SECOND RESEARCH CO-ORDINATION MEETING
OF THE
FAO/IAEA CO-ORDINATED RESEARCH PROGRAMME D1.40.07

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

4 - 8 March 1996
CIMMYT Center
Mexico

REPORT
D1-RC-555.2

By
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Scientific Secretary of the Meeting
Department of Research and Isotopes
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1. INTRODUCTION

Demand for food in developing countries is growing faster than their current ability to increase production. Irrigated wheat accounts for about 40% of wheat production but efficiency of nutrients used is thought to be quite low i.e. by international standards. Nitrogen fertilizer in particular is considered as a major economic input because it accounts for about two thirds of all the fertilizers used. According to FAO and World Bank data, there has been a dramatic increase in N fertilizer use for irrigated wheat production. These findings might be expected because the availability of irrigation greatly reduces the chances of crop failure, caused by droughts. Therefore, producers are more likely to allocate their resources to irrigated areas where profitability is more stable. Poor management of inputs i.e. water nutrients and pesticides, can easily reduce the effectiveness of the others. In the case of inefficient N use by crops, the unused Nitrogen poses a threat to the environment through ground water pollution or volatile N losses to the atmosphere. Nuclear, and related techniques, are extremely useful in assessing these parameters.

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 committed to establishing the goals and objectives of the Co-ordinated Research Programme on the above subject, a programme that was initiated in cooperation with CIMMYT, Mexico, and IFDC, USA. Based on recommendations of the consultants meeting, the Joint FAO/IAEA Division, through the Soil Fertility, Irrigation and Crop Production Section, started the implementation of an International Research Programme, with 12 Research Contract Holders from developing Countries and 6 Research Agreement Holders from industrialized Countries with the following overall objectives:

- 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-wheat model and produce a nitrogen recommendation expert system to refine specific management strategies with respect to fertilizer applications, expected yield and other parameters.

Further recommendations on the implementation of this programme can be found in the Report of the Consultants Meeting (C.Hera, 311-D1-CT-1457, 94-01-07). This report describes the objectives and the programme; furthermore, conclusions and recommendations given for the implementation of the project are outlined here.
The first Research Co-ordination meeting on this Programme was held in IAEA Headquarters, 3-6 October, 1994. All recommendations on the implementation of this research, as well as a guidelines, can be found in the relevant report (P. Moutonnet. D1-RC-555).

2. THE CO-ORDINATED RESEARCH PROGRAMME

This international network research project is operated as a part of the IAEA Research Contract Programme. As such, the FAO/IAEA Coordinated Research Programme (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" is formed by 18 research teams 12 of which are contract holders and 6 agreement holders. The contract holders were selected from applications received until July 1994. The CRP will last for 5 years (1994-1999). Research coordination meetings (RCM) are held every 15-18 months. Such meetings encourage close contact and provide a forum for information exchange between scientists and institutes involved.

3. OBJECTIVES OF THE MEETING

The objectives of the second Research Coordination Meeting were as follows:

i) to present the scientific results already obtained along the first experimental season;

ii) to discuss, and agree, of detailed experiments to be conducted between now and the next RCM according to possible modifications of the guidelines.

The meeting also included a workshop on CERES - Wheat, a plant growth simulation model (CIMMYT Computer training room).

4. THE MEETING

The meeting was attended by 16 scientists from 14 participating Member states and 2 staff members of the Soil Fertility, Irrigation and Crop Production Section of the Joint FAO/IAEA Division and the Soil Science Unit of the FAO/IAEA Agriculture and Biotechnology Laboratory. The list of participants is given in Annex 1.

The meeting was formally opened by Prof. T.G. Reeves, Director General of CYMMIT, who welcomed the participants and informed them on the importance of this CRP and the related objectives of his Institute. Dr. Pierre Moutonnet, Soil Fertility, Irrigation and Crop Production Section, also addressed the participants during the opening ceremony. The programme prepared for the meeting was followed with some minor changes in the order of presentations, Annex 2.

4.1 Presentations

The progress reports of the participants covered a wide range of topics on irrigation and nitrogen fertilization research, and on first trials conducted in connection to this programme. Excerpts from the presentations are give in Annex 3.
4.2. **Workshop**

The fourth day of the meeting, 7 March 1996, was devoted to a workshop. Dr. W. Baethgen conducted an introductory training course on CERES-Wheat Model at the CIMMYT Computer Services training room which was equipped with 10 PCs especially hired for the group.

4.3 **Discussion Sessions**

The last day was devoted to discussing the following points:

- Implementation plans of the CRP and guidelines for future experimented work;

- following the previous discussions a synthesis was done by Dr. s Baethgen, Schepers, and Vachaud, according to their expertise, i.e. CERES-Wheat model, Chlorophyll meter, and soil water flux calculation, Annex 4;

- each participant was asked to complete a list of the equipment/supplies required to carry out the research;

- the last afternoon was devoted to the revision of the experimental guidelines with particular emphasis on soil rotation and plant sampling at physiological maturity growth stage, Annex 5. Time was also allocated for individual discussion with the Scientific Secretary.

5. **CONCLUSIONS AND RECOMMENDATIONS**

- The objectives of the meeting were successfully completed.

- This meeting confirmed the usefulness of the first Research Co-ordination Meeting in reviewing the current status and future trends of the application of tracer techniques and neutron gauges in Nitrogen fertilizer and irrigation researches.

- Through the presented reports and related discussions it was clear that the objectives of the CRP are quite relevant to improve N-fertilizers use efficiency and to reduce ground water pollution hazards.

- The CERES-Wheat model is able to provide a realistic estimate of crop growth, nutrient uptake and water use, taking advantage of data generated with nuclear techniques. However, its adequate use requires intensive training: this is expected to be given during the next RCM. At the same time a collective procurement of DSSAT 3.0 Software will be pursued.

- Soil and plant samples will be sent to the Scientific Secretary for $^{15}$N% atom excess measurement in the Seibersdorf Laboratory; the contract holders are asked to carefully follow the guidelines already procured. A new version of guidelines regarding soil solution samples treatment, is being prepared and will be sent later.

- Participants of the CRP are encouraged to submit applications to training courses, and to publish their results.
6. ACKNOWLEDGEMENTS

The author is grateful to all participants for their active participation in this meeting. In particular, the author would like to thank Dr. Ortiz-Monasterio and Ms. L. Ainsworth who kindly intervened as local organizers of the meeting.
SECOND RESEARCH CO-ORDINATION MEETING OF THE
FAO/IAEA CO-ORDINATED RESEARCH PROGRAMME (CRP)
ON
THE USE OF NUCLEAR TECHNIQUES FOR OPTIMIZING FERTILIZER
APPLICATION UNDER IRRIGATED WHEAT TO INCREASE THE EFFICIENT
USE OF FERTILIZERS AND CONSEQUENTLY
REDUCE ENVIRONMENTAL POLLUTION

CIMMYT CENTRE
MEXICO
4 - 8 March, 1996

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SECOND FAO/IAEA RESEARCH CO-ORDINATION MEETING
ON "THE USE OF NUCLEAR TECHNIQUES FOR OPTIMIZING
FERTILIZER APPLICATION UNDER IRRIGATED WHEAT TO INCREASE
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4 - 8 MARCH 1996

INTERNATIONAL MAIZE AND WHEAT
IMPROVEMENT CENTRE (CIMMYT)
MEXICO D.F. MEXICO

Scientific Secretary: Pierre Moutonnet (IAEA)  ANNEX 2

PROGRAMME

Monday, 4 March
08:00    Registration (Outside Sasakawa)
09:15    Official Opening  Address of a
             Representative of CIMMYT
             International. Prof. Timothy
             Reeves
09:45    Remarks by Scientific Secretary  Address of a
          Representative of the IAEA
          (Mr. P. Moutonnet)
10:00    Coffee Break (Group Picture on the front steps of the main building)

Session I  Chairman: I. Ortiz-Monasterio (CIMMYT, Mexico)
10:30
11:30
12:30 Lunch Break (Guest House)

Khalil (Bangladesh)
Boaretto (Brazil)
Session II  Chairman:  J. Schepers (USA)

14:00  Vidal (Chile)
15:00  Abdel Monem (Egypt)
16:00  Coffee Break
16:30  Sachdev (India)
17:30  Sanchez-Yanez (Mexico)
18:30 - 19:30  Welcome Reception (Guest House)

Tuesday, 5 March

Session III  Chairman:  C. Kirda (Turkey)

08:00  Uvalle-Bueno (Mexico)
09:00  Bazza (Morocco)
10:00  Coffee Break

Session IV  Chairman:  G. Vachaud (France)

10:30  Qing (P.R. of China)
11:30  Cioban (Romania)
12:30  Lunch Break (Guest House)

Session V  Chairman:  W. Beathgen (IFDC, USA)

14:00  Arslan (Syria)
15:00  Kirda (Turkey)
16:00  Coffee Break
16:30  Eckert (IAEA, Seibersdorf)

Wednesday, 6 March

Session VI  Chairman:  M.S. Sachdev (India)

08:00  Ortiz-Monasterio
       CIMMYT, Mexico)
08:40  Baethgen (USA)
09:20 Schepers (USA)
10:20 Coffee Break
11:00 Vachaud (France)
11:40 Cepuder (Austria)
12:20 Lunch Break (Guest House)
13:30 Departure for a one-afternoon field visit (Microbus CIMMYT)

Thursday, 7 March (Computer room B-22)

08:00 Beathgen (USA) - Intensive Training Course to DSSAT V3 Software
10:00 Coffee Break
10:30 Continuation of training
12:30 Lunch Break (Guest House)
14:00 Continuation of training
16:00 Coffee Break
16:30 Cases study
20:00 Closing dinner (Rincon Mexicano)

Friday, 8 March Chairman: P. Moutonnet (IAEA)

09:00 Discussion on experimental plans - Continuation of cases study
10:30 Coffee Break
11:00 Discussion on implementation plans and on simulation model results
12:30 Lunch Break (Guest House)
14:00 Upgrading of experimental guidelines and work plans
15:30 Coffee Break
16:00 CLOSING SESSION
16:30 Individual discussions
Isotope-aided studies on nitrate movement in soil under irrigated wheat with emphasis on ground water pollution

M. I. Khalil, Bangladesh Institute of Nuclear Agriculture (BDN-8040)

A field experiment with winter wheat as test crop was conducted during 1994-95 to study the yield response, fertilizer N and water use efficiency of wheat under varying fertilizer levels viz. N₀- unfertilized control (control), N₁- 60, N₂- 120 and N₃- 180, kg N ha⁻¹. The experimental soil is mostly sandy loam in texture, and has higher infiltrability and hydraulic conductivity. Results showed that wheat crop emerged 5 days after sowing of seeds with a thermal time of 97.3 °C.d. The phyllochron for leaves 1 through 8 was 87 °C.d and 5 tillers formed between 12-28 days after emergence. Initially total dry matter (TDM) production was lower and increased with the advancement of crop growth and varied significantly due to N levels. Leaf area (LA) and leaf area index (LAI) increased with the increase in N levels up to anthesis period and thereby started decreasing. At grain filling stage, a decreasing trend in straw weight and a linear increase in spike weight after anthesis were observed. The physiological maturity attained within 108 days after emergence. Soil water content (SWC) in 0-120 cm soil profile did not vary significantly but immediately after irrigation, an increasing trend in percolation losses was observed below 90 cm depth. Yield and water use efficiency (WUE) of wheat varied significantly due to N levels - the highest grain yield (4.19 tons ha⁻¹) and WUE (165 kg ha⁻¹ cm⁻¹) being found from the N₃ treatments having 180 kg N ha⁻¹ and decreased with decrease levels of N application. Crop N content gradually decreased and N uptake by wheat remarkably increased after anthesis period and varied significantly among the treatments. ¹⁵N isotope study showed considerable increase in %Ndff, fertilizer and soil N uptake with the increase rate of fertilizer application. Wheat utilized 38.8 and 38.1 per cent of N-fertilizer for N₂ and N₃ treatments, respectively. N use efficiency increased with the decrease rate of fertilizer N. NH₄-N content in the 0-120 cm soil profile did not vary considerably. NO₃-N content varied significantly due to N levels and increased to some extent with increased rates of fertilizer N. Increase in NO₃-N content below root zone indicated leaching losses immediately after application of irrigation water. The total N loss ranged between 16.9 and 79.3 kg ha⁻¹ and increased with the increase in N levels.

Nuclear Techniques for Optimizing the N Fertilizer application in wheat under irrigated conditions

A.E. Boaretto, Nuclear Energy Centre, Brazil (BRA-8087)

The wheat growing season in "São Paulo State", is from March to October. Focussing N fertilization, the research developed these last years showed that wheat responds positively to this nutrient. N is applied at sowing at dose of 20 kg ha⁻¹, complemented with P, K and B. In case of irrigated cultivation, N is applied also at tillering stage on soil surface at doses ranging from 0 to 120 kg ha⁻¹, which can be applied in just one application. The experiment carried out in 1995 was located at experimental station of "Instituto Agronomico" "São Paulo State" (latitude = 22°54 S, longitude = 47°05 W, and 674 m above sea level).
IAC 24 is a spring wheat genotype most planted in state of "São Paulo", that grows well in acid soils. The cycle of IAC 24 is about 130 days. The dose of 90 kg ha\(^{-1}\) of N initiated the major yield of grains, an increase of 870 kg ha\(^{-1}\) of grains compared with the control (without N fertilization). The efficiency of the N fertilization ranged from 20.3 to 6.3 kg of grains for each kg of N applied.

The ammonia volatilization, resulting from urea applied on soil at tillering stage, was measured. There was a direct and positive relation between the rate of N applied and the amount of ammonia volatilized. Nitrogen recovery from urea application at sowing varied from 37 to 44% of the quantity of N applied.

**Water and nitrogen fertilization effects on nitrogen uptake efficiency of spring wheat**

I. Vidal, Faculty of Agronomy, Chillan, Chile (CHI-8041)

Our objectives were: i) to measure the contribution made by applied and native soil N to the total nitrogen taken up by spring wheat under different irrigation levels, and ii) to generate an experimental data set on soil, crop and climate within ME-I that can be used for validating the CERES-Wheat Simulation Model.

A line-source sprinkler irrigation system was used to establish a gradient of three water levels of increasing drought delineated by distances 0-5, 5-10 and 10-15 m away from the sprinkler line. The total water applied by block ranged from 57 to 221 mm at distances of 15 to 1 m away from the line-source, respectively.

Stripped at right angles to the line-source were plots of four fertilizer N levels (0, 75, 150 and 225 kg N ha\(^{-1}\)). The N level factor was arranged within each water level as a split plot design. Within each fertilized treatment \(^{15}\)N microplots of 5 lines of 1.2 m were installed. \(^{15}\)N labeled urea (2.9% a.e. \(^{15}\)N) was applied in the same doses that in the main plot.

The chlorophyll meter was effective as predictor of N deficiency. We suggest a sufficiency value of 44 SPAD units at GS-45. Chlorophyll meter reading of leaves at GS-45 and GS-69 accounted for 72 to 82% of variation in grain yield, respectively. The interaction Nitrogen rate x water for grain yield was significant. Quadratic yield increases were found under different levels of soil water treatment in response to increase N. The contribution made by fertilizer and native soil N to total nitrogen taken up by spring wheat was increased by increasing the water level and with an optimum at dose of 150 kg N ha\(^{-1}\). Due to application of nitrogen fertilizer the uptake of native soil N increased over the control treatment without fertilization (positive "priming" or "added N interaction").

**Optimizing fertilizer application under irrigated wheat**

Mohamed A.S. Abdel Monem, ICARDA, Cairo, Egypt (EGY-8433)

Because of its intensive agriculture system, Egypt consumes a lot of nitrogen fertilizers. Percentage of N recovery ranges between 40% in the old irrigated land and 28% in the sandy soil. A field trial was conducted in 1994/1995 season to study nitrogen use efficiency by wheat
under irrigation in Egypt. Soil of the experimental site was classified as Typic Torrifluvents with 35% clay and pH of 8.4. The experimental design was split-plot design with irrigation treatments as the main plots, and N treatments as sub-plots. The two irrigation regimes were W1 (4 irrigations) and W2 (6 irrigations). Nitrogen treatments were 0, 70, 140 and 210 kg N/ha applied at 2 splits (% at planting and % at stage Z-31). Microplots (1 x 1 m) were marked in each plots to be fertilized with 15N-labelled urea (4.91% atom excess). For the rate of 140 kg N/ha, labelled urea was applied either at planting (%), or at stage Z-31 (%), while for the rate of 210 kg N/ha, labelled urea was applied either at planting (%), or at both (% and %). Wheat seeds (Satha 69) were broadcasted at rate of 84 kg/ha. The trial was harvested on the 15th of may, 1995.

Results obtained from the experiment show that, percentage increase in straw and grain yield of wheat ranged from 59 to 150 as compared to no fertilizer application, due to N fertilization. Nitrogen uptake also has increased from 17.8 to 58.4, and from 35.6 to 113.7 kg N/ha, for straw and grain yield respectively, as N rate increased from zero to 210 kg N/ha. Also, data show that, there is no significant difference in wheat yield due to irrigation 4 or 6 times. Percentage of Ndff by both straw and grain was estimated using the results of 15N analysis of the plant samples. An average of 19.6% of the N yield in wheat derived from the first dose, while 61.8% was derived from the second dose (%). When all the applied rate was applied as labelled N-15, an average of 77.4% was considered as Ndff. Total of 58.2 kg N/ha is considered derived from the rate of 140 kg N/ha, while 66.2 kg N/ha is derived from the rate of 210 kg N/ha. Percentage Ndff in the soil after harvest was found to be very low, ranging between 0.3% to 1.1%. Water consumptive use (mm) by wheat crop or actual evapotranspiration (ETa) was estimated using % soil moisture after and before irrigation for different soil layers. Data show that Eta by wheat was 406 mm when using 6 irrigations and 334 mm using 4 irrigations. Potential evapotranspiration (ETa) was calculated using Blaney-Criddle method modified by Doorenbos and Pruitt, and by Penman-Monteth, also crop coefficient (Kc) was estimated.

From this first year trial it could be concluded that utilization coefficient ranged from 40% for the fertilizer applied at rate of 140 kg N/ha, to 38.5% for the rate of 210 kg N/ha. Also about 33% saving in the amount of applied water can be achieved, while obtaining the same yield.

Use of Nuclear Techniques for Optimizing Fertilizer Application under Irrigated Wheat to Increase the Efficient Use of Nitrogen Fertilizers and Consequently Reduce Environmental Pollution.

M.S. Sachdev, Nuclear Res. Lab., Indian Agric. Res. Institute, New Delhi (IND-7943)

The results on grain and straw yield, nitrogen content, total and fertilizer nitrogen uptake and fertilizer nitrogen use were reported. There was wide variation in the dry matter yield recorded at Z-30 sampling amongst the replications. In N-0 treatment it ranged 390-479 kg/ha, in N-60, 414-467 kg/ha, in N-120, 602-644 kg/ha, and in N-180, 643-707 kg/ha. In nitrogen fertilized plots the N content in plant samples was more or less similar but it was much lower in check plot samples.

At 50% anthesis stage nearly 85-90% of the total nitrogen uptake by the wheat crop at
harvest stage was accounted for in the straw and ears portion. At harvest stage the mean grain yield recorded was 2.02 Mg/ha in check plots, 3.5 Mg/ha in N-60 treatment, 5.11 Mg/ha in N-120 treatment and 5.7 Mg/ha in N-180 treatment. Similar was the trend in straw yield. In the wheat grain from check plots there was significantly lower nitrogen content and application of 180 kg N/ha resulted in significantly higher nitrogen content in wheat grain as well as straw. The total nitrogen uptake by wheat crop was 35.7, 86.7, 134.9 and 172.3 kg/ha in N-0, N-60, N-120 and N-180 treatments, respectively.

Fertilizer Nitrogen Uptake and Use Efficiency: the N-15 data revealed that in N-120 treatment the fertilizer N use efficiency from first split of 40 kg N/ha was only 27.8% and from second split applied at Z-30 stage was 63.4%. However, in N-180 treatment it was 25.3 and 49.6%, respectively. The overall fertilizer N use efficiency by wheat from N-120 and N-180 treatments was 51.9% and 41.54%, respectively.

Changes in Soil NH₄-N and NO₃-N Content: the soil NH₄ content in check plots in all the soil layers to a depth of 120 cm showed decline, while in N treated plots except in top layer (0 to 15 cm depth) it maintained a more or less steady value. In top layer it first increased with basal N application and again increased with second application of fertilizer N at Z-30 stage but thereafter it continuously decreased and by 50% anthesis stage reached a steady value more or less similar to that observed before wheat sowing. The NO₃-N content in different soil layers increased after Z-30 fertilizer N application and showed a maxima in each layer. This maxima occurred in different soil depths progressively in deeper layers. There was considerable higher NO₃-N in all the soil layers in N-180 treatment.

NH₄-N and NO₃-N in soil Solution: in soil solution samples collected from microplots in N-120 and N-180 treatments from 60 cm, 90 cm and 120 cm depths, there was very little NH₄-N as compared to that observed in soil samples extracted with 2N KC1 solution from similar depths. However, NO₃-N content of soil solution showed an initial increase at 60 cm depth followed by that at 90 cm and 120 cm depths. The concentration of NO₃-N at all the three depth samples was nearly two times more in case of fertilizer application of 180 kg N/ha as compared to 120 kg N/ha application. The fertilizer derived NO₃-N in soil solution also showed the similar trend, however, it was 3-4 times more in N-180 treatment than in N-120 treatment.

Residual Fertilizer Nitrogen Traced in Soil: in N-120 treatment the residual fertilizer nitrogen in soil after wheat harvest could be traced up to 90 cm depth only and bulk of it was present in upper 60 cm soil depth. But in case of 180 kg N/ha application the fertilizer N could be found to depth of 150 cm and a substantial portion was present in lower soil layers (90 to 150 cm depth) and the fertilizer derived N in nitrate fraction was found even in 150 to 180 cm soil layer.

Studies on N-Use Efficiency by Irrigated Wheat, Using N¹⁵ Labelled Fertilizers

X. Uvalle-Bueno, CIANO/INFAP, CIMMYT, Obregon, Mexico (MEX-8091)

The experimental design was a RCBD with four treatments and four replications. Treatments were four different nitrogen rates (0, 84, 167 and 250 kg N/ha). All rates were applied using a split application (1/3 at planting and 2/3 with first auxiliary irrigation).
Nitrogen applications were done in the furrow using urea as the N source. The crop received a total of five irrigations: the preplant irrigation on Nov. 8, 1994, and four auxiliary irrigations on Jan. 20, Feb. 14, Mar. 7, and March 24, 1995. Plots were machine harvested on April 21, 1995.

A quadratic response to grain yield from the large plots resulted in a better fit than the linear response. Grain yield under 0 N application was relatively high (87% of the maximum yield) indicating large amounts of soil residual N after the soybean crop. The large amounts of residual N may be related to the poor performance of the soybean crop associated with the attack of the white fly. Yields of the soybean crop were only 1 Mg/ha when in a normal year yields are around 2 Mg/ha. The summer of 1993 was the first that the white fly had attacked the soybean crop in the Yaqui Valley. Thus there were no known tolerant cultivars or chemical control available. This high level of initial soil nitrogen did not allow a good differentiation between treatment 84 kg N/ha (50% of maximum) and 167 kg N/ha (maximum) as we had expected.

Biomass accumulation during the growing season was similar in all fertilized treatments and lower in the unfertilized treatment. The largest difference in biomass accumulation between the fertilized treatments occurred in the post-anthesis period. The lower production of biomass in the unfertilized treatment was associated with lower light interception and lower chlorophyll content in the top leaves resulting in lower radiation use efficiency. There were differences only between the fertilized and the unfertilized treatment in nitrogen accumulation in the above ground biomass through the growing season.

The estimation of fertilizer N uptake (FNU) by the isotopic method indicates the difference en FNU between the fertilized treatments with 250, 167 and 84 kg N/ha and determines 35, 39, and 40% FNU respectively. The FNU by plots that received N-15 with the 2/3 of the total rate applied at Z-30, after no N-15 applied at planting, was higher than plots that received N-15 with the 1/3 of the total rate applied at planting. The difference was higher in 9.7, 51.5 and 23.7% for the treatments with 250, 167, and 84 kg N/ha respectively.

Effect of bacteria and humic acids on the yield of wheat under irrigated.


The aim of this step in the present research was to evaluate the effect of several rhizobacteria inoculated in irrigated wheat at low nitrogen rate - urea less than 80 kg ha⁻¹ - under its dry weight at booting and inflorescence emergence of the stem and root system.

In this way greenhouse experiments were conducted with wheat’s seed inoculated with several rhizobacteria isolated from different sources. Plastic containers fill with sterile sandy were used a as support for the plants and a mineral solution for its nutritional demand. Plants were kept during 30-50 days under this condition and the moisture adjusted at 60% holding field capacity. Plants control were feed with urea (150 kg. ha⁻¹). Results indicate that some bacterium alone or bacterial mixing were statistically similar or better than the plants control in terms of dry weight which suggest that these microorganisms could be a good choice for improving the nitrogen fertilizer assimilation of the root system of wheat at low nitrogen rate under irrigation.
Contribution to the improvement of applied water and N-fertilizer efficiencies for irrigated wheat

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The present study had the objectives of reviewing previous research on water and N fertilizer management in an irrigated area of 60,000 ha where wheat is one of the most important crops. In addition, a survey of over 80 farms was conducted and concerned all practices related to water and N fertilizer application so as to identify strengths and weaknesses of these practices. Of this large number of farms, a sub-sample of 8 farms were closely monitored for soil water content, canopy temperature, and N and water application for assessing the potential of N leaching. Previous research on wheat in the area concerned essentially water management and revealed that the stage of tillering is the most likely to be subjected to severe water stress. While one to two irrigations around this stage lead to the best water-use efficiency and a competitive yield, farmers still apply three to four irrigations. Water and N applications are based only on farmers trial and error and experience rather than on any scientifically based recommendation, although such recommendations exist especially for the amount and timing of N application.

The soil N content is relatively high at the wheat crop installation, and soils have an important mineralization potential. However, such sources of N are not taken advantage of and N fertilizers are applied irrespective of the soil type or its N content. As a result, the potential of N loss is high. The survey coincided with a very dry year and irrigation water was rationed on a very restricted rotation basis which subjected the crop to severe water stress. The crop fertilization was generally higher than the recommended amounts, especially for nitrogen and did not take into consideration the soil type. In addition, the amount of N applied after emergence varied widely, from 20 to 112 U/ha which led to 38% and 14% of the farms applying respectively above and below the recommended quantity of 60 to 80 U/ha, depending on the type of soil.

Although precipitation during the crop cycle was very low, the restriction on water allocation and the priority of other crops allowed farmers to apply only 130 to 250 mm, in two to four irrigations which subjected the wheat crop to a water-deficit of 40 to 60%. The resulting mean yield (3,000 kg/ha) was way below the region’s potential although where the stress was limited during the critical stages, it reached very competitive figures (5,700 kg/ha). It was relatively higher with early sowing and in soils with high water holding capacity and was related only to the amount of water used by the crop, rather than to fertilizers or any other factor. The non response of yield to fertilizer N was explained by (1) the fact that water was so limiting that it affected the yield before nitrogen deficit if any, and (2) N left from previous crops is high and the nitrification potential of the soils is quite important. In either case, a large part of the applied nitrogen is lost to drainage and volatilization and does not contribute to the yield formation. The evident consequences of the present practice is the lower benefit from the applied N and the high potential of groundwater contamination.

Yield response of wheat to irrigation and nitrogen fertilizers in Romania

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Wheat yield response to different rates and times of N fertilizer application in conditions of Eastern part of Romania was aimed to be evaluated. The investigation has been carried out beginning with the autumn of 1994 in a flat plain area. Four rates of N fertilizer was used as follows: unfertilized (check plot), 60 kg N/ha, 120 kg N/ha and 180 kg N/ha. The N (urea) fertilizer rates had been split in two applications: one third in autumn at sowing time and two thirds at Zadoks growth stage 30. $^{15}$N was applied in the following way in order to study fertilizer use efficiency and N leached N on the soil profile. $^{15}$N fertilizer as urea with 2% atom excess was applied in order to study fertilizer use efficiency, but $^{15}$N fertilizer as urea with 10% atom excess was added in order to study fertilizer movement in the soil below root zone and the possibility of ground water pollution. The irrigation system was used to maintain the soil content moisture not less than 50% of the soil water holding capacity down to 40 cm.

By utilizing the neutron gauge in the determination of the soil moisture evolution, it is possible to establish, quickly and correctly, the right time for the application of the intended amounts of water. The amount of N derived from fertilizer, as determined in the straw and grain yields, is higher when the N fertilizer is applied in spring at tillering time, the values of this indicator going higher with higher N rates. The figures for the N utilization efficient range from 17.5 to 45.1% the highest value being recorded with an N application of 120 kg/ha at tillering time. The amount of N from fertilizer as determined on the 0-80 cm soil profile is 14 to 29.9 kg N/ha according to the rates used. On the basis of the data regarding the N derived from fertilizer in plant and soil, we concluded that an important part of the applied fertilizer is wasted either by leaching down the soil profile or volatilization.

Nuclear techniques for optimizing fertilizer application under irrigated wheat

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Wheat production in Syria is important because it is the main ingredient of bread. Its yield from unit area and the total production from the non-irrigated areas fluctuates from year to year because of its dependence on rain which fluctuates a lot. Its yield increased the last decade by using new high production cultivars, increasing the amounts of added fertilizers and irrigation by ground or surface water. In spite of its yield increase, the average yield of the high production cultivars remains low (2861 kg ha$^{-1}$ during 1981 to 1990 period) according to the agricultural statistical abstract of 1990. One way of increasing wheat yield is by getting in touch with the scientists involved in its production all over the world through co-ordinated research programmes initiated by FAO/IAEA. Having the opportunity to be involved in present CRP made us initiate a project using nuclear techniques for optimizing fertilizers application under irrigated wheat to increase the efficient use fertilizers and water, and consequently reduce environmental pollution. Therefore, we selected a field in the semi-arid area and used two cultivars and four N fertilizer treatments (according to the first RCM recommendations) with one irrigation treatments in a factorial experiment using sprinkler irrigation system. The primary results showed a significant effect of adding N fertilizer on grain yield. The yield obtained from Sham 3 cultivar was higher than Sham 6. Using nuclear techniques in monitoring soil water content with time helped us reduce leaching water and nutrients below the root zone by applying the correct amount of irrigation water when it is needed. Using labelled N fertilizers helped us know the fate of N fertilizer.
Wheat yield response to irrigation and nitrogen fertilizer applications

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Wheat yield response to different rates of N fertilizer applications under different degree of transpiration deficits was aimed to be evaluated. A single line source sprinkler irrigation system was used with the intention of studying fertilizer N - irrigation interactions. However, experimental data subject to discussion here is limited to only one year, 1994/95 growing season during which annual rainfall received was unusually high. Therefore, irrigation treatments envisaged could not be realized. Results presented, therefore, do not include any data on irrigation.

Lowest grain yield (3.34 Mg.ha\(^{-1}\)) was recorded under no N-fertilizer treatment. There was no significant yield increase beyond 80 kg N.ha\(^{-1}\) fertilizer application. Under the treatment where no N fertilizer was applied, total dry matter production was nearly stopped after 100 days from planting (DAP); whereas, it continued even after 100 DAP in the plots receiving fertilizer. Spike weight increase showed similar trend. The results utilizing \(^15\)N-labeled N fertilizer showed that wheat benefited the least from the fertilizer applied during the planting. N fertilizer utilization was 2 to 3 times more from the application when two thirds of the N applied during the tillering at Z-25 stage. Percent N derived from fertilizer was not influenced by the rate, but influenced rather by the timing of N application.

Residual soil N left in the soil after the harvest of wheat seems to be proportional to N fertilizer rate used for wheat, and proportionally higher residual N left in the soil under high rate of N application. Recovery of N fertilizer by wheat was nearly 50 % under the highest rate of N application (240 kg N.ha\(^{-1}\)), and the remaining N was retained in the soil after the harvest. Yield of maize crop, planted following wheat, showed, therefore, a good response to the preceding N treatments used for wheat, clearly indicating that maize benefited from the residual N, left within the soil profile after wheat. Recovery of residual N by maize was over 30 % which was about 10 to 15 % N fertilizer applied to the preceding crop, wheat.

The use of nuclear techniques to increase wheat production and decrease the nitrogen loss from ammonium bicarbonate

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The effects of fertilizer application method with immediate irrigation on nitrogen uptake by winter wheat \((Triticum aestivum\) c.v. 78-1) were described by \(^15\)N tracing techniques in the experiment in 1994. The results showed that when urea was applied on the soil surface with immediate irrigation, the nitrogen recovery efficiency (NRE) was 48.8% at maturity stage, higher by 9.4% and nitrogen loss decreased by 28.5% than that of urea applied method without immediate irrigation. The NRE of ammonium bicarbonate surface applied method without immediate irrigation was only 22%, while it was 29.3% and nitrogen loss decreased by 14.0% with immediate irrigation; however when ammonium bicarbonate was banded beneath soil surface at 10 cm depth, immediate irrigation didn’t significantly affect the NRE. When Dicyandiamide (DCD), a nitrification inhibitor, was incorporated into soil at 10 cm depth with ammonium bicarbonate at a rate equivalent to 4% of nitrogen applied rate, the NRE was 40.9%, equivalent to that of urea application, with banded on the surface method, higher by
18.9% and grain yield increased by 30.3% with comparison with that of surface applied ammonium bicarbonate without immediate irrigation. It was also indicated that over 50% of fertilizer N residue was distributed into the upper soil profile (0-30 cm).

To optimize management of nitrogen in the intensive agricultural system, nitrogen application rate is a major concern considered by the farmers in China. In this experiment conducted from 1994 to 1995 in Shijiazhuang by means of $^{15}$N tracing techniques, optimum rate of nitrogen applied, N1.0 (150 kg N ha$^{-1}$, based on the recommended option of local farmer), above 50% of optimum rate, N1.5 (225 kg N ha$^{-1}$) and low 50% of optimum rate, NO.5 (75 kg N ha$^{-1}$) were conducted to investigate the nitrogen recovery efficiency (NRE) and yield of irrigated winter wheat under local management condition. Both nitrogen fate affected by applied rate and possibilities of nitrate pollution produced by excessive N application were investigated. The results suggested that nitrogen uptake and grain yield of wheat in fertilized treatments except N1.5 treatment (225 kg N ha$^{-1}$) were higher than those in unfertilized treatment, the nitrogen uptake and grain yield in N1.5 treatment were lower than those of other fertilized treatment and nearly equal to those of unfertilized treatment (CK). Highest yield (6.80 ton grain ha$^{-1}$, 14.70 ton top ha$^{-1}$ was obtained in optimum N applied treatment, N1.0, while the highest NRE 38.5%) of ammonium bicarbonate by winter wheat was found in NO.5 treatment due to relative high fertility in the field. The NRE of N1.0 treatment was also relative high, 32.4%, due to fertilizer application with banding application method. Highest residue of fertilizer N was determined in N1.5 treatment, of which 46% existed in the top layer of the soil (0-50 cm). There was no significant difference in the part of fertilizer in soil between the other N treatments (31.2% in NO.5 treatment, 31.1% in N1.0 treatment). The unaccounted parts of N calculated in N balance were 30.2%, 36.5%, 31.2% in NO.5, N1.0, N1.5 treatments, respectively. About one-third of applied N fertilizer was leaching to 50 cm in the soil profile as nitrate or gaseous loss through volatilization, denitrification. Results from the experiment also suggested that possibilities of nitrate leaching to wasn’t found in NO.5, N1.0 treatments, but found in N1.5 treatment. The after-effect of residue N in soil on the next crop in N1.5 treatment was the greatest in the three N-applied-rate treatments. It is necessary for control of residual N to choose optimum rate and split application time of N fertilizer.

A decision support system for high-yield cultivation of winter wheat was built based on CERES-wheat model. According to the experiment results, the genetic coefficient of 5144 were defined and the data of soil profile properties and initial conditions in the experiment site and validation of CERES-wheat model were made with data of 1995, 1-year field experiment. Meanwhile, the simulation experiments were made to analyze the feasibility of optimization and decision-making using CERES-Wheat model, the predicted data generated from the model simulation was compared with measured data from the field experiment. Based on the studies mentioned above, the growth stage of winter wheat with CERES-model could be simulated under nominal cultivated condition (without water and fertilizer stress). Nitrogen application could increase crop growth and stimulate N uptake. However, because modeling ammonium volatilization was not included in the simulation and other particular and complicate condition remained, effects of N application and N balance was not simulated well in the report.

*In-situ Nitrogen balance of an irrigated maize by continuous monitoring plus sampling at harvest.*

G. Vachaud, University, LTME, Grenoble, France (FRA-8037)
Field experiments with $^{15}$N-labelled fertilizer were conducted on irrigated maize crops in 1991, 1992 and 1993 on the Experimental Farm at La Côte Saint-André (France). The dynamics of soil and fertilizer-N (nitrate transport and N balance during cropping and intercropping periods) were continuously monitored using $^{15}$N isotopic tracing and tensio-neutronic method together with porous cups installed at 0.3, 0.5 and 0.8 m depth. Direct measurements of field water balance (real evapotranspiration and drainage below the root zone) were also done on the same sites. The balance of the labelled fertilizer at harvest was determined by conventional soil coring and plant sampling. The two methods were used successfully during the 3 years in which there were different climatic conditions. The result show that the traditional fertilizer input in the area (250 kg N ha$^{-1}$) could be reduced nearly 30% without any substantial reduction in yield, but with a considerable reduction of non-point-source pollution due to nitrate leaching. It is also shown that, with the combined used of the two methods it is possible to characterize separately the fertilizer uptake, the fertilizer leaching, the immobilization and the gas losses.

Efficient use of Nitrogen fertilizer for irrigated wheat

I. Ortiz-Monasterio, CIMMYT Wheat Programme, Mexico (MEX-8012)

The Crop Management and Physiology sub-program at CIMMYT has been working for several years to increase N use efficiency in irrigated spring wheat. Progress in apparent N fertilizer recovery has increased from about 30 to 60%, by using split applications that synchronize the timing of the largest N application with the time of rapid crop uptake. On the other hand, nothing was known about the pathways and drivers of N lost to the environment under farmers management or improved practices. Therefore, it was difficult to assess the impact of these losses on the environment. As a result of this, a collaboration was initiated among three institutions to study the problem of nitrogen use efficiency in the Yaqui Valley. These institutions are CIMMYT, that is focusing in the agronomic components, the University of California-Berkeley that evaluates the ecological impact and Stanford University through the Institute of International Studies that is looking at the technical, economic and policy determinants of N fertilizer use. CIMMYT recognizes that N use efficiency in wheat is a world wide problem, however, this is particularly important in the Yaqui Valley because:

a) it is a location representative of what CIMMYT defines as mega environment 1 (ME1), where more than 40% of the wheat production in developing countries is grown.
b) it is the place were the green revolution was born about thirty years ago.
c) it is an area where the main cost of production for wheat is fertilizer use.
d) the consequences of fertilization on emission of nitrous oxide have been studied in temperate agricultural systems; however, very little information exists from developing countries in the tropics and sub-tropics.
e) the effect of fertilization on emission of nitric oxide has received much less attention in the temperate world, and virtually none in developing world agriculture outside of flooded rice systems.

The use of nitrification inhibitors represents an interesting alternative to the use of split applications, particularly in areas where there is a risk factor associated with split applications and rain events. Thus, CIMMYT has started a small collaboration with Purdue University for the evaluation of nitrification inhibitors, particularly when used with NH$_3$, but also with urea.
Optimizing fertilizer application under irrigated wheat

J. Schepers, University of Nebraska, Lincoln, U.S.A. (USA-8092)

The study was conducted in western Nebraska about 600 km from Lincoln where our offices are located at the University of Nebraska. Normal precipitation is about 400 mm but in 1995, it was about 50% in excess of the long term average. The study was in cooperation with University of Nebraska wheat breeders and a soil fertility specialist located on site (Sidney, Nebraska). The study consisted of 3 cultivars grown at four N rates (0, 15, 30 and 45 kg N/ha) under linear-drive sprinkler irrigation. The soils specialist at the location was hired by Industry, therefore, co-ordination was handled by Lincoln staff. The first attempt to apply fertilizer was cancelled because of a blizzard, and the second because of a rain storm. Finally, the fertilizer was applied on 6 April 1996. Chlorophyll meter readings at anthesis and 3 weeks later showed no N treatment difference or yield difference. Isotopic N determinations have been completed, but calculations are not yet completed. Since depleted NH₄NO₃ was used as the tracer on all plots rather than enriched fertilizer on micro plots, results are questionable, because of the low fertilizers rates, and relatively high yields (7-8 Mg/ha).

Field measurements to investigate the nitrogen leaching by means of the ¹⁵N-method

P. Cepuder, Univ. of Agric. Forest. and Nat. Renew. Resources, Vienna (AUT-8438)

In an apple-tree orchard, a field study allowing the comparison of different techniques of soil water sampling and determination of the nitrate concentration was conducted. Suction cups and tensionics are used to obtain soil water samples in the root zone at different depths (15, 45, 75 cm). Percolation and nitrogen leaching are measured by small lysimeters and suction cups below the root zone (105 cm). Soil water samples are taken continuously and/or weekly.

The isotope ¹⁵N is applied as a marked nitrogen fertilizer (Ammonium Sulfate, 5% ¹⁵N atom excess) during a period of ten weeks. The soil is a chernozium. The texture varies from a deep sandy loam to a shallow sandy silt above gravel. The comparison of the different measurement methods will be presented.
Report of Chlorophyll Meter activities - March 4-8, 1996

J. Schepers, University of Nebraska, U.S.A. (USA-8092)

About half of the locations obtained and used chlorophyll meters in their research. General experiences were very positive. Some questions were raised about data interpretation. The general approach was to calculate a sufficiency index based on the meter readings for the 150% N rate for a given data and cultivar. Several scientists only reported meter readings during the growing season without conversion to a sufficiency index. Several scientists used the meter reading for a given data and cultivar as a critical value and had questions about how much data would be required to interpret the data over years, cultivars, etc. Discussion about the reference concept (150% N rate) should solve this problem, because calculation of a sufficiency index permits comparison of data across N rates, cultivars, and sampling dates.

In most cases, chlorophyll meter readings increased with crop age until several weeks after anthesis and then, declined until harvest. In at least one case where meter readings were taken before the last fertilizer application, the meter values showed a deficiency, (sufficiency index (90%) that was temporarily corrected by the fertilizer application, but later became deficient again.

Yields generally, followed chlorophyll meter readings. Comparison of relative yield and relative chlorophyll meter readings should provide a good evaluation of N stress as yield. This approach will permit all locations to compare data. In some cases, even the 150% N rate did not appear to reach a yield plateau. In several cases, even the low N rate (50%) did not respond to N fertilizer. In these cases, consideration should be given to adjusting the 100% N rate.

To the extend possible, participants in the project should collect one set of data before the last fertilizer application so that they can determine if there was an N deficiency in the 100% treatment. This would permit subsequent measurements to determine how the crop recovered from an N stress. In all cases, chlorophyll meter readings and yield should be divided by the value for the 150% N rate (i.e., referring to an adequately fertilized plot).

Comments and recommendations

W. E. Baethgen, IFDC, USA (USA-7971)

1. Experimental results

1-A Nitrogen fertilizer use efficiency: Although several experiments were conducted with rational and efficient irrigation management practices, N fertilizer use efficiency (NUE) was always less than 50%. In many situations the wheat crop N uptake is similar or larger than the total amount of N applied in the fertilizer. However, in those situations NUE is still less
than 50%, and a considerable proportion of the N fertilizer remains in the soil after harvest. These results may indicate that in some of those situations the N fertilizer timing and/or placement may not be the optimal. In all experiments, NUE of fertilizer applied at Zadoks growth stage 30 (Z-30) is higher or much higher than the corresponding to applications at sowing. These results agree with most research found in the literature, and emphasize the importance of adequately timing the fertilizer applications to match the crop needs throughout the growing season. The results also emphasize the need for developing diagnostic tools that can be used at Z-30 (SPAD, soil tests, etc.), for establishing adequate fertilizer recommendations.

1-B Ammonium-N and Nitrate-N content in the soil: Results of soil analyses in some of the experiments revealed unusually high soil NH4-N and low soil NO3-N levels. Verification of these results would suggest limitations to the nitrification process which often cannot be explained with soil pH values (> 5.5) or temperature conditions. Given the nature of the present project these situations should be especially studied and understood (N in the soil remaining as NH4-N is not subjected to leaching).

2. Experimental methods

2-A. In several experiments, the N = 150% (or N = 1.5) did not produce maximum wheat yields. The recommended methodology called for defining N = 100% as the rate producing maximum yields, and N = 150% as the excessive rate which would promote nitrate leaching. In those experiments, N rates should be revised.

2-B. Some experiments showed no or small response to N fertilizer application. The recommended methodology also required experimental conditions which would promote high crop response to N fertilizers (e.g., avoiding legumes as previous crops, avoiding situations with known high residual soil N, etc.). Experimental conditions in these cases should also be revised.

2-C. All experiments should try to ensure that the only factor affecting crop yields should be N. All other factors such as other nutrients, diseases, pests, weeds, etc., should be controlled with fertilizers, pesticides, etc., whenever it is possible.

3. DSSAT-3 and modeling activities

One of the key objectives of the CRP is to assemble data sets for DSSAT-3, and calibrate/test the CERES-Wheat simulation model. Three conditions must be met to achieve this objective:

A. A complete version of DSSAT 3 (including the CERES models) should be made available to each participant.

B. Each participant should be adequately trained in the use of DSSAT 3 and the CERES-Wheat model. A minimum of 5 days is required to train participants.

C. All participants should acquire and provide the complete data sets (crop, soil and weather) required to calibrate and test the CERES-Wheat model, as described in the research protocol.
Soil water balance

G. Vachaud, LTHE, University, Grenoble, France (FRA-8037)

In order to compare in a better way, the results obtained by the contractors, it is advised to focus on:

- Water use efficiency calculation (ETa),
- Nitrogen losses under its different forms (total N, Ndfs, Ndff) in view of environmental protection concerns.

Using concurrently a neutron gauge, a bank of tensiometers, and a series of porous ceramic cups would allow:

1. in situ determination of soils characteristic curves h (Θ), together with the field capacity profiles;
2. monitoring of hydraulic head at two different depth below the root zone, so as to calculate ΔH/ΔZ versus time.
3. the determination of soil unsaturated hydraulic conductivity K(Θ) either through internal drainage process, or zero flux plane calculation.
4. the installation of a bank of porous ceramic cup to assess NO₃-N content with depth and time. When installed on a micro-plot receiving ¹⁵N-labelled fertilizer, the monitoring of soil solution ¹⁵N% a.e. would allow the calculation of the fertilizer losses through leaching.
5. the irrigation water input should be checked.
6. Soil water content profiles and tensiometers/porous ceramic cups measurements should not be made according to a constant pace (i.e. one week); it is better to operate according to irrigation events with measurements made both before and after water supply.
<table>
<thead>
<tr>
<th>Time</th>
<th>Soil Sampling</th>
<th>Growth Stage</th>
<th>Plant Sampling</th>
<th>Date</th>
<th>Soil Water</th>
<th>SPAD Meter</th>
<th>Soil Solution</th>
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<tr>
<td>Planting</td>
<td>Data</td>
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<td>Record</td>
<td>Data</td>
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<td>Collect samples</td>
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<td>Full emergence</td>
<td>A</td>
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<td>Record</td>
<td>Data</td>
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<td>after rainfall</td>
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<td>Second fertilization</td>
<td>Data ↑ ↓</td>
<td>Record</td>
<td>B ↑ ↓</td>
<td>Record</td>
<td>Data</td>
<td>Data</td>
<td>and irrigations.</td>
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<tr>
<td>Z-30 stage*</td>
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<td>Record</td>
<td>B ↑ ↓</td>
<td>Record</td>
<td>Data</td>
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<tr>
<td>Anthesis*</td>
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<td>Record</td>
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<td>Anthesis + 7-10 days</td>
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<td>Harvest</td>
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Note: Soil sampling is always done immediately before fertilizer application.

Definitions
* Z-30 stage - when 10% of main stems have nodes detectable at ground level.
* Anthesis - when 50% of the spikes have at least one anther
* Physiological Maturity - when 50% of the glooms have no green color
A - Counts the number of plants per unit area by replication
B - Total above ground dry matter and total N from a recorded number of representative plants or from a given area
Sample at the time of second fertilization or Z-30, whichever comes first: it is the meaning of ↑ ↓ (wash soil from tissue before analysis)
C - Determine dry matter and total N in spike and straw separately: Record DM & N for spikes, and DM & N for straw.
D - Determine dry matter and total N in grain and straw separately: Record DM & N for grain, and DM & N for straw.
Here dry matter means: Kg Dry Matter/ha or grams DM/m²

C1 - On microplots which received $^{15}$N-labelled fertilizer (same as C, plus $^{15}$N a.e. measurement)
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>
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<tr>
<th>Year</th>
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</tbody>
</table>

Where:  
EA₁, EA₂, etc. = experimental area for each experiment  
P = preceding crop with uniform irrigation and fertilization  
W = wheat experiment  
R = residual effect studies (optional)

The discussions lead to the conclusion that the preceding crop (P) should not to be wheat crop. It will be chosen according to the prevalent crop rotation. However, a legume crop should be avoided.