# Rational use of fertilizer

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Inorganic fertilizers have become the pillars supporting a burgeoning world population. With population doubling during the lifetime of each of us, a tremendous strain has been put on the ability of agriculture to feed mankind. Agriculture has responded magnificently, with yields of most crops more than doubling in the past 15 years. Cereal production increased by 150% (Table 1). Unfortunately however, over one-half of this increase can be attributed to an input dependent on a non-renewable resource in its manufacture. inorganic fertilizer [1].

The world's fertilizer production rose from 8 million tons at the end of the second world war to 113 million tons in 1978 Before the increase in energy prices, the United Nations Industrial Development Organization (UNIDO) predicted that production would increase to 300 million tons by the year 2000. The grim reality of a ten-fold increase in energy prices, and the realization that energy stocks may not always be available for fertilizer production, force us to modify such estimates today.

The developing countries have the greatest need for an increased food production. They have 60% of the world's land devoted to cereals, but are attempting to feed 73% of the 4.4 billion people in the world. Fertilizer production and use increased much more rapidly in developing countries than in developed ones from the early 1960s to 1978 (Table 1). As a result, cereal yields more than doubled, but population increase kept pace and per caput cereal production increased only slightly. The real concern for developing countries is the immediate future. Where food is most urgently needed, the gap is widening.

Inorganic fertilizers are an expensive resource in a developing country. Usually they have to be imported, thus drawing on the nation's scarce foreign reserves. They may be the only input for which the farmer requires hard currency. It is thus crucial that fertilizer be used in the most effective manner so that each unit will produce additional food. Its use will then be encouraged and more food produced where it is most urgently needed. The efforts of the Joint FAO/IAEA Division in this field are directed towards the developing nations.

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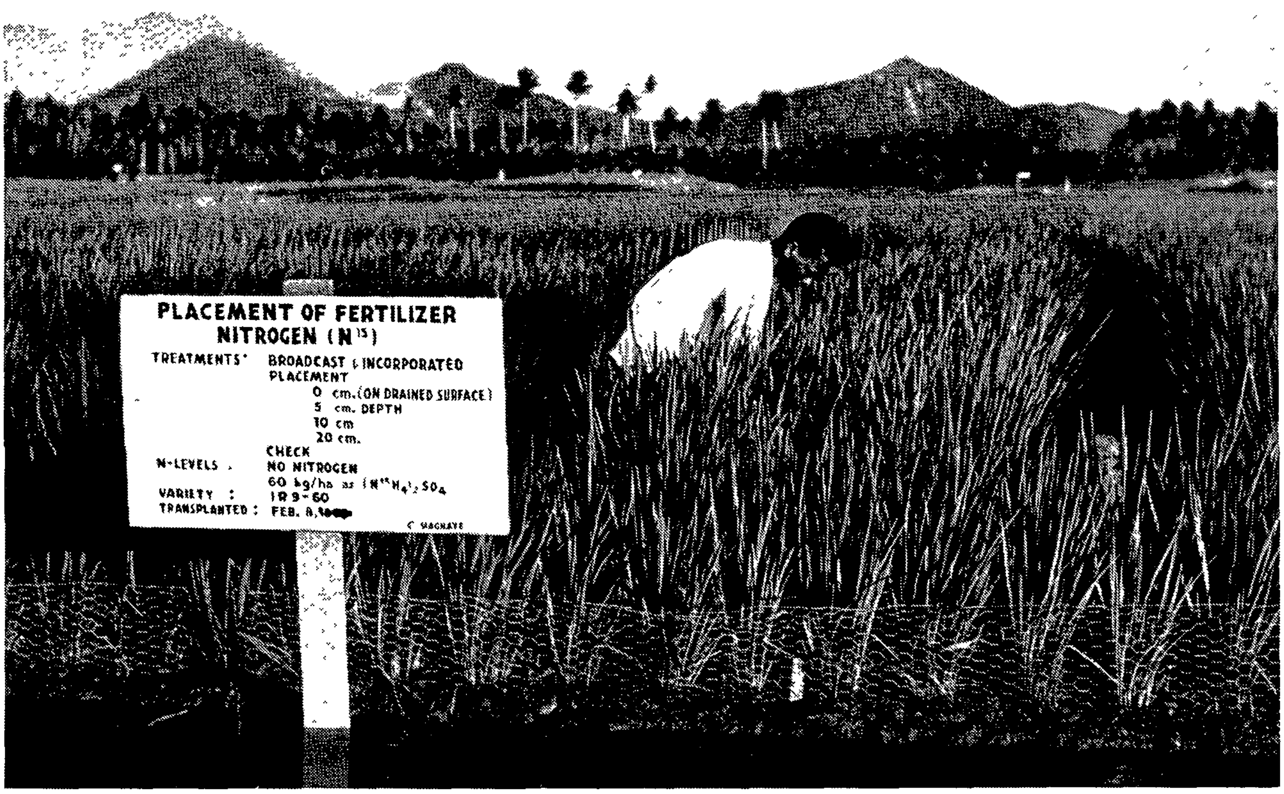
Agronomists must be able to recommend the best rate, form, placement and time of application of nutrients for each crop and for the soil and climatic conditions under which the crop is to be grown. This information cannot be obtained without a strong research programme. The experience of the Joint FAO/IAEA Division has shown that a direct measurement of fertilizer uptake efficiency is the most effective way of obtaining this information. This can only be done by labelling the fertilizer nutrient with an isotope. Fortunately, radioisotopes exist for phosphorus, sulphur, calcium, zinc, iron, manganese, and several other nutrients. The cost of the stable isotope N-15 and equipment to analyse it has declined in recent years so that field-plot scale research with isotopically-labelled nitrogen (N) fertilizer is now widely practised.

**Table 1. Annual fertilizer use ($N + P_2O_5 + K_2O$) and cereal production [2]**

| | Developing countries 1961–65 | Developing countries 1978 | Developed countries 1961–65 | Developed countries 1978 |
|---|---|---|---|---|
| Fertilizer production (million tons) | 2.7 | 19 7 | 37 9 | 93 0 |
| Fertilizer consumption | | | | |
| (kg/arable ha) | 7 6 | 39 4 | 50 6 | 115.1 |
| (kg/person) | 2 3 | 9.4 | 33.1 | 67 5 |
| Cereal production | | | | |
| (million tons) | 289 | 745 | 344 | 851 |
| (kg/arable ha) | 464 | 1100 | 542 | 1310 |
| (kg/person/day) | 0 53 | 0 64 | 1.36 | 2 02 |

## Using fertilizers efficiently

The first international co-ordinated research programme still serves as an illustration of how labelled isotopes in fertilizers can be used to resolve a practical problem. Many studies had been conducted showing that cereal crops took up fertilizer containing phosphorus (P) more efficiently when the fertilizer was placed near the seed at planting, than when it was broadcast and incorporated uniformly throughout the surface soil. Attempts by the International Rice Commission to establish the most effective placement of fertilizer-P for flooded rice had, however, been inconclusive. The Agricultural Unit of the IAEA, later to become the Joint FAO/IAEA Division, initiated a co-ordinated study using phosphate fertilizer labelled with P-32.




**Studying the uptake of nitrogen by plants with the use of nuclear techniques – the labelled isotope N-15.**

The results attained were clear, decisive and unexpected. In all nine locations where the experiment was carried out, surface application of the phosphate or hoeing to incorporate the fertilizer to a shallow depth were of equal effectiveness and twice as effective as placing the fertilizer below the seed in the hill or between the rice rows [3]. Only with a labelled fertilizer could these dramatic results have been obtained.

Other field research with flooded rice in the same co-ordinated programme – this time using fertilizers labelled with N-15 – produced nearly as dramatic results (Photo above). Nitrate sources of nitrogen which are normally very effective for cereals were shown to be virtually worthless at 14 of 15 locations when applied below the rice at transplanting. Ammonium sulfate and urea, which contain their nitrogen in an ammonium form, were of equal effectiveness but much superior to sodium nitrate. Ammonium nitrate was intermediate in effectiveness because one-half the nitrogen was in a nitrate form

When the nitrogen was applied in the irrigation water two weeks before primordial initiation, these same trends were evident, and the proportion of the plant nitrogen derived from the fertilizer was higher than when the fertilizer was applied at planting.

The effect of higher uptake efficiency from nitrogenous fertilizer applied later in the growing season, as compared to nitrogen applied at or shortly after transplanting, was confirmed in studies conducted with rice at seven locations in another co-ordinated international programme [4] Nitrogenous fertilizer was applied four times during the growing season. at transplanting; 3 weeks after transplanting; one week before primordial initiation; and at the flag-leaf stage. Four identical treatments of fertilizer application were made, but at each time of application, one of the four treatments received fertilizer labelled with N-15 while the other three received unlabelled fertilizer. In this way the uptake efficiency of each fertilizer application could be measured. Rice plants were harvested and analysed for N-15 at up to eight stages of maturity, made to determine when the applied fertilizer was actually taken up.

The uptake of applied nitrogen took place very rapidly. Nitrogen applied before primordial initiation was already utilized to its maximum extent by the flag-leaf stage, long before heading Nitrogen, applied at the flag-leaf stage, was clearly used at once as it had already reached its maximum utilization at the first sampling thereafter – at the heading stage

In assessing the efficiency of use of fertilizers, however, the exciting information was that nitrogenous fertilizer applied at the flag-leaf stage was used twice as efficiently by rice as that applied at transplanting or 3 weeks later.

Zinc (Zn) deficiency is considered by the International Rice Research Institute (IRRI) to be the most widespread nutritional disorder of flooded rice in the Philippines and is recognized as a problem in most other rice-producing countries. A research programme on isotope-aided micronutrient studies in rice production, focusing on Zn nutrition, was recently carried out by the Joint FAO/IAEA Division. Field experiments in nine rice-producing countries showed that only 5 kg Zn/ha, in the form of $ZnSO_4$, completely eliminated Zn deficiency and supplied up to 89% of the Zn in the rice grain No additional advantage was obtained by doubling the rate to 10 kg/ha Where studies could be conducted on the same site for a series of years, this low rate of zinc remained effective in the second and third cropping seasons, supplying about 30% of the zinc in the second year and 15 to 20% in the third year [5]. Other studies in the programme indicated that the Zn fertilizer could be applied in many different ways and be equally effective and that there was little or no advantage in using more expensive chelated formulations of Zn in flooded rice.

These four studies are presented as examples of field programmes which have changed fertilizer practices in a large part of the world The results could not have been obtained or would not have been as conclusive without the direct measurement of efficiency with which plants use fertilizer. Isotopes provide the only direct method for assessing fertilizer uptake.

The results of many of these isotope-aided studies were recently summarized by the Joint FAO/IAEA Division and published by the FAO for use by agriculture industry specialists [6] Similar techniques are currently being used by international groups of scientists in studies co-ordinated by the Joint FAO/IAEA Division to develop fertilizer practices for multiple cropping where a legume and cereal are intercropped and to determine the effect of agrochemicals on fertilizer use efficiency.

The economic returns from the exploitation of results such as these are massive One country which participated in a research programme on nitrogen fertilization of maize estimated that it benefited to the tune of US $36 million a year after its farmers had adopted the fertilizer placement practices found to be most efficient in the programme. In Sri Lanka, coconut palm production was increased with the use of *less* fertilizer. Additional savings are possible, as it has been estimated that 50% of the fertilizer used at present in all countries could be saved by improved practices based on sound research results.

**Alternative nutrient sources**

The ultimate solution to increasing requirements for inorganic fertilizers in food production is to replace fertilizers with other sources of nutrients which are less expensive, or are locally available. Nature has evolved associations by which certain plants can, in combination with appropriate micro-organisms, use part of the 80% of the atmosphere which is nitrogen gas ($N_2$) in their growth This utilization of $N_2$ gas by plants is called biological nitrogen fixation (BNF). Many countries have sources of natural rock phosphates which in certain soils, or under appropriate conditions, can replace phosphate fertilizers A special microbial/plant-root association, mycorrhiza, may allow a plant to exploit rock phosphates or forms of phosphorus and other soil nutrients which are unavailable to non-mycorrhizal plants. This association may one day be developed to be as important as BNF is today. Isotope techniques can play a role in all these types of research, but nitrogen fixation will be used as an example here.

Biological nitrogen fixation is difficult to measure because once nitrogen is in the plant, it is normally impossible to determine if it came from fertilizer, soil, or the atmosphere. Comparing the nitrogen taken up by a fixing plant to that of a non-fixing one gives an inaccurate estimate of BNF since plants, especially those belonging to different groups, frequently take up different amounts of soil nitrogen. Attempts to label gaseous $N_2$ with N-15 have given inconclusive results because the chamber containing the $N_2$ generally interferes with plant growth

The reduction of acetylene to ethylene by the micro-organisms associated with plant roots can be measured with great sensitivity Since the same enzyme system which reduced $N_2$ to $NH_4^+$ also reduces acetylene to ethylene, the technique has been used to estimate BNF Unfortunately, the technique has many limitations, the main one being that the estimate is only valid during the brief period and under the conditions which the measurement was made. Even with a large number of measurements, BNF cannot be accurately extrapolated over a growing season.

The staff of the Joint FAO/IAEA Division and the Agriculture Unit of the Agency's Seibersdorf Laboratory thus developed field-scale techniques by which BNF could be quantified over a growing season using isotopic techniques [7].

This technique has been used successfully in research co-ordinated by the Joint FAO/IAEA Division to quantify the increase in BNF due to various cultural practices. Phosphate fertilizer (105 kg P/ha) increased nitrogen-fixation by soybeans in Hungary from 7 to 71 kgN/ha. Improved strains of *Rhizobium* increased BNF from 79 to 102 kgN/ha by soybeans in India; improved inoculation techniques increased fixation by groundnuts in Ghana from 82 to 106 kgN/ha. Fertilizer nitrogen normally decreases BNF although total nitrogen uptake may be increased especially where BNF is not maximized. Surprisingly, however, BNF by broadbeans was increased by nitrogen fertilizer in Egypt, and although BNF was decreased in soybeans in Romania and Senegal, the results suggest that certain soybean varieties and certain strains of *Rhizobium* may be less sensitive to high levels of fertilizer nitrogen than

**Table 2. The use of $(NH_4)_2SO_4$ labelled with N-15 to measure nitrogen fixation by a legume crop**

| Crop and location | Labelled starter N applied (kg/ha) | Other treatments | N fixed (kg/ha) |
|---|---|---|---|
| Soybean | 40 | 0 kg P/ha at planting | 7 |
| Hungary | 40 | 35 kg P/ha at planting | 42 |
| | 40 | 70 kg P/ha at planting | 62 |
| | 40 | 105 kg P/ha at planting | 71 |
| Soybean | 20 | without inoculum | 79 |
| India | 20 | with inoculum | 102 |
| Groundnut | 15 | no inoculum | 82 |
| Ghana | 15 | inoculum on seed | 94 |
| | 15 | inoculum in soil | 100 |
| | 15 | inoculum in soil + B + Mo | 106 |
| Broadbean | 17 5 | – | 20 |
| Egypt | 35 | – | 26 |
| | 70 | – | 34 |
| | 140 | – | 33 |
| Soybean | 20 | *Rhizobium* strain $SO_7$ | 78 |
| Romania | 20 | *Rhizobium* strain $SO_{146}$ | 71 |
| | 20 | Multistrained inoculant | 107 |
| | 100 | *Rhizobium* strain $SO_{146}$ | 64 |
| | 100 | Multistrained inoculant | 41 |
| Soybean | 20 | Variety 44A73 | 33 |
| Senegal | 100 | Variety 44A73 | 19 |
| | 100 | Variety 4173 | 2 |
| | 100 | Variety Jupiter | 34 |

others (Table 2). It may therefore be possible to identify legume associations which can maximize BNF and not compete for fertilizer nitrogen when intercropped with a cereal.

Everyone is hoping for a scientific breakthrough which will lead to the development of non-leguminous crops which can obtain their nitrogen through BNF. Recent progress in recombinant-DNA transfer research has promised that such plants can eventually be developed. The Joint FAO/IAEA Division looks forward to using isotope techniques which have been proven to be effective research tools with legumes to maximize BNF with such new plant types when they become available

**References**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**Another experiment involving the application of fertilizer labelled with N-15 to check the most efficient way using fertilizer on rice.**