

A series of 30 to 45 minute presentations served to provide essential background information pertinent to the project and to introduce the areas of expertise offered by the IAEA participants and consultants. The combined expertise of those making presentations and comments offered by other IAEA personnel served to identify the problems and opportunities associated with the proposed project. Details of the individual presentations (authors and titles shown below) served as the basis for discussion about the project and are reflected in the final proposal.

Dr. S. Machi (IAEA)  Welcoming the Participants. IAEA Mandate and Objectives of the Consultants Meeting.

Dr. B. Sigurbjörnsson (IAEA)  Achievements in Wheat Breeding. Economical Implications of Fluctuating Grain Production.
Dr. C. Hera (IAEA) "Use of Nuclear Techniques for Optimizing Fertilizer Application Under Irrigated Wheat to Increase Yields and Reduce Environmental Pollution".

Dr. G. Hardarson (IAEA) Maximizing Fertilizer Efficiency by Grain Crops. FAO/IAEA CRPs and FAO Statistics.

Dr. H. Axmann (IAEA) "Stable Isotope $^{15}$N - Terminology and Methods of Determination".

Dr. F. Zapata (IAEA) "Isotopic Aided Studies for Increasing Fertilizer Nitrogen Uptake by Crops".

Dr. C. Kirda (Turkey) "Irrigated Wheat in Turkey - Use of Neutron Moisture and/or Gamma Density Gauges".

Dr. P. Moutonnet (France) "Field Measurement of Nitrate - Environmental Pollution and Protection".

Dr. E. Acevedo (Mexico) "Results from CIMMYT's Research on Fertilizer Application under Irrigated Wheat".

Dr. W. Baethgen (Uruguay) "Computer Demonstration of a Nitrogen Recommendation Expert System which is Linked to the CERES-Wheat Simulation Model". IFDC-contribution.

Dr. J. Schepers (USA) "Use of Nitrogen Fertilizer Under Irrigated Wheat - Environmental Preservation".

Seibersdorf Laboratory Tour and Discussion.

5. CONCLUSION AND RECOMMENDATIONS

The process for providing important background information, gathering information from the consultants, outlining the goals of the meeting, soliciting comments, and stimulating discussion was well conceived and orchestrated by the scientific secretary of the meeting and others of the FAO/IAEA staff. The firm grasp of the situation and constructive comments by members of the group resulted in a proposal that should be relatively easy to implement and manage. Continued involvement by Dr. W. Baetghen to co-ordinate the model assessment activities and perhaps participation by other on the consulting team will be required to assure success of the project. The individuals who conceptualized this project are to be commended for their vision and grasp of reality because such a project is probably the only way that this important work could ever be accomplished. Benefits of such a project to the world community will take some years to be recognized, but the likelihood of success is good.
Recommendations for initiating the research and incorporating the data into the CERES-Wheat model follow:

Sites: It is strongly recommended that the proposed experiments are established in National Research Centers or Universities. Ideally these institutions would have previous experience in research involving $^{15}$N stable isotope and neutron moisture gauge techniques.

The field area where the experiment will be established should be planted to a wheat cultivar common to the region and uniformly fertilized and irrigated in the year preceding initiation of the research. Ideally this same crop, fertilizer application, and irrigation system should be used every year prior to the establishment of a new experiment. Residual effects of N fertilizer could be studies in subsequent years, but each new wheat N experiment should be established on a new experimental area that is adjacent to the previous years experimental site. A schematic representation of this recommendation follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>P</td>
<td>W</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EA_1</td>
<td>P</td>
<td>W</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EA_2</td>
<td>P</td>
<td>W</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EA_3</td>
<td>P</td>
<td>W</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EA_4</td>
<td>P</td>
<td>W</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EA_5</td>
<td>P</td>
<td>W</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

where: EA_1, EA_2, etc. = experimental area for each experiment  
P = preceding crop with uniform irrigation and fertilization  
W = wheat experiment  
R = residual effect studies (optional)

Nutrients other than N (P, K, micronutrients, etc.) and lime (when needed) should be applied before planting at rates that will ensure non-limiting conditions for the wheat. Cultural practices such as pest, disease, and weed control should follow local recommendations to ensure non-limiting conditions for the experiment.
Irrigation: The irrigation system should be used to maintain the soil moisture content not less than 50% of the soil water holding capacity in the surface 40 cm. The same amount of irrigation water will be applied to all plots but the amount of irrigation water to be applied will be based on the water requirement for the optimum N rate ($N_{1.0}$).

Soil water content should be monitored in all plots using the neutron gauge technique. In addition, tensiometer type devices should be placed at the bottom of the root zone and another 20 cm deeper in the optimum N rate plots ($N_{1.0}$). It is strongly recommended to avoid irrigation systems that will result in run off and/or water moving between plots. Sites with adequate infrastructure could include several additional irrigation treatments (e.g., continuous gradient with sprinklers; sub-optimal, optimal, and excessive irrigation, etc).

Soil Solution: Suction sampling devices should be placed in plots with the optimum and above optimum N rates. Sampler depths should be at the bottom of the root zone and 20 cm deeper. Porous cup samples (ceramic or stainless steel) or tensionic devices can be used to collect a small volume of liquid on an intermittent basis (10 day intervals). Solution samples will be analyzed for nitrate-N and isotopic N concentrations.

Cultivars: One cultivar with economic significance for the region should be selected for the experiment. Optionally, sites with adequate infrastructure can include additional cultivars with specific objectives for the study (e.g., CIMMYT).

N Fertilizer: Four fertilizer treatments will be included as follows:

- $N_0$ = unfertilized check plot
- $N_{0.5}$ = N rate equivalent to 50% of the optimum rate
- $N_{1.0}$ = N rate equivalent to the optimum rate
- $N_{1.5}$ = N rate equivalent to 50% above the optimum rate.

The N fertilizer rates will be split in two applications: one-third at planting and two-thirds at Zadoks growth stage 30 (end of tillering, 10% of main stems with nodes detectable at finger point). At least two $^{15}$N microplots will be established in the experiments (plots with $N_{1.0}$ and $N_{1.5}$). Fertilizers (N, P, K. micronutrients, etc.) will be applied following local recommendations.

Plot Size: Approximately 10m by 6m, divided longitudinally: one half will be used for soil and plant sampling, and the other undisturbed half will contain the microplots and will be used for yield determination. Microplot size for $^{15}$N samples will be 1.0m$^2$.

Crop N Status: Chlorophyll meters will be used to monitor crop N status on a weekly basis and to make relative comparisons about if and when N deficiencies develop.
CERES-Wheat Data:

Site Description: Complete soil profile description by horizon including: pH, organic C, bulk density, % sand, % silt, % clay, saturated water content, upper drained limit water content, lower limit water content, available water, nitrate-N, ammonium-N, albedo of the top horizon, estimates of run off and drainage, and latitude and longitude.

Climate Data: Daily record of maximum and minimum air temperature, solar radiation, and precipitation.

At Planting: Soil moisture content, ammonium-N, nitrate-N, and pH.

At Emergence: Date, emerged plants/m², row spacing.

At Zadoks GS-30 (end of tillering first node): Date, total above ground (TAG) dry matter and N content, soil nitrate-N and ammonium-N content. The second N fertilizer dose is applied at this growth stage.

At Flag Leaf Ligule Emergence: Date plus data same as at Zadoks GS-30.

At 50 % Anthesis (not spike emergence): Date. TAG dry matter and N content. First sampling for grain fill and physiological maturity determination: cut four rows 0.5m long of TAG material, separate spike and rest, count spikes, and take dry weight of spikes and the rest. (This will be the zero grain point for the grain filling rate line). This type of data will be collected at 3 to 4 day intervals until harvest.

The above recommendations for the experimental work of the CRP were made on the basis of the suggestions of the experts participating in the Consultants Meeting. I am sure that much more discussion about treatments and other details concerning the future field experiments will take place and will be improved and finalized during the first Research Coordination Meeting planned to be held in Vienna, Austria, in 1994, with the participation of Contract- and Agreement Holders who will in fact run the experiments.

6. PUBLICATIONS

The participants of the Consultants Meeting suggested that presented papers at the meeting, with author improvements, be published in a special edition of Fertilizer Research. Mr. Hera will submit format requirements for the journal. Papers are due to be sent to the IAEA by September 1994.
7. ACKNOWLEDGEMENTS

This Consultants Meeting was conducted as a starting activity of the FAO/IAEA CRP on "The Use of Nuclear Techniques for Optimizing Fertilizer Application under Irrigated Wheat to Increase the Efficient Use of Nitrogen Fertilizers and Consequently Reduce Environmental Pollution".

The contribution of CIMMYT, Mexico and IFDC, USA to initiate this CRP is highly appreciated. We are looking forward to a future co-operation for a successful implementation of the programme.

The author of the report is grateful especially to Dr. J. Schepers, and also to Dr. W. Baethgen and to Dr. E. Acevedo for their kind assistance and contribution for the preparation of the conclusion and recommendation of the meeting.
Growth Stages in Wheat

Growth Stages According to Zadoks

<table>
<thead>
<tr>
<th>Zadoks</th>
<th>Feekes</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1</td>
<td>First leaf through coleoptile</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
<td>Main shoot only</td>
</tr>
<tr>
<td>25</td>
<td>3</td>
<td>Main shoot and 5 tillers</td>
</tr>
<tr>
<td>30</td>
<td>5</td>
<td>Erect stems</td>
</tr>
<tr>
<td>31</td>
<td>6</td>
<td>1st node detectable in stem</td>
</tr>
<tr>
<td>37</td>
<td>8</td>
<td>Flag leaf just visible</td>
</tr>
<tr>
<td>39</td>
<td>9</td>
<td>Flag leaf ligule/collar just visible</td>
</tr>
<tr>
<td>45</td>
<td>10</td>
<td>Boot swollen</td>
</tr>
<tr>
<td>50</td>
<td>10.1</td>
<td>First spikelet of head visible</td>
</tr>
<tr>
<td>60</td>
<td>10.5</td>
<td>Flowering</td>
</tr>
</tbody>
</table>

Growth Stages According to Feekes

Annex 1

Consultants Meeting, IAEA Headquarters, Vienna
29 November - 2 December 1993

List of Participants

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Mr. S. Kumarasinghe  
Mr. M.P. Salema  
Ms. I. Puschnig  

Soil Fertility, Irrigation + Crop Production  
Soil Fertility, Irrigation + Crop Production  
Soil Fertility, Irrigation + Crop Production  
Secretary (Ex. 1647)

Mr. F. Zapata  
Mr. G. Hardarson  
Ms. H. Axmann  
Mr. F. Awonaike  
Mr. W. Quist  

Head, Soils Science Unit, Laboratory, Seibersdorf  
Laboratory, Seibersdorf  
Laboratory, Seibersdorf  
Laboratory, Seibersdorf  
Laboratory, Seibersdorf
ANNEX 2

FAO/IAEA CONSULTANTS MEETING

on

"THE USE OF NUCLEAR TECHNIQUES FOR OPTIMIZING FERTILIZER APPLICATIONS UNDER IRRIGATED WHEAT TO INCREASE THE EFFICIENT USE OF NITROGEN FERTILIZERS AND CONSEQUENTLY REDUCE ENVIRONMENTAL POLLUTION"

29 November - 02 December 1993

MEETING ROOM: A 22-10
Ext. 1625

Scientific Secretary: Christian HERA (IAEA)

AGENDA

Monday, 29 November

Session I

09.00 Official Opening
- S. Machi - Welcoming the Participants
- B. Sigurbjörnsson - Achievement in Wheat Production

09.45 Remarks by Scientific Secretary

10.00 Coffee Break

Session II

Chairman: C. Kirda (Univ. of Cukorova)

10.30 Ch. Hera (IAEA)
"The Use of Nuclear Technique for Optimizing Fertilizer Application under Irrigated Wheat to Increase the Yield and Reduce Environmental Pollution".
11.00  G. Hardarson (IAEA)  
Maximizing fertilizer efficiency by grain crops - results from 
FAO/IAEA CRPs and FAO statistics.

11.30  H. Axmann (IAEA)  
Stable isotope $^{15}$N - basic terminology; methods of determination.

12.30  Lunch

Session III

14.30  E. Acevedo (CIMMYT)  
Some results from CIMMYT's research on fertilizer application under 
irrigated wheat.

15.15  W. Baethgen (IFDC)  
IFDC contribution on optimizing fertilizer application under irrigated 
wheat and reduce environmental pollution. Nitrogen use efficiency in 
wheat.

18.00  Cocktail Party

Tuesday, 30 November

Session IV

Chairman: E. Acevedo

09.00  J. Schepers (Univ. of Nebraska)  
Use of nitrogen fertilizer under irrigated wheat. Environmental 
preservation.

09.45  P. Moutonnet (CEA)  
Field measurement of nitrate. Environmental pollution and protection.

10.30  Coffee break

11.00  C. Kirda  
Irrigated wheat in Turkey. Use of neutron moisture and/or gamma density 
gauges.

11.45  F. Zapata (IAEA)  
Isotopic aided studies for increasing fertilizer nitrogen uptake by wheat 
and environment protection.

12.30  Lunch
Session V

Chairman:  P. Moutonnet

14.30       H. Axmann (IAEA)
            15N enrichment/nitrogen rates to be used in field trials. Detection
            levels/Dilution factors.

15.45       W. Baethgen
            Computer demonstration of a nitrogen recommendation expert system
            which is linked to the CERES-Wheat simulation model.

16.00       Coffee break

16.30       General discussions.

Wednesday, 1 December

Session VI

Chairmen:  F. Zapata/H. Axmann

09.00       Departure to Seibersdorf Laboratory.

09.45       Visit of Soil Science Unit facilities. Discussions with SSU staff.

12.00       Lunch

14.30       Discussion on future work programme.

16.00       Departure to Vienna.

Thursday, 2 December

Session VII

Chairman:  J. Schepers

09.00       Discussion on future work programme.

10.30       Coffee break

11.00       Continuation of future work programme.

12.30       Lunch
Session VIII

Chairman: B. Sigurbjörnsson (IAEA)

14.30 Presentation of recommendation.

Remarks: Invited participants are kindly requested to make written recommendations on the topics discussed according to their expertise.