FAO SOILS BULLETIN 37

improved use of plant nutrients

FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS ROME

CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

FAO, in contact with the countries which it serves, has become increasingly aware of the very considerable loss of plant nutrients which still occurs when they are applied to the field, particularly in developing countries.

With this point in view, FAO organized an Expert Consultation in April 1977, with participants from countries consuming both a high and low quantity of fertilizer, to identify possibilities for a more intensive and rational utilization of the valuable plant nutrients in mineral and organic fertilizers, with emphasis on conditions in developing countries. The conclusions reached should serve interested countries as a guide for follow-up activities in the more rational use of plant nutrients at the research and practical level.

The programme of the Consultation included three main sections:

- Soils in relation to the efficiency of fertilizer use; this point dealt with the quantitative prediction of fertilizer demand, gains and losses of soil nitrogen and potassium efficiency under various conditions, and effects of secondary and micro nutrients, soil management and the role of soil testing in improved nutrient efficiency.
- Plants in relation to the efficiency of fertilizer use, including items of iron uptake and assimilation efficiency, cropping systems, methods of fertilizer application and the use of isotopes in studies on the efficient use of fertilizers.
- Fertilizer technology dealing with new aspects of compounding, coating and conditioning and other recent developments in relation to nitrogen, phosphorus and potassium fertilizers.

The Working Groups at the Consultation made a number of recommendations and suggested guidelines under the main headings: research, soil testing, fertilizer formulations and cultural practices. Under this item, the participants were convinced that in all these fields there are still ample possibilities for improvement and for making the costly and sometimes scarce plant nutrients more efficient and their use more economic.

This publication in the series of FAO Soils Bulletins is considered as a source of information and a guide for applied research and practice-oriented field activities, especially in developing countries. It is not, however, intended to be a publication for basic research.

FAO's Soil Resources, Management and Conservation Service will be pleased to deal with any queries in connection with this publication.

II. RECOMMENDATIONS

The efficient use of fertilizers and soil nutrients requires the knowledge of basic data on soil, climate and soil nutrient status; the basic soil data required are pH, texture, organic matter and soil type. Keeping these facts in mind, the Expert Consultation made the following recommendations:

A. RESEARCH

1. Fertilizer Nitrogen

It is recommended that investigations should especially be made on the problem of poor recovery of fertilizer nitrogen.

2. Soil Acidity

Research is needed to determine what economic methods exist for controlling the increase of soil acidity. Where higher quantities of mineral fertilizers are used, the need to balance the acidifying effects of the fertilizers should be recognized, and methods of balancing acidity established.

3. Plant Type

Plant characteristics have an important influence on the efficiency of fertilizer recovery. Root morphology, harvest index and other characteristics are involved. Selection of plant types should be made not only in terms of high response to fertilizers, but also in terms of efficient use of nutrients and their effects on acidity.

4. Cropping Systems

Fertilizer efficiency should be assessed in terms of the cropping system as a whole, including systems involving tillage and no tillage. There is a major need for studies of fertilizer efficiency in multiple cropping systems involving inter and relay cropping.

Tracer and other methods coupled with long term cropping system experiments are recommended for evaluating fertilizer efficiency.

5. Crop Residues

Fertilizer efficiency should be assessed in the context of conservation of all crop residues on or in the soil, and use of fertilizers should be developed taking into account methods for conservation of all residues arising in the cropping system.

6. Nitrogen Fixation

The requirement for nitrogen fertilizers in any cropping system can be reduced by including legumes among the crops, also pasture and cover crop legumes. Further research on methods to assess the contribution of nitrogen by the legumes to the system is needed. The effect of interaction between nutrients and other factors on nitrogen fixation is important and also requires further study.

Although it is realized that the requirement for nitrogen fertilizers may be reduced by non-symbiotic fixation, it is stressed that further basic research is required to establish the factors which control the contribution to a cropping system. The contribution by algae, for example, is important in paddy rice production, and attention should be given to proper fertilization of rice to allow the optimum contribution from biological nitrogen fixation.

B. SOIL TESTING

Measurements of soil nutrient status are usually required. In order of importance, they are:

i. macro-nutrients - N,P,K and, in special instances, Ca, Mg and S

ii. micro-nutrients - deficiency and toxicity need to be assessed.

1. Macro-Nutrients

N - Routine testing is not recommended, but appropriate tests should be made on research sites where N is being studied. Recommendations for N usage for particular crops should be based on yield response experiments, modified for soil type and climatic conditions, assuming that effective methods of application are used.

P - Routine testing is recommended. The method used should be selected on the basis of soil type related to its successful use on similar soil types. Local field experiments to evaluate the test are essential.

K - Recommendations are the same as for P, except that in the more arid areas, testing may not be necessary.

Ca- Routine pH measurements and crop requirements should be used as a guide to liming requirements.

2. Mg, S, and Micro-Nutrients

Routine testing is not generally recommended except in problem areas. Recommendations should be based on visual crop symptoms and, where possible, local experiments. In addition, plant analysis may supplement soil testing.

C. FERTILIZER FORMULATIONS

1. Rock Phosphate

Ground rock phosphate is often the cheapest form of phosphate fertilizer available and provides phosphorus, and also a liming effect, in soils of pH below 5. Some ground rock phosphates have been shown to give good crop response. Its use should always be considered when developing fertilizer programmes in areas where highly acid soils predominate. Partial acidulation may be necessary to assist early crop growth.

2. Controlled Release Fertilizers

Presently available slow release fertilizers are mostly uneconomic in current circumstances, except for highly specialized use. However, advantages in terms of fertilizer efficiency may be offered by "superpellet" or "briquette" techniques which have similar advantages to the mud ball technique. Further research on preparation of simple and compound fertilizers in this form is required, and studies of their efficiency for rice and other crops.

3. Compound Fertilizers

Where compound fertilizers are used, more stress should be put on checking that the nutrient ratios correspond to the actual requirements.

D. CULTURAL PRACTICES

1. Application Methods - Placement

These methods are suggested to increase fertilizer efficiency and minimize fertilizer loss:

N - Flooded rice - for pre-plant and at planting, place at 5-10 cm depth; subsequently, at panicle primordial initiation stage - broadcast; always use ammonium forming fertilizers.

- Other crops - apply so that the fertilizer is in the moist soil in the root zone when the plant needs it.

- Recovery of nitrogen fertilizers in flooded rice production is commonly less than 50% and further studies of application methods which may minimize losses through, e.g. denitrification, are needed in rice cultivation and also in the production of other crops.

P - All crops - with acidulated phosphates, recommendations are as for nitrogen on upland soils. In soils that immobilize P strongly, mixing with the soil should be restricted. With rock phosphates, finely divided forms should be used on acid soils and mixed thoroughly. Additional research on phosphate placement is needed to obtain more effective utilization by specific crops.

K - Recommendations are the same as those for acidulated phosphates for all crops.

Ca - On acid soils, liming materials should be mixed with the top soil. On saline soils, gypsum should be broadcast with subsequent irrigation.

Mg, S and Micro-Nutrients - Methods should be evaluated locally.

2. Timing

Fertilizer efficiency is very dependent on proper timing of application with respect to the development of the plant, particularly in the tropics. Too early application of nitrogen is particularly likely to lead to inefficiency in crop uptake.

3. Soil Acidity

In any fertilizer development programme, very careful consideration should be given to the longer-term effects likely to arise from acidification associated with increased removal of basic cations by crops, and the effects of the fertilizer. This is particularly important where fertilizers containing ammonium are used.

4. Soil Erosion

A major factor reducing the efficiency of fertilizer is soil erosion. In any fertilizer development programme it is essential that the cropping system should be established in such a way that erosion is controlled. Zero tillage with mulch practices have particular advantages in this respect in the humid tropics, and the importance of maintaining satisfactory levels of organic matter in some soils should be recognized.

5. Other Cultural Practices

Appropriate cultural practices, e.g. timely planting, have a major effect on efficiency of fertilizer use.

TRAINING

The need for intensified training of research and extension personnel is stressed in the field of efficient use of plant nutrient sources.

IV. WORKING PAPERS

Paper 1 PROBLEM AREAS AND POSSIBILITIES OF MORE EFFICIENT FERTILIZER USE

S.A. Barber

Purdue University, Lafayette, Indiana, U.S.A.

1. INTRODUCTION

Recent rises in the cost of fertilizer make it particularly important to use fertilizer nutrients as effectively as possible so that limited purchases of fertilizer will produce as large an increase in foodstuffs as possible.

This paper refers to some of the principles that determine efficiency of use of a fertilizer nutrient and suggests ways in which present practices may be changed in order to increase efficiency.

In the present context fertilizer efficiency is defined as the amount of increase in yield of the harvested portion of the crop per unit of fertilizer nutrient applied. Clearly it is dependent on the efficiency of recovery of the nutrient from the soil and the use to which it is put by the plant. While efficiency may often be highest at low rates of application and decrease as the rate is increased, the aspect to be examined is that of obtaining greater yields from the same rate of applied fertilizer by changing practices. Many of the details have been published by the American Society of Agronomy in Special Publication No.26 (Barber, 1976). Sections of this publication are summarized as follows.

2. RECOVERY AND EFFICIENCY OF USE OF PLANT NUTRIENTS IN THE SOIL

2.1 Current Efficiency of Fertilizer Uptake

The mobility of N in the soil usually results in a relatively high degree of efficiency of uptake (50% or more), so uptake is capable of being increased by a factor of about 2.

Phosphorous uptake by the first crop is usually below 10% and in still smaller amounts by subsequent crops. There is much scope for improvement.

Potassium uptake is intermediate between that of N and P at 20-40%.

2.2 Increasing Efficiency of Fertilizer Uptake by Crops

Nutrients reach the surface of the plant root by mass flow and diffusion. Mass flow provides much of the N but relatively little of the P and K. The distance that N can move by diffusion is much greater than that of P and K. The diffusion coefficients of N, P and K are fairly closely related to the efficiences of their uptake. Root hairs contribute more to P uptake than to K uptake as P diffuses less far than K.

2.3 Model for Evaluating Uptake

A mathematical model has been developed (Claassen and Barber 1975) by the use of which it is possible to study the effect and interaction of the main plant and soil parameters determining nutrient uptake.

2.4 Soil Factors Influencing Fertilizer Efficiency

The diffusion coefficient (Nye 1968) probably has a greater effect on the rate of nutrient supply to the plant than nutrient concentration in the soil solution and buffering capacity, but its magnitude is affected by buffering capacity and two other parameters.

2.5 Plant Factors that Influence Fertilizer Efficiency

Plant breeders may have some opportunity to change plant root systems so as to increase the efficiency of fertilizer use. Improvements possibly lie in the development of plants with higher nutrient uptakes from more concentrated soil solutions, a denser root system, more numerous and longer root hairs and, perhaps, with mycorrhizal infections (Gerdemann 1974) and more abundant root exudates (Riley and Barber 1971).

2.6 Flux Parameters that Influence Uptake Efficiency of each Nutrient

The root system has characteristics which are likely to favour the uptake of N,P and K individually. Desirable features are: for N, abundant roots with a high rate of N absorption; for P, an extensive root system with numerous long root hairs, and for K abundant roots at high density in the soil.

2.7 Modifying the Soil to Improve Fertilizer Efficiency

Modifications to improve P uptake include reduction of the buffering capacity to reduce adsorption and increase the diffusion coefficients, and adjusting the pH to reduce P fixation and increase the P concentration in the soil solution. K uptake can be improved by decreasing the buffering capacity.

2.8 Combining Plant and Soil Effects

Changing the method of placement of fertilizer holds some promise of improvement. Broadcasting P and K tends to lead to high fixation and high buffer capacity. An intermediate method of bands ploughed in is suggested (Barber 1974).

2.9 Efficiency of Fertilizer Use after Uptake

Examples were given of how planting date may affect the proportion of grain to straw without greatly changing total dry matter production, and of how timing of the application of fertilizer affects grain production.

2.10 Chemical Methods of Controlling Nutrient Forms and Influencing Efficiency

Nitrapyrin has been used to check the activity of *Nitrosomonas* and so extend the period during which ammonium nitrogen remains in that form and is not liable to leaching losses.

2.11 Reducing Nitrogen Need by Developing More Crops for Symbiotic Nitrogen Fixation

Somatic hybridization (Gamberg *et al* 1974) may one day enable non-leguminous crops to be bred which would be capable of fixing nitrogen.

3. DEVELOPING VARIETIES WITH MORE EFFICIENT FERTILIZER UPTAKE CHARACTERISTICS

Little research has been done on altering plant root systems so that they more effectively absorb applied or naturally occurring nutrients. In developing countries, it may be important to get efficient use of nutrients where soil levels are low. Some results of preliminary experiments with maize (Neilson, personal communication) are given in Table 1.

Table 1 DIFFERENCES BETWEEN MAIZE CULTIVARS IN ROOT PARAMETERS AFFECTING NUTRIENT UPTAKE

cv.	Root length (m) per gramme of		I_{max} 1/	C_{min} 2/
	Shoot	Root	cm^{-1} sec^{-1}	M
W65a	18.0	95.9	0.46	0.14
H84	7.9	48.6	0.76	0.29
A619	10.1	81.0	0.31	0.49

1/ The maximum rate roots will absorb P

2/ The concentration in solution at which net P uptake ceases.

Root length per gramme of root and per gramme of shoot varied widely, as did the maximum P absorption and the minimum concentration to which the roots could reduce the P in solution. While high I_{max} occurred with the least root length, the range present indicates a potential for developing more efficient cultivars.

In order to facilitate the breeding of new cultivars with greater ability to absorb nutrients, research is needed on matters such as the following: the degree of variability of root systems within a species; how the root system should be modified; the type of root system needed by various plant species; the biological mechanism within the plant that regulates the rate of nutrient absorption per unit area of root; the regulation of the rate and nature of root growth; the regulation of the incidence of root hair length and growth, and the determination of the degree of infection of roots with mycorrhiza.

Related to the same aim is the need for information on the physical and chemical properties of the soil that influence the extent and morphology of the root system and whether the soil can be modified to reduce its buffer capacity for P and K and increase the flux of nutrients to the root.

REFERENCES

Barber, S.A. A program for increasing the efficiency of fertilizers. Fert.
1974 Solutions 18(2): 24-25.

Barber, S.A. Efficient fertilizer use p.13-30. In F.L. Patterson (ed)
1976 Agronomic research for food. Spec. publ. No.26. Madison. American Society of Agronomy.

Claassen, N and Barber, S.A. A simulation model for nutrient uptake from soil
1975 by a growing plant root system. Agron. J. 68: 961-964.

Gamberg, O.L. et al Protoplast and cell culture methods in somatic hybridization
1974 in higher plants. Can.J.Genet. Cytol. 16: 737-750.

Gerdemann, J.W. Mycorrhizae. In E.W. Carson (Ed). The plant root and its environment, pp.305-319. University Press of Virginia, Charlottesville.

Nye, P.N. The use of exchange isotherms to determine diffusion coefficients in soil. Trans. 9th Int. Cong. Soil Sci. I: 117-126.

Riley, D and Barber, S.A. Effect of ammonium and nitrate fertilization on
1971 phosphorous uptake as related to root-induced pH changes at the root-soil interface. Soil Sci. Soc. Ama. Proc. 35: 301-306

Paper 2

FERTILIZATION DECISION MODEL - A SYNTHESIS OF SOIL AND PLANT PARAMETERS IN A COMPUTERIZED PROGRAMME

U. Kafkafi, B. Bar-Yosef and Aviva Hadas

Institute of Soil and Water, The Volcani Centre, Bet-Dagan, Israel

1. INTRODUCTION

The growth of plants depends on many factors such as water and nutrient supply, disease control, temperature and radiation. Assuming "optimum supply of water and nutrients" De Wit (1958) calculated the potential dry matter production (PDMP) in each world climatic zone. Although the potential yields are known, the actual yields everywhere are far less (Burringh et al 1975). The main problem is the practical application of the "optimum supply of water and nutrients" to various soil types and crops. The efforts needed to maintain optimum conditions are often so costly that achieving PDMP is uneconomic. In forage grasses, the harvested portion of the crop represents the total dry matter production (excluding the roots). For crops that grow continuously on the same field and are harvested periodically, the control and correction of their nutrient status can be accomplished by interpreting correctly their leaf analysis. A flow chart for the evaluation of the macronutrient status of grass plants and fertilization recommendations was suggested by De Wit et al (1963). For annual crops, fertilization decisions are taken before seeding and are usually based on soil tests (Olsen et al 1954; Esdaile and Colwell 1963; Sadan et al (1969) correlated with yield obtained during several years of field work. While such tests are good for the relatively non-mobile nutrients, phosphate and potassium (Bray 1963), no correlation for initial soil nitrogen has been established. More nitrogen than any other nutrient is taken up by plants (Epstein 1972), and its uptake is proportional to its concentration in the soil solution (Smith 1976). However, the nitrate concentration in the soil solution under a growing crop changes continuously owing to uptake by plants (Kafkafi and Halevy 1974), leaching by rainfall or irrigation (Levin 1964), by denitrification (Woldendorp 1963; Bar-Yosef and Kafkafi 1972; Volz et al 1976) and mineralization of organic nitrogen (Stanford and Smith 1972).

Before deciding to use a fertilizer, the farmer must know: (a) the probability of response to a particular nutrient in his field, for the crop he is planning to grow; (b) if fertilizer is needed, how much to add; (c) the kind of fertilizer needed and when to apply it. The integrated knowledge of soil science, plant nutrition and field experience is combined in the following fertilization model to create, in the soil, optimum conditions for plant growth.

2. THE MODEL

To prevent any stress during growth an optimum concentration of nutrients should be maintained in the soil solution throughout the uptake period. This is the main assumption of the model and it is supported by the work of Dijkshoorn et al (1968). Once the "optimum" levels of nutrients are determined and the permitted deviations from the optimum are known, good management for preventing nutrient stress is a matter of keeping the balance between losses and gains in the system. Losses are attributed to plant uptake, leaching by rainfall or irrigation, microbial and soil reactions. Gains are due to mineralization of organic matter and fertilization. The model contains therefore, two main aspects: (a) definition of "optimum" nutrient concentration, and (b) simulation of processes, mostly dynamic, which determine the concentration of the nutrient in the soil as a function of time and soil depth.

1/ Contribution 1977 Series No. 128-E.

At the time interval, in which the concentration deviates from the "optimum" more than permitted, a decision is made on the kind and amount of fertilizer to be applied.

Determination and Considerations of "optimum" Concentrations

2.1.1 The optimum N-NO_3 in soil solution

For plants grown in nutrient solution, Hoagland and Arnon (1950) reported a nutrient solution composition which has since been widely used. The nitrate concentration in Hoagland and Arnon's solution is 10 - 15 meq/litre (140 - 210 ppm N-NO_3).

The maximum growth rate of maize grown in the field was obtained when the concentration of nitrate in the soil solution was 10 ± 5 meq/l (Table 2). Nitrate in solution above that level caused a reduction in yields by reducing the phosphate concentration in the plants, probably by anionic competition, as demonstrated by De Wit et al (1963). The depression of phosphate uptake by high nitrate concentration was observed even at high levels of soil phosphate. This concentration of N-NO_3 was the optimum for wheat grown under saline conditions (Torres and Bingham 1973).

Table 2 EFFECT OF SOIL PHOSPHATE LEVEL ON NUMBER OF TILLERS AND SPIKELETS AND ON STRAW AND GRAIN YIELDS OF A SEMI-DWARF WHEAT WITH VARIOUS LEVELS OF NITROGEN FERTILIZATION

Nitrogen (kg N/1000m^2	No. of plants per m^2		No. of tillers per m^2 (incl.main stem)		No. of spikes per m^2		Grain yield (g/m^2)		Grain/straw %	
	Soil P(ppm)		Soil P(ppm)		Soil P(ppm)		Soil P(ppm)		Soil P(ppm)	
	4	32	4	32	4	32	4	32	4	32
0	236	212	250	250	229	223	111	122	36	38
3	236	216	292	368	230	242	239	245	38	39
6	226	197	319	537	239	290	294	415	39	38
12	241	204	322	634	260	355	351	505	40	37
24	220	220	361	761	282	383	343	510	40	32
S.E. for N	9.1		11.5		11.9		13.6		0.9	
S.E. for P	8.7		17.6		14.3		7.9		0.9	

Evaporation and transpiration may reduce the water content in a particular root zone to about 50% of field capacity before the next rainfall occurs or irrigation is applied. In such a case the nitrate concentration may be doubled, causing a reduction in yield. Taking the above into consideration, we chose the value of 100 ppm N-NO_3 in the soil solution as the optimum concentration that should be maintained during the main uptake period of most plants.

2.1.2 Concentration of N-NH_4 in the soil

Mineralization of soil organic matter and urea or ammonium fertilizers are the sources of N-NH_4 in soils.

The rate of nitrification of organic and mineral ammonium nitrogen is dependent mainly on C/N ratio, temperature and moisture tension (Standford and Smith 1972). The nitrification parameters 2/ used in our model are the same as those determined by Stanford and Smith (1972) for organic nitrogen which were found to operate in Israeli climatic conditions, and those of Frederick (1956), Sabey(1969) and Sabey et al (1956, 1959, 1969, 1971), for N-NH_4.

In the field, the concentration of ammonium N in the root zone is usually small. However, the use during the cold winter season of urea fertilizer as a top dressing, or combined with irrigation water applied daily for vegetable crops through trickle irrigation systems, can create regions in the root zone that are rich in ammonium. For such conditions the model should take into consideration the toxicity effects of ammonium uptake on plants (Kafkafi et al 1971; Van Tuil 1965). A limit for a maximum amount of ammonium in the medium is therefore imposed during the growing season; it is 20% of the total nitrate plus ammonium in the soil for plants which are known to be sensitive to ammonium uptake, e.g. tomato (Arnon 1937, Kafkafi et al 1971), tobacco, cucumber (Ingerstad 1973).

2.1.3 Considerations for phosphate

Phosphate is retained on the soil surface and only a small fraction of it is present in the soil solution. The plant takes its phosphate from the soil solution (Olsen and Kemper 1968). The distribution between the solution and the surface is usually determined by adsorption isotherms, the parameters of which can be used in predicting the diffusion of phosphate towards the adsorbing root (Bar-Yosef et al 1972). In order to use such parameters in predicting the needs for fertilizer application, information is required about the many parameters such as the functional relationship between phosphate diffusion coefficient (D_p) and moisture content and phosphate concentration. More information is also needed on the rate of uptake of a unit root length and the permeability coefficient as a function of tissue age and external concentration (Bar-Yosef 1971, and Olsen and Kemper 1968). In the meantime, this approach is being used only on a research scale.

The most widespread soil test for available phosphate for calcareous soils is the bicarbonate method suggested by Olsen et al (1954). A calibrated scale of extractable P is usually correlated with yield response and the level of P for the most economic application is suggested (Esdaile and Colwell 1963).

The bicarbonate test was found to be reliable in predicting whether there is any chance of a response to additional phosphate fertilizer (Sadan et al (1969). The test as such cannot tell the farmer how much fertilizer to apply to raise his soil test value from level x to level y. Kafkafi et al(1968) have shown that the recovery

---

2/ The flow chart in Annex 1 contains only first approximations. The operating model contains the FMIN and FNIT equations specified in Annexes 3 and 4 respectively.

of applied phosphate by the bicarbonate soil test is a function of the soil surface area. Using this parameter and knowing the recovery percentage, one can calculate the amount of phosphate that should be applied to a field to raise the soil test value to a predetermined level. The surface area is not a common soil test parameter that is usually measured in advisory service laboratories.

For the soils of Israel in which montmorillonite is the dominating clay, Banin and Amiel (1969) have found a linear relationship between the soil surface area and the hygroscopic water content. Combining the information provided in the last two cited works enabled the use of a simply determined soil parameter in the calculation of the reocvery percentage of applied phosphate for most of the soils of Israel.

2.1.4 The optimum level of extractable P

Field response experiments and a permenant fertilization plot experiment (Bar-Yosef and Kafkafi 1972, Kafkafi and Halevy 1974) have demonstrated that the level of bicarbonate P that should be maintained in the soil is dependent on the crop, climate and nitrogen level.

Table 3 EFFECT OF SOIL PHOSPHATE LEVEL ON NUMBER OF TILLERS AND SPIKELETS AND ON STRAW AND GRAIN YIELDS OF A SEMI-DWARF WHEAT WITH VARIOUS LEVELS OF NITROGEN FERTILIZATION

Nitrogen (kg N/1000m^2)	No. of plants per m^2 Soil P(ppm)		No. of tillers per m^2 (incl.main stem) Soil P(ppm)		No. of spikes per m^2 Soil P(ppm)		Grain yield (g/m^2) Soil P(ppm)		Grain/Straw % Soil P(ppm)	
	4	32	4	32	4	32	4	32	4	32
0	236	212	250	250	229	223	111	122	36	38
3	236	216	292	368	230	242	239	245	38	39
6	226	197	319	537	239	290	294	415	39	38
12	241	204	322	634	260	355	351	505	40	37
24	220	220	361	761	282	383	343	510	40	32
S.E. for N	9.1		11.5		11.9		13.6		0.9	
S.E. for P	8.7		17.6		14.3		7.9		0.9	

For wheat, where rainfall is slight during the ripening period, an excess of phosphate is dangerous as it produces more sterile tillers (Table 3) which deplete the water essential for development of the grain. This is given as an example to stress the point that the value of an "optimum" soil test may vary with every change in the growing conditions. The model should therefore allow differentiation between the parameters that may change from crop to crop and region to region, and the more stable and permanent relationships based on fertilizer reaction in the soil. The bicarbonate extractable optimum P level determined for wheat in the Negev of Israel

(200–350 mm annual precipitation) was 6 ppm (Sadan <u>et al</u> 1969), and for the northern part of the country (600–800 mm) it was 10–12 ppm. For tomatoes for processing, however, the levels are much higher: 24 ppm for hot and 35 ppm for cold periods of seeding (Feigin and Sagiv 1975). Once the specific requirements of a plant are known (termed here BICarbonate OPtimum), the quantity of phosphatic fertilizer needed to raise the soil level to that optimum can be calculated, based on the soil test level. 2/

2.1.5 Considerations for potassium

The concentration of potassium in the soil solution is in rapid equilibrium with the exchangeable potassium. The roots can take up potassium from very low concentrations (Epstein 1972).

The rate at which the potassium is taken up by intensively grown crops (Feigenbaum and Kafkafi 1972) is faster than the rate of potassium release from non-exchangeable sites. For practical reasons only the exchangeable potassium just before seeding is considered as an immediate potential supplier of potassium to the plant. No response to potassium was found when the exchangeable potassium percentage (EPP) of the cation exchange capacity (CEC) was higher than 0.5 in clay soils or 7 in sandy soils.

Potassium is taken up by plants in large quantities during their vegetative growing period. The total amount of potassium removed by a particular crop depends on the harvested part of the plant. Alfalfa grown in Israel is harvested every 28–35 days for 9–11 cuts a year, and can remove 850 kg K/ha (Kafkafi <u>et.al</u> 1977) every year. Wheat can contain as much as 500 kg K/ha at ear emergence (Fig.1), but about 60% of it returns to the soil at harvest time.

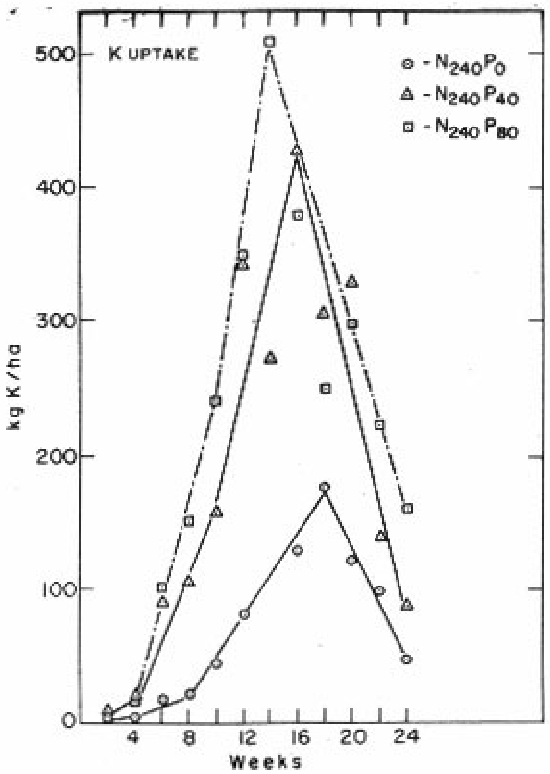


Fig. 1 Potassium uptake by wheat throughout the growing season

The quantity of K removed by the crop should not be limited by K in the soil. It is obvious, therefore, that a sandy soil with a CEC of 5 meq/100 g needs more frequent potassium addition than a clay soil with a CEC of 50, provided the two soils contain the same type of clay material.

2.1.6 Exchangeable potassium percentage optimum (EPPOP) [3]

The above considerations and the linear relationship that was found by Banin and Amiel (1969) between the CEC and the hygroscopic moisture content (as a percentage of air-dried soil - TETAID) resulted in the following equation:

$$\text{EPPOP} = 7 \times \text{TETAID}^{-1}$$

2.1.7 Plant parameters

The amount of nutrients required by a plant to reach the potential yield can be calculated. However, the rate of uptake and the exact time period in which the uptake occurs is unique for each crop. The nutrient uptake curves as a function of time are essential information in planning accurate fertilization. Data have been published for Israel on maize (Bar-Yosef and Kafkafi 1972), wheat (Kafkafi and Halevy 1974), and cotton (Halevy 1976). The importance of this information increases as one starts to combine irrigation and fertilization by means of trickle irrigation. In such systems it is possible to supply daily the exact amount of fertilizers needed and to prevent leaching of nitrate. The other plant parameter which must be known is the effective depth of the root zone and its changes during the growing season. Such information is continuously being accumulated (Kafkafi et al 1965, Sagiv et al 1974).

In most annual crops 80% of the root volume is restricted to the upper 50 cm of soil. For taproot crops like cotton and tomato, the roots may take up nitrogen from deep layers at the end of the season. Therefore, the effective root depth is a time-dependent parameter.

2.1.8 Fertilization considerations

The optimal concentrations are calculated to prevail on seeding day. The programme then checks at pre-set time intervals the gains and losses in the system. If the losses due to uptake by plant or other factors exceed the permitted deviation from the optimum, the amount of fertilizer needed to restore the optimum conditions is calculated and printed.

Nitrate nitrogen requires frequent additions owing to its high mobility in soil and its uptake by plants in large quantities. Our experience indicates that lowest permitted concentration is 50 and the highest is 250 ppm $N\text{-}NO_3$. Below and above these values plant growth may slow down. The P and K fertilizers can often be applied during soil preparation before seeding. However, in sandy soils top dressings of these fertilizers are sometimes required, especially if trickle irrigation is used and a limited root volume develops (Bar-Yosef 1976).

The flow chart in Annex 1 presents the frame and first approximations in our approach. A more detailed and sophisticated programme has been written and is currently being checked under field conditions.

---

[3] See Annex 1, first page.

At present the main advantage of the fertilization model is to force the experimenter to quantify his parameters and to plan future experiments to learn the permitted deviations from the optimum without causing drastic reductions in yields. Such a tool can help us in more efficient utilization of plant nutrients in any specific combination of local conditions of soils and crops.

REFERENCES

Arnon, D.I. Ammonium and nitrate nutrition of barley at different seasons in
1937 relation to hydrogen ion concentration, manganese, copper and oxygen
supply. Soil Sci. 44: 91-121.

Banin, A and Amiel A. A correlative study of the chemical and physical
1969 properties of a group of natural soils of Isreal. Geoderma 3: 185-198.

Bar-Yosef, B. Fluxes of Ca and P into intact corn roots and their dependence on
1971 solution concentration and root age. Pl. Soil 35: 589-600.

Bar-Yosef, B. Effects of various trickle irrigation and fertilization regimes on
1976 nutrient and water distribution in two sandy soils,and nutrient uptake
by tomato plants. Agric. Res. Org, Bet Dagan Pamph. 16. 161.

Bar-Yosef, B and Kafkafi, U. Rates of growth and nutrient uptake of irrigated
1972 corn as affected by N and P fertilization. Soil Sci. Soc. Amer. Proc.
36: 931-936.

Bar-Yosef, B., Bresler, E. and Kafkafi, U. Uptake of P by plants growing under
1972 field conditions. II. Computed and experimental results for corn
plants. Soil Sci. Soc. Amer. Proc. 36: 789-794.

Bray, R.H. Confirmation of the nutrient mobility concept of soil plant
1963 relationships. Soil Sci. 95: 124-130.

Burringh, P., van Heemyt, H.D.J. and Starring, G.S. MOIRA: A model of
1975 international relations in agriculture. The absolute maximum food
production of the world. Third ASA Symp. on Global Modelling (Food and
Agriculture), Luxemburg.

Dijkshoorn, W., Lathwell, D.J. and de Wit, C.T. Temporal changes in carboxylate
1968 content of ryegrass with stepwise changes in nutrition. Pl. Soil 29:
369-390.

Epstein, E. Mineral utilization of plants, New York, Wiley.
1972

Esdaile, R.J. and Colwell, J.D. Assessing economic rates of phosphatic
1963 fertilizer application for wheat in northern N.S.W. by soil analysis.
C.S.I.R.O. Agric. Gaz. 74: 282-284.

Feigenbaum, Sala and Kafkafi, U. The effect of illite content in soils on the
1972 potassium supply to plants. In Potassium in Soil. 9th Coll. Int.
Potassium Inst., 15 July 1972, Landshut. pp. 109-116.

Feigin, A, and Sagiv, B. The response of tomatoes for processing to N and P
1975 fertilization. Prelim, Rep. Agric. Res. Org., Bet Dagan No.750. (In
Hebrew).

Frederick, L.R. The formation of nitrate from ammonium nitrogen in soils:
1956 I. Effect of Temperature. Soil Sci. Soc. Amer. Proc. 20: 496-500.

Halevy, J. Growth rate and nutrient uptake of two cotton cultivars grown under
1976 irrigation. Agron. J. 68: 701-705.

Hoagland, D.R. and Arnon, D.I. The water-culture method for growing plants
1950 without soil. Calif. Agric. Exp. Stn. Circ. No. 347 (rev.).

Ingerstad, T. Mineral nutrient requirement of cucumber seedlings. Plant
1973 Physiol. 52: 332-338.

Kafkafi, U. and Halevy, J. Rates of growth and nutrient consumption of semi-
1974 dwarf wheat. Trans. 10th Int. Cong. Soil Sci., Moscow 4: 137-143.

Kafkafi, U., Hadas, Aviva and Hagin, J. The effect of soil surface area and time
1968 of contact on the extraction of phosphate from superphosphate by soil tests and test plants. Agrochemica 12: 231-239.

Kafkafi, U., Walterstein, I. and Feigenbaum, Sala. Effect of potassium nitrate
1971 and ammonium nitrate on the growth, cation uptake and water requirement of tomato grown in soil culture. Israel J. Agric. Res. 21: 13-30.

Kafkafi, U. <u>et. al.</u> Root activity of dryland sorghum as measured by radio-
1965 phosphorus uptake and water consumption. <u>In</u> Isotopes and radiation in soil-plant nutrition studies, Int. Atomic Energy Agency, Vienna, pp. 481-488.

Kafkafi, U. <u>et al.</u> Studies on fertilization of field-grown alfalfa. 1. Effect
1977 of potassium source and time of application. Pl. Soil 46(1): 165-173.

Levin, I. Movement of added nitrates through soil columns and undisturbed soil
1964 profiles. Trans. 8th Int. Cong. Soil Sci., Bucharest 4: 1011-1021.

Olsen, S.R. and Kemper, D.W. Movement of nutrients to plant roots. Adv. Agron.
1968 29: 91-151.

Olsen, S.R. <u>et al.</u> Estimation of available phosphorus in soils by extraction with
1954 sodium bicarbonate. U.S.Dep. Agric. Circ. No. 939.

Parker, D.T. and Larson, W.E. Nitrification as affected by temperature and
1962 moisture content of mulched soils. Soil Sci. Soc. Amer. Proc. 26: 238-242.

Sabey, B.R. Influence of soil moisture tension on nitrate accumulation in soils.
1969 Soil Sci. Amer. Proc. 33: 263-266.

Sabey, B.R. and Johnson, D.D. Effect of soil moisture tension on nitrate
1971 accumulation in Drummer silty clay loam. Soil Sci. Soc. Amer. Proc. 35: 848-850.

Sabey, B.R. <u>et al.</u> Influence of temperature on nitrification in soils. Soil
1956 Sci. Soc. Amer. Proc. 20: 357-360.

Sabey, B.R., Frederick, L.R. and Bartholomew, W.V. The formation of nitrate
1959 from ammonium nitrogen in soils. III. Influence of temperature and initial population of nitrifying organisms on the maximum rate and delay period. Soil Sci. Soc. Amer. Proc. 23: 462-465.

Sabey, B.R., Frederick, L.R. and Bartholomew, W.V. The formation of nitrate from
1969 ammonium nitrogen in soils. IV. Use of the delay and maximum rate phases for making quantitative predictions. Soil Sci. Soc. Amer. Proc. 33: 276-278.

Sadan, D., Machol, D. and Kafkafi, U. Soil tests for fertilizer recommendations
1969 under extensive conditions. In Transition from extensive to intensive agriculture with fertilizers. pp. 277–280. Berne, International Potash Institute.

Sagiv, B. et al. Combined irrigation and fertilization of tomatoes grown on sand
1974 dunes. Symposium Israel-France. Agric. Res. Org. Bet Dagan Spec. Publ. No. 39.

Smith, O.L. Nitrogen, phosphorus and potassium utilization in the plant soil
1976 system: An analytical model. Soil Sci. Soc. Amer. Proc. 40: 704–714.

Stanford, G. and Smith, S.J. Nitrogen mineralization potentials of oils. Soil
1972 Sci. Soc. Amer. Proc. 36: 465–472.

Stanford, G., Frere, M.H. and Schwaninger, D.H. Temperature coefficient of soil
1973 nitrogen mineralization. Soil Sci. 115: 321–323.

Stanford, G. and Epstein, E. Nitrogen mineralization water relations in soils.
1974 Soil Sci. Soc. Amer. Proc. 38: 103–107.

Torres, C.B. and Bingham, F.T. Salt tolerance of Mexican wheat: 1. Effect of
1973 NO_3 and CaCl on mineral nutrition, growth and grain production of four wheats. Soil Sci. Soc. Amer. Proc. 37: 711–715.

Van Tuil, H.D.W. Organic salts in plants in relation to nutrition and growth.
1965 Cent. Agr. Publ. Doc., Wageningen. Agric. Res. Rep. No. 657.

Volz, M.G. et al. Soil nitrate loss during irrigation: Enhancement by plant roots.
1976 Agron. J. 68: 621–627.

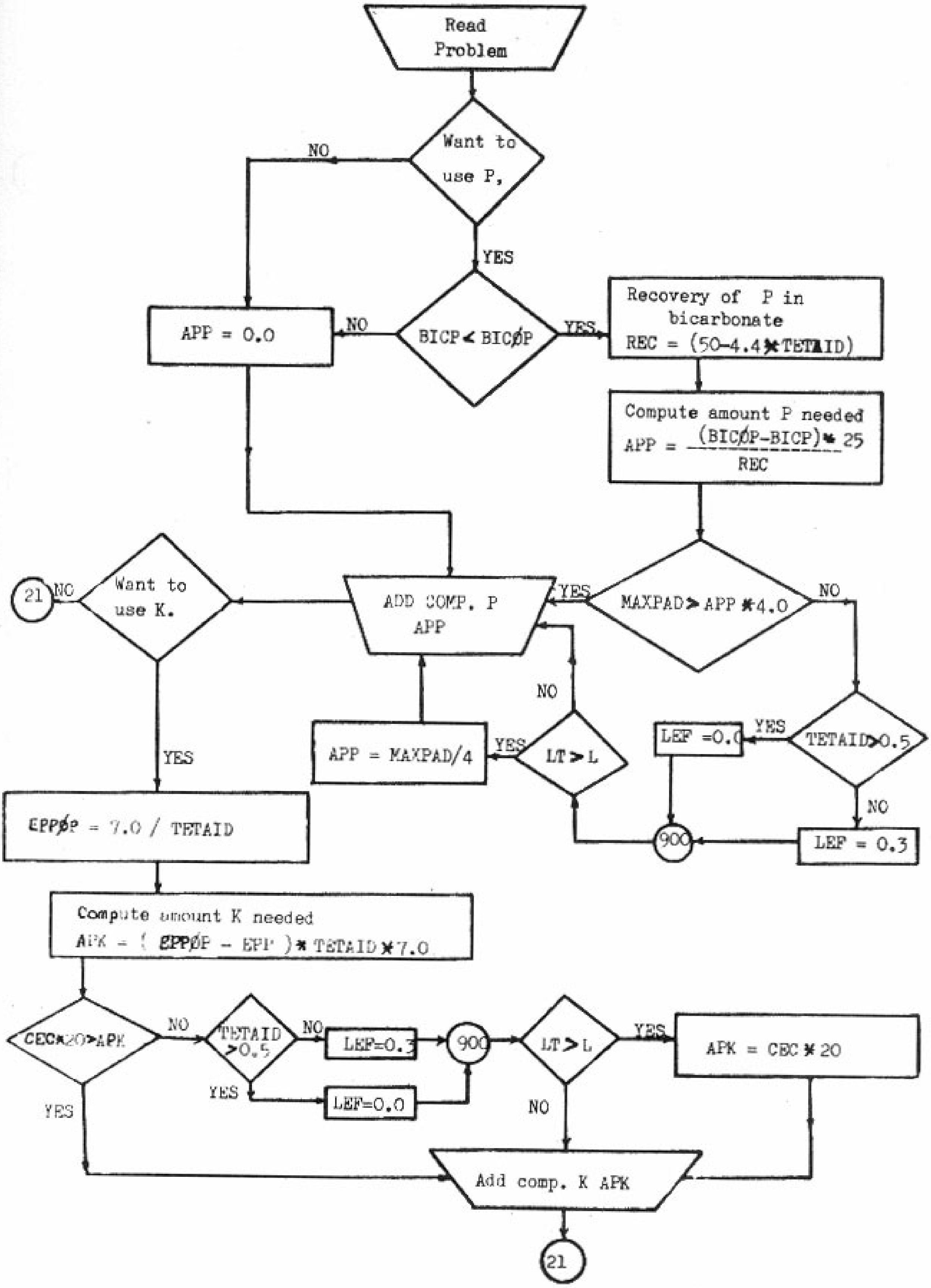
Wit, C.T. de Transpiration and crop yields. Versl. Landbouwk Onderz 64.6
1958 Wageningen.

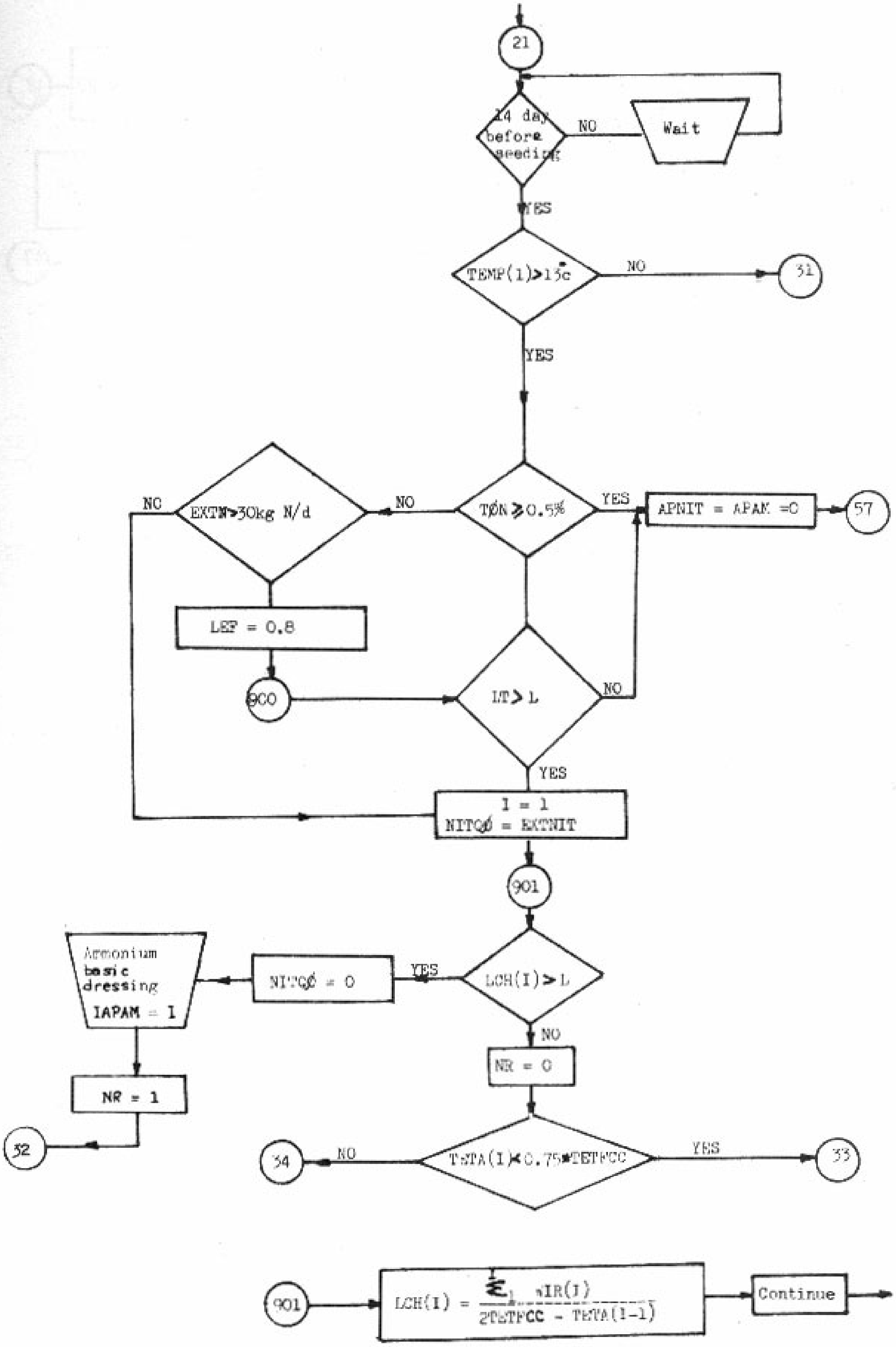
Wit, C.T. de, Dijkshoorn, W. and Noggle, J.C. Ionic balance and growth of plants.
1963 Versl. Landbouk Onderz 69.15 Wageningen.

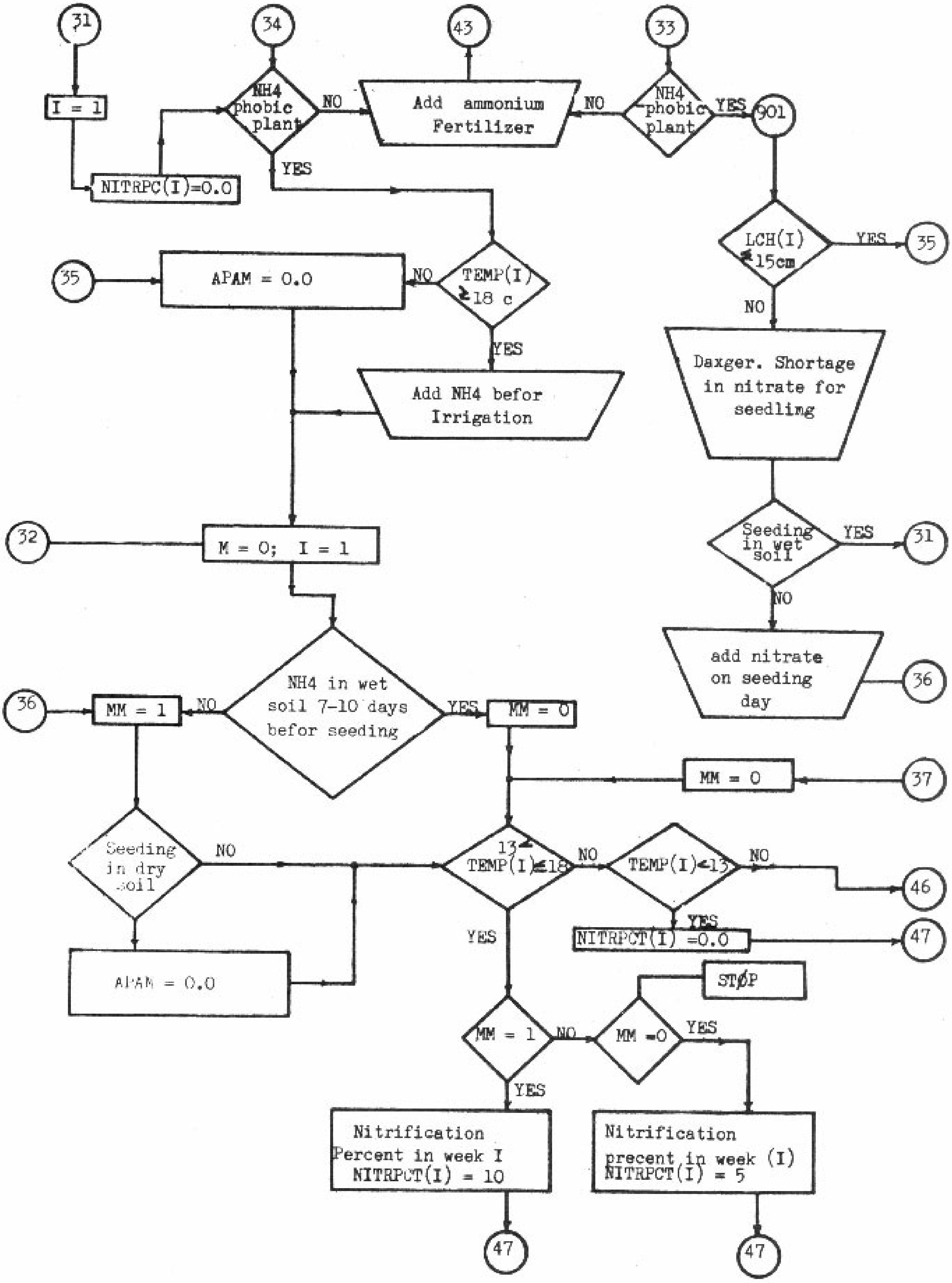
Woldendorp, J.W. The influence of living plants on denitrification. Meded.
1963 Landbhoogesch. Wageningen 63(13): 1–100.

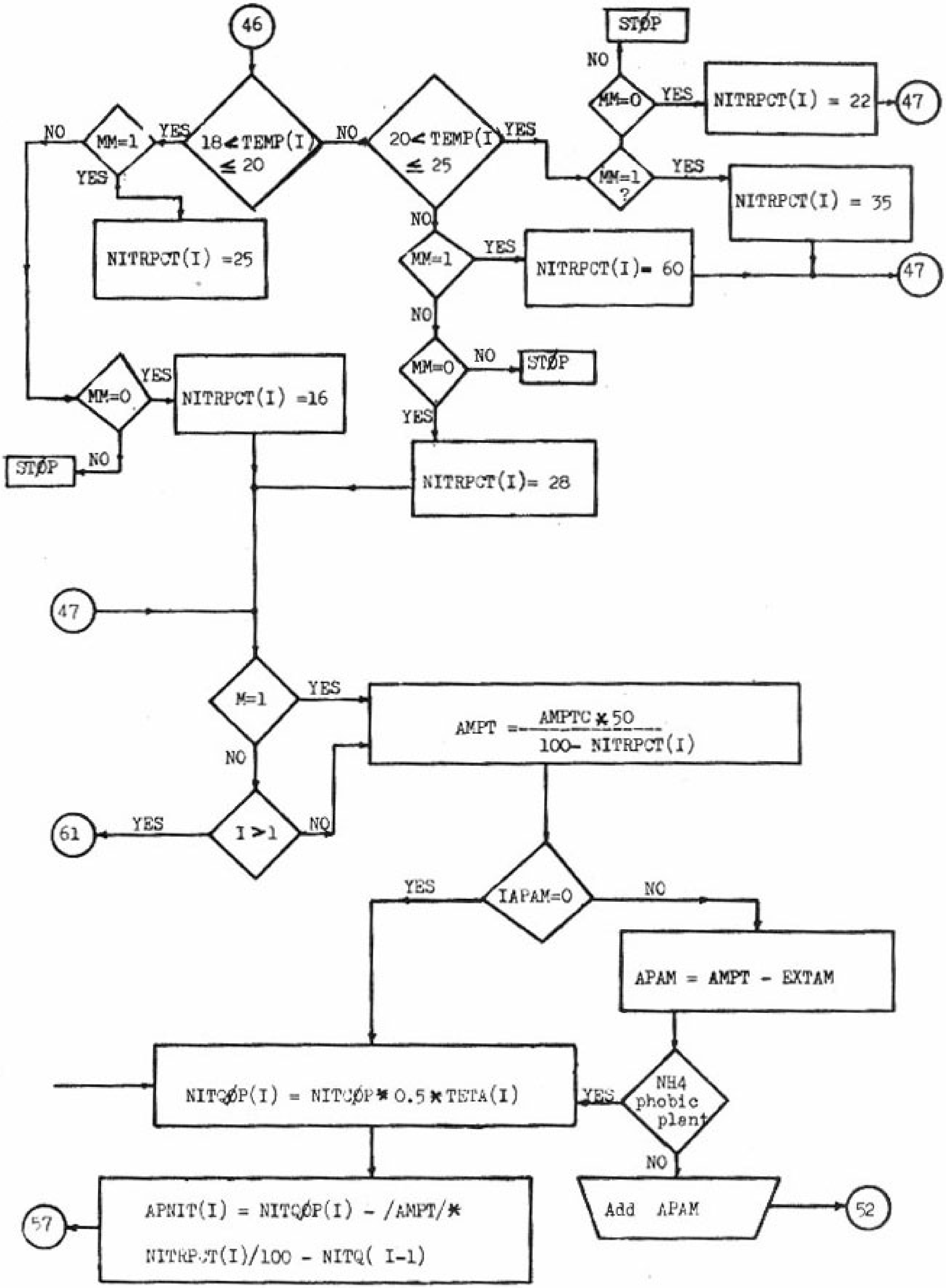
Annex 1 to Paper 2

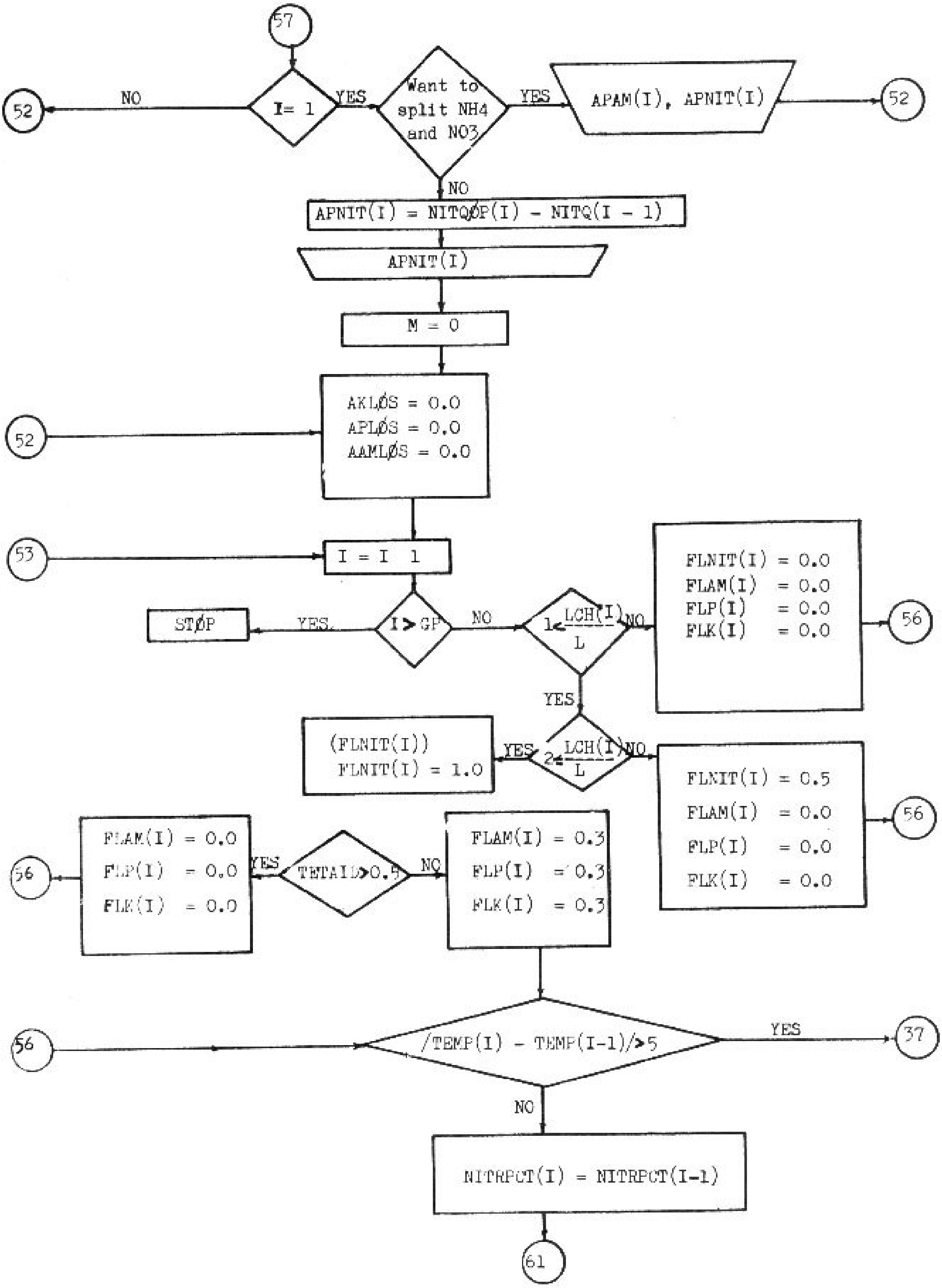
Fertilization Consideration Flow Chart

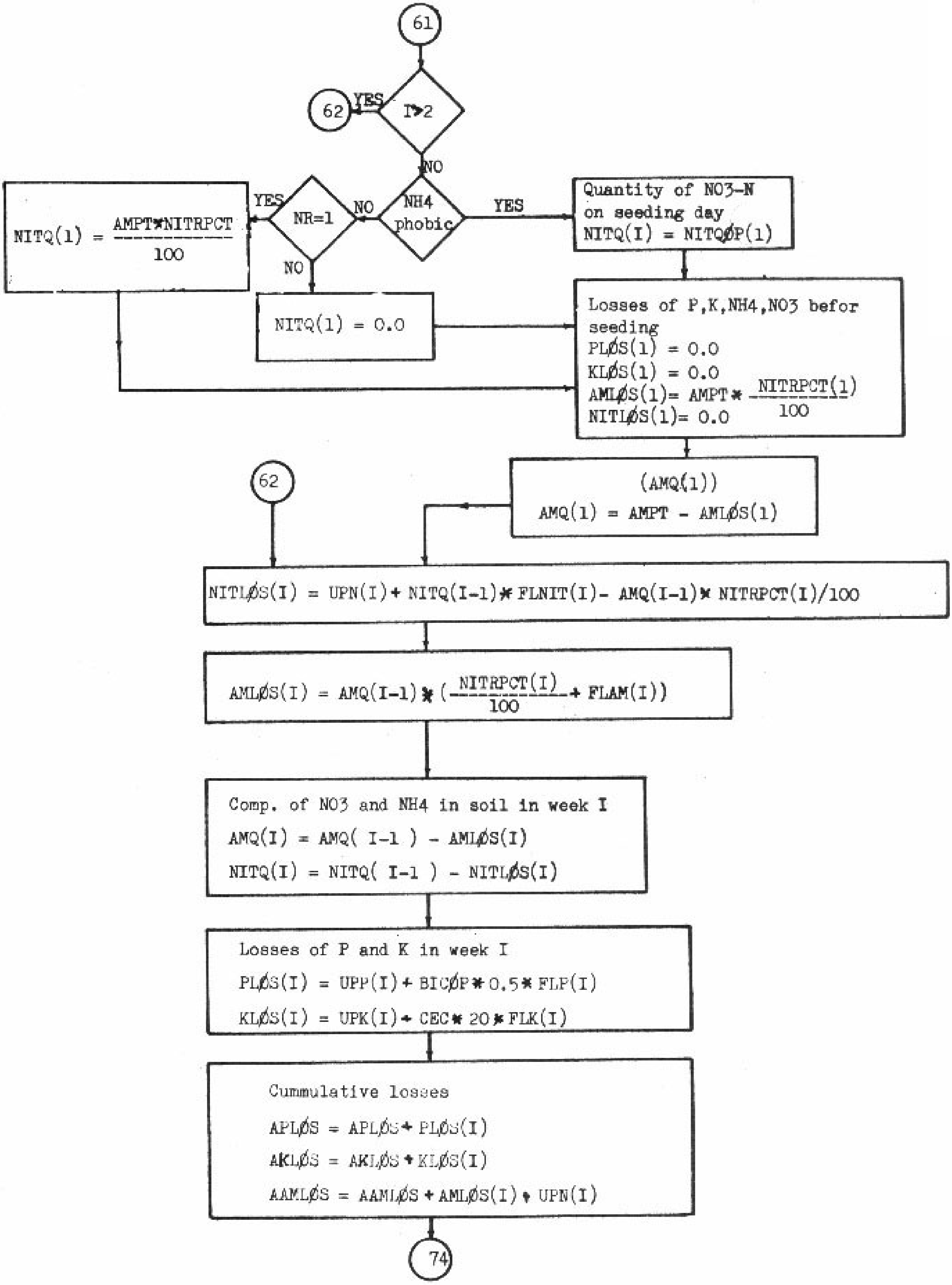


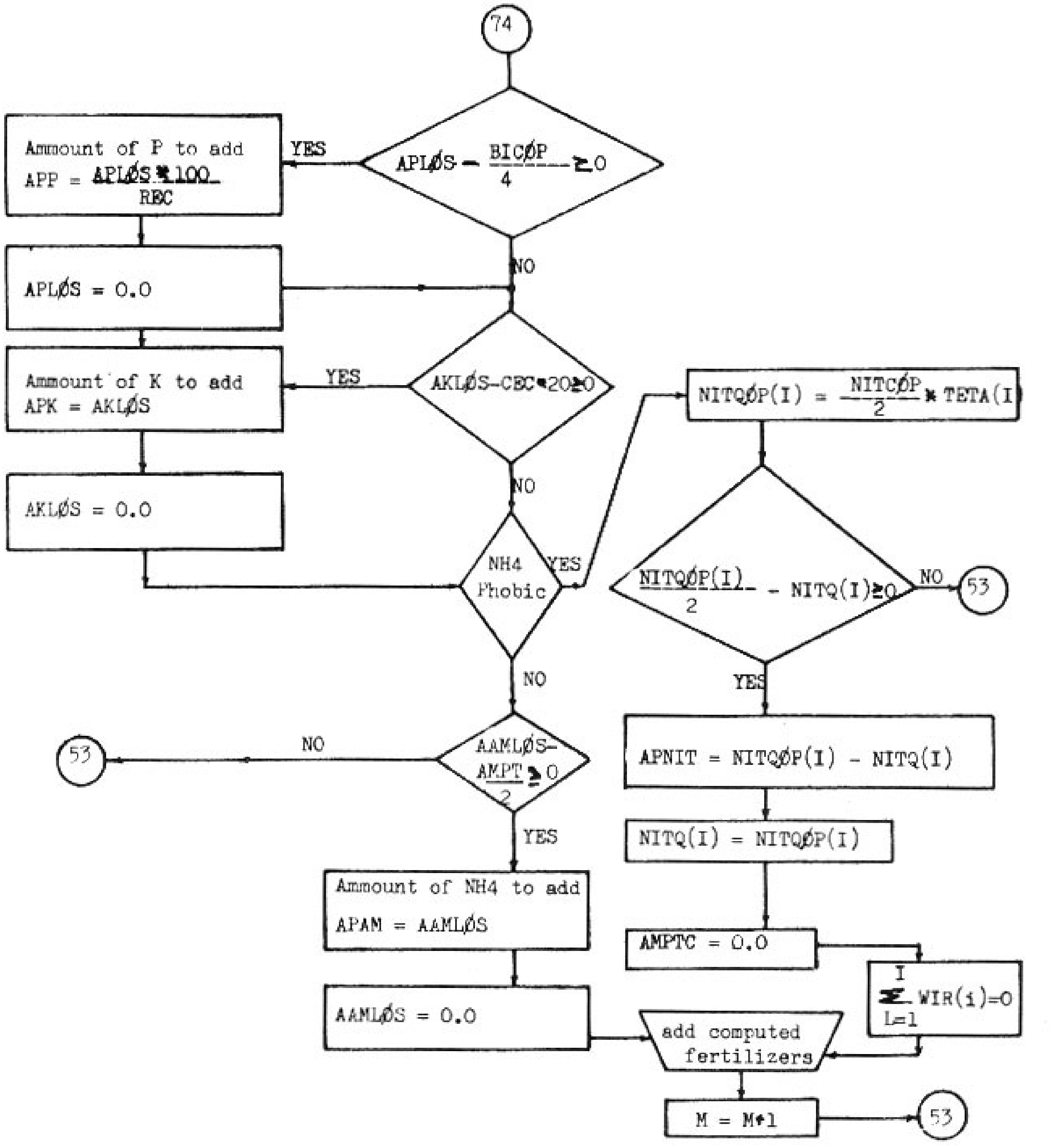

21
14 day before seeding
NO
Wait
YES
TEMP(1)>13c
NO
31
YES
TØN ≥ 0.5%
YES
APNIT = APAM =0
57
NO
EXTM>30kg N/d
NO
LEF = 0.8
900
LT > L
NO
YES
I = 1
NITQØ = EXTNIT
901
LCH(I) > L
YES
NITQØ = 0
Ammonium basic dressing
IAPAM = 1
NR = 1
32
NO
NR = 0
TETA(I)< 0.75*TETFCC
NO
34
YES
33
901
LCH(I) = Σ_1 NIR(I) / 2TETFCC - TETA(I-1)
Continue


31
I = 1
NITRPC(I)=0.0
34
NH4 phobic plant
NO
YES
43
Add ammonium Fertilizer
33
NH4 phobic plant
NO
YES
901
LCH(I) ≤ 15cm
YES
35
NO
Daxger. Shortage in nitrate for seedling
Seeding in wet soil
YES
31
NO
add nitrate on seeding day
36
35
APAM = 0.0
NO
TEMP(I) ≥ 18 c
YES
Add NH4 befor Irrigation
32
M = 0; I = 1
NH4 in wet soil 7-10 days befor seeding
36
MM = 1
NO
YES
MM = 0
MM = 0
37
Seeding in dry soil
NO
APAM = 0.0
13 ≤ TEMP(I) ≤ 18
NO
TEMP(I) < 13
NO
46
YES
NITRPCT(I) =0.0
47
YES
STØP
MM = 1
NO
MM =0
YES
YES
Nitrification Percent in week I NITRPCT(I) = 10
Nitrification precent in week (I) NITRPCT(I) = 5
47
47


46
18 ≤ TEMP(I) ≤ 20
YES
MM=1
NO
YES
NITRPCT(I) =25
NO
20 < TEMP(I) ≤ 25
YES
STØP
NO
MM=0
YES
NITRPCT(I) = 22
47
MM=1 ?
YES
NITRPCT(I) = 35
NO
MM=1
YES
NITRPCT(I)= 60
47
NO
MM=0
NO
STØP
YES
NITRPCT(I)= 28
MM=0
YES
NITRPCT(I) =16
NO
STØP
47
M=1
YES
AMPT = AMPTC * 50 / 100- NITRPCT(I)
NO
I > 1
NO
YES
61
IAPAM=0
YES
NO
APAM = AMPT - EXTAM
NITQØP(I) = NITCØP * 0.5 * TETA(I)
YES
NH4 phobic plant
NO
Add APAM
52
APNIT(I) = NITQØP(I) - /AMPT/* NITRPCT(I)/100 - NITQ(I-1)
57


57
I= 1
NO
52
YES
Want to split NH4 and NO3
YES
APAM(I), APNIT(I)
52
NO
APNIT(I) = NITQ0P(I) - NITQ(I - 1)
APNIT(I)
M = 0
52
AKL0S = 0.0
APL0S = 0.0
AAML0S = 0.0
53
I = I 1
STOP
YES
I > GP
NO
1< LCH(I)/L
NO
FLNIT(I) = 0.0
FLAM(I) = 0.0
FLP(I) = 0.0
FLK(I) = 0.0
56
YES
(FLNIT(I))
FLNIT(I) = 1.0
YES
2< LCH(I)/L
NO
FLNIT(I) = 0.5
FLAM(I) = 0.0
FLP(I) = 0.0
FLK(I) = 0.0
56
56
FLAM(I) = 0.0
FLP(I) = 0.0
FLK(I) = 0.0
YES
TETAIL>0.5
NO
FLAM(I) = 0.3
FLP(I) = 0.3
FLK(I) = 0.3
56
/TEMP(I) - TEMP(I-1)/>5
YES
37
NO
NITRPCT(I) = NITRPCT(I-1)
61


61
I>2
YES
62
NO
NH4 phobic
YES
Quantity of NO3-N on seeding day
NITQ(I) = NITQØP(1)
NO
NR=1
YES
NITQ(1) = AMPT*NITRPCT / 100
NO
NITQ(1) = 0.0
Losses of P,K,NH4,NO3 befor seeding
PLØS(1) = 0.0
KLØS(1) = 0.0
AMLØS(1)= AMPT* NITRPCT(1) / 100
NITLØS(1)= 0.0
62
(AMQ(1))
AMQ(1) = AMPT - AMLØS(1)
NITLØS(I) = UPN(I)+ NITQ(I-1)* FLNIT(I)- AMQ(I-1)* NITRPCT(I)/100
AMLØS(I) = AMQ(I-1)* (NITRPCT(I) / 100 + FLAM(I))
Comp. of NO3 and NH4 in soil in week I
AMQ(I) = AMQ(I-1) - AMLØS(I)
NITQ(I) = NITQ(I-1) - NITLØS(I)
Losses of P and K in week I
PLØS(I) = UPP(I)+ BICØP* 0.5* FLP(I)
KLØS(I) = UPK(I)+ CEC* 20* FLK(I)
Cummulative losses
APLØS = APLØS+ PLØS(I)
AKLØS = AKLØS+ KLØS(I)
AAMLØS = AAMLØS+ AMLØS(I)+ UPN(I)
74


74
APLØS − BICØP/4 ≥ 0
YES
Ammount of P to add
APP = APLØS*100/REC
APLØS = 0.0
NO
AKLØS−CEC*20≥0
YES
Ammount of K to add
APK = AKLØS
AKLØS = 0.0
NO
NH4 Phobic
YES
NITQØP(I) = NITCØP/2 * TETA(I)
NITQØP(I)/2 − NITQ(I)≥0
NO
53
YES
APNIT = NITQØP(I) − NITQ(I)
NITQ(I) = NITQØP(I)
AMPTC = 0.0
Σ (L=1 to I) WIR(i)=0
NO
53
AAMLØS−AMPT/2 ≥ 0
YES
Ammount of NH4 to add
APAM = AAMLØS
AAMLØS = 0.0
add computed fertilizers
M = M+1
53


900
LT = LEF * (Σ (I=1 to I) WIR(I) − L* TETFC (1 − FPM))/TETFC
Continue

Annex 1 to Paper 2

The parameters and their units, in their order of appearance in the flow chart.

Parameter	Meaning	Unit	Source
BICP	Bicarbonate-soluble P in soil	ppm P	Soil test
BICOP	Optimum concentration of bicarbonate-soluble P for a particular crop	ppm P	Previous knowledge Soil test
TETAID	Hygroscopic water content	percent	Soil test
MAXPAD	Maximum phosphate adsorption	ppm P	Adsorption isotherm
GP	Growth period (benefit of fertilization)	week	Nutrient uptake curve
I	Index (number of weeks before seeding)	week	
WIR (I)	Weekly irrigation or rainfall in the Ith week	cm	Measurement
TETFC	Volumetric moisture content at field capacity	unitless	Soil test
FMP	Volumetric moisture content at which irrigation must be added		Programmer decision
L	Effective root depth	cm	Measurement
EPP	Exchangeable Potassium Percentage	percent	Soil test
CEC	Cation Exchange Capacity	meq/100g	Soil test
TEMP (I)	Average soil temp. at 20 cm depth in Ith week	°C	Measurement
TOTN	TOTal soil Nitrogen content	percent	Soil test
EXTN	EXTractable Nitrogen (ammonium + nitrate)	kg/d[1] N	Soil test
EXTAM	EXTractable AMmonium-N	kg/d N	Soil test
EXTNIT	EXTractable NITrate-N	kg/d N	Soil test
AMPTC	AMmonium Permitted Concentration in soil	ppm	Predetermined
NITCOP	NITrate Concentration OPTimum in soil solution	ppm	Predetermined
TETA (I)	Volumetric water content of soil in the Ith week	fraction	Measurements or estimation according to transpiration
UPN (I)	UPtake of Nitrogen in Ith week	kg/d N	Nutrient uptake curve
UPP (I)	UPtake of Phosphate in Ith week	kg/d P	Nutrient uptake curve
UPK (I)	UPtake of Potassium in Ith week	kg/d K	Nutrient uptake curve

---

1/ d = decare = 1000 m^2

Annex 2 to Paper 2

Mineralization functions of soil organic nitrogen[2]

[1] $N_t = N_o\ (1 - e^{-kt})$

N_t – nitrogen mineralized (ppm) at time t (days)

N_o – potential mineralizable nitrogen (ppm)

k – rate constant (day^{-1})

[2] $N_o = 0.196 \times TOTN$

TOTN – total organic nitrogen in the range 200–1500 ppm and $C/N \simeq 10$

T = Temperature (Kelvin)

[3] $k = 7.3 \times 10^{6} \times 10^{-2758/T}$

[4] $FMIN = \frac{TETA}{FC} \times 0.196\ TOTN \times (1 - e^{-kt})$

TETA – actual soil moisture content

FC – field capacity moisture content

---

[2] Based on work by Stanford and Smith (1972), Stanford *et al* (1973) and Stanford and Epstein (1974).

Annex 3 to Paper 2

FNIT

Nitrification functions [3] of N-NH_4°

[1] $FNIT = K^* (NH_4) * R_T \times R_m$

K- at $R_T = 1$ and $R_m = 1 = 0.25$ week^{-1}
T = 25°C and moisture tension of
0.1 bar.

[2] $R_m = 0.51 - 0.39 \log M$

R_m = moisture coefficient

R_T = temperature coefficient

[3] $M = 0.6 - 0.3\ TETA/FC$

at moisture content higher than field capacity

[4] $M = 29.7 - 29.4\ TETA/FC$

at moisture content below field capacity

[5] $R_T = 10^{12.02} * 10^{-3573/T}$

T - temperature (Kelvin) in the range 281 - 303 K

---

[3] Calculated from the work of Fredrick (1956), Sabey (1969), Sabey and Johnson (1971), Sabey *et al*. (1956, 1959, 1969) and Parker and Larson (1962).

Paper 3

NITROGEN TRANSFORMATIONS AND BEHAVIOUR IN SOILS IN RELATION TO NITROGEN AVAILABILITY FOR CROPS

G. Stanford

United States Department of Agriculture, Beltsville, Maryland

1. INTRODUCTION

Soil N exploitation began with cultivation. Before N fertilizers became a significant factor in agriculture, much was learned about the kinetics of soil N exploitation from long-term field studies conducted under different soil and crop management systems. Studies by Jenny (1933) illustrate the exponential nature of soil N decline under cultivation.

In the older agricultural areas of the world, a quasi-equilibrium with respect to N gains and losses had been reached long before cultivation began on most soils of the U.S.A. Since the organic N content of U.S. soils before cultivation has been fairly well defined (Allison 1973), rough approximations of the N losses sustained since cultivation began are possible. About 50 percent of the initial N was lost during the first century of cultivation, equivalent to an average annual loss of about 16 million tonnes of N. The annual loss was certainly much higher than this during the first 50 years, a period when losses by leaching, erosion, and other means must have greatly exceeded crop removals particularly on the more fertile soils.

The almost linear increase in world consumption of fertilizer N during the past few decades has diverted attention from the continuing importance of the soil as a source of N to crops. The new challenge is to devise means of judiciously exploiting both soil and fertilizer N, with minimal adverse environmental effects. The N cycle in agriculture (Fig.2) shows the complexities involved in meeting this challenge (Frere 1976).

2. MAINTENANCE OR RESTORATION OF SOIL ORGANIC N

The level of organic matter that can be sustained, economically, is a function of soil properties, climate, cropping systems and cultural or management practices. Factors that may be controlled to varying degrees include (a) nature, frequency, and amount of crop residues returned; (b) use of fertilizers and animal wastes, and (c) tillage methods.

The amount of residues that must be returned annually to maintain a given organic matter content is strongly dependent on soil properties and climate. In a 12 year study of southern Blackland soils, an annual return of about 4 000 kg/ha of residues was required to maintain the level of organic matter (Laws 1961).

In general, residue production is positively correlated with yields of a given crop. The annual return of residues has increased during the relatively recent period of expanding fertilizer use, introduction of higher yielding varieties and improved cultural practices. In the past 25 years, for example, average maize yields in the U.S.A. have increased by about 50 percent. The corresponding increase in amount of residues returned to the soil is estimated to be 1 t/ha. Relatively little is known about the accompanying changes that have occurred in the organic N content of soils, although increased incorporation and retention of applied N would be expected.

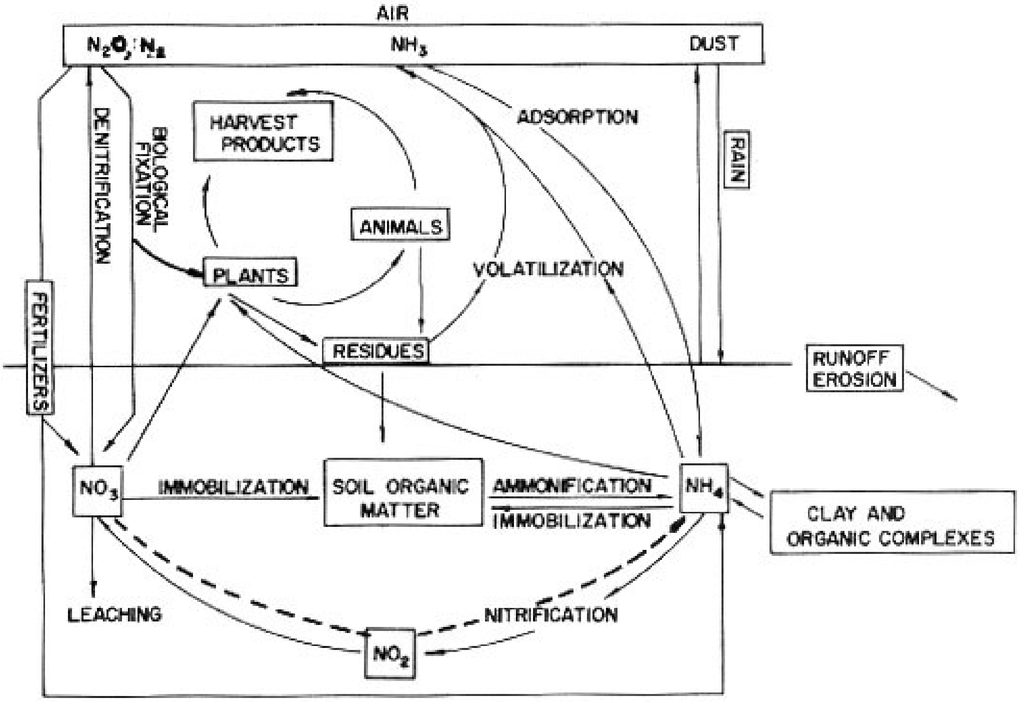


Fig. 2 The nitrogen cycle in agriculture

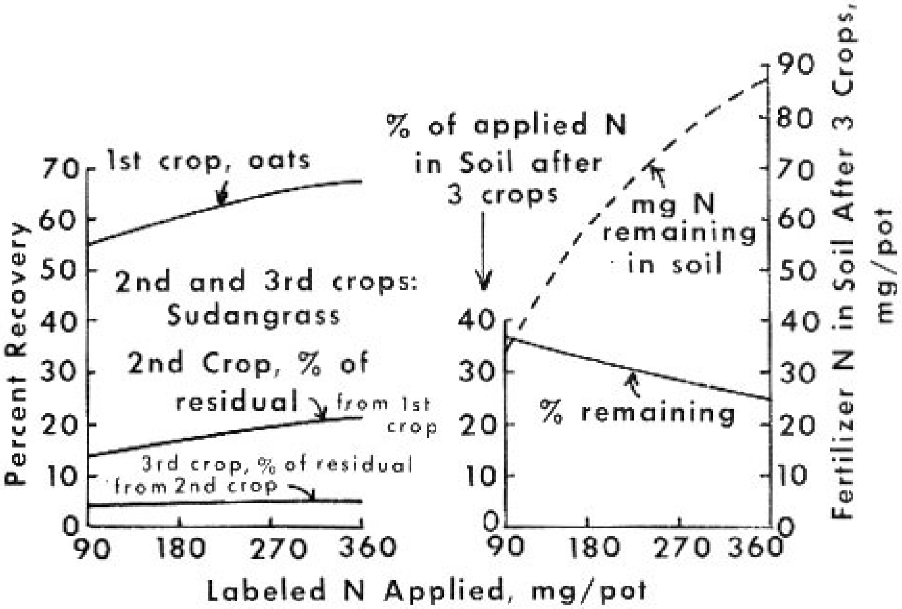


Fig. 3 Recovery of labelled N by oats and two successive crops of Sudan grass and amounts of residual organic N, derived from fertilizer, remaining in soil after cropping. Adapted from Legg and Allison (1967). Data represent mean of 12 soils

Studies using fertilizer labelled with ^{15}N to determine the extent of N incorporation in soil organic matter and its subsequent availability to plants have been reviewed by Allison (1973). Legg and Allison (1967) investigated this problem with several soils in a glasshouse study. Average recoveries of the initial N applied and residual ^{15}N fertilizer by successive crops are shown in Fig.3. Although amounts of immobilized N remaining after cropping were substantial and increased with rate of applicatiom, only 4 to 5 percent of the residual organic N from the first two crops was removed in the final crop. Such data emphasize the need for evaluating the cumulative effects of crop residues and increased use of fertilizer N on soil N status under field conditions.

Soil organic matter decomposition is accentuated by cultivation. Until recently, the primary purposes of cultivation have been to prepare a seedbed and to control weeds. Interest in no tillage or some form of minimal tillage developed when it became possible to control weeds with herbicides, and suitable farm machinery was devised for planting in untilled land (Triplett and Van Doren 1977). Since cultivation hastens biological activity in soil, minimal or no tillage is expected to conserve N.

Cooperative field experiments are underway (Bennett et al 1975; Bandel et al 1975) to compare the N economy under no tillage and conventional tillage. Maize is grown each year with application of labelled N fertilizer (ammonium sulphate or ammonium nitrate) at rates of 0, 45, 90, 135, and 180 kg/ha. Between maize crops, a rye cover crop is seeded on the untilled plots. The rye is killed with herbicide each year before maize is planted. With no tillage, the maize stover and rye residues remain on the surface. With conventional tillage, maize stover is ploughed under each year. Results for the third year, at one location in Maryland, are given in Fig.4. At suboptimal N rates, yields of maize grain and fertilizer N recoveries were distinctly lower on untilled than on ploughed plots. These differences may reflect greater immobilization of fertilizer N with no tillage than with ploughing. As the studies continue, amounts of labelled N incorporated into the soil will be evaluated in relation to tillage method and N applied.

3. MINERALIZATION OF SOIL ORGANIC N

The amounts of N released to the crop from the organic N pool are not well correlated with the total organic matter or N contents of soils (Stanford and Smith 1972). The conversion of organic N to NH_4^+ and NO_3^- ions generally is referred to as mineralization. However, in laboratory incubations, we measure net mineralization, the resultant of concurrent mineralization and immobilization (Fig.2).

In our laboratory, we have devised a method of determining N mineralization potential, N_o. The quantity, N_o, is defined as the amount of soil N that is potentially mineralizable according to first order kinetics. Thus, the amount of N mineralized per unit of time, t, is considered to be proportional to the antecedent pool of mineralizable N, i.e., $-\ dN/dt = kN$ (at t_o, $N = N_o$). The progress of N mineralization is described by repeated soil incubations of one week or longer at 35°C and optimum soil water content (ca. field capacity), with intermittent leachings of mineral N. Potentially mineralizable N (N_o) may be estimated from the linear regression of log $(N_o - N_t)$ on t, where N_t represents cumulative N mineralized during successive incubations (Stanford and Smith 1972).

The amount of N actually mineralized during the cropping season reflects day to day fluctuations in temperature and soil water content. Since the

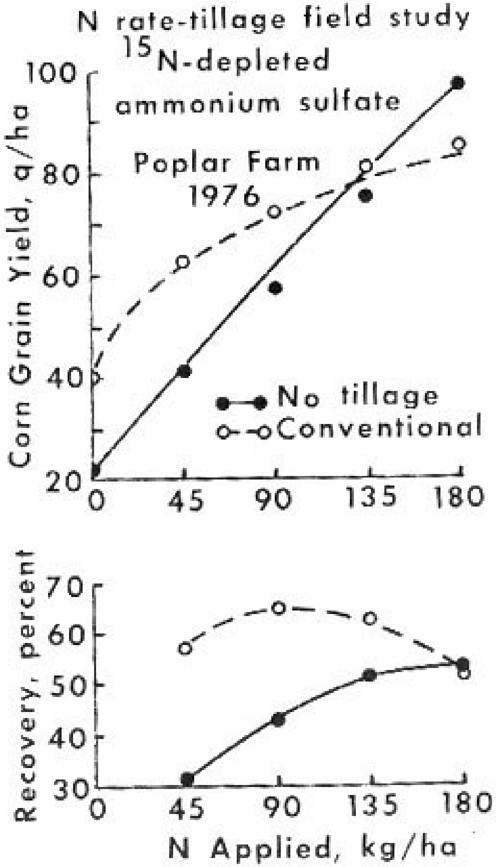


Fig. 4 Maize grain yields and percentage recovery of applied labelled N in relation to tillage method and N application rate. (Unpublished data obtained in 1976 from cooperative experiments with V.A. Bandel)

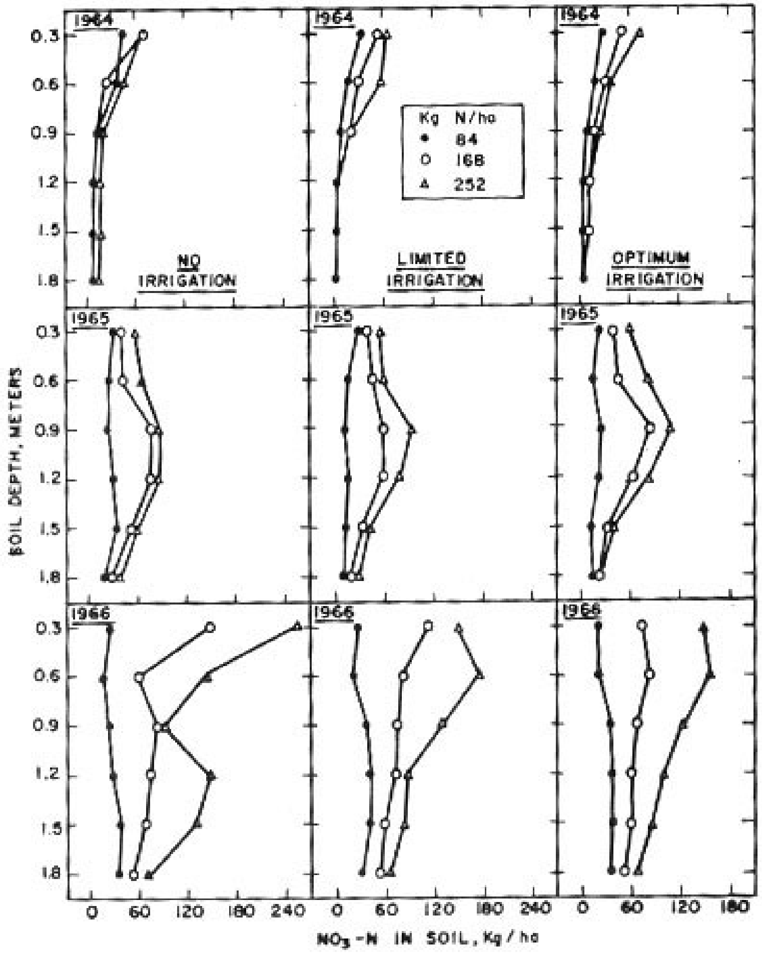


Fig. 5 NO_3^-- N found after 3 successive years of maize on Sharpsburg silt loam as affected by N rate and irrigation level, following several years of lucerne influence of these factors on mineralization rate has been defined, their gross effects can be estimated from weekly or monthly averages as described elsewhere (Stanford et al 1977).

4. FATE OF N APPLIED IN EXCESS OF CROP NEEDS

The goal in fertilizer N use is to supplement adequately the N supplied by soil N mineralization in ways that are consistent with economic crop production. In the absence of reliable bases for predicting how much N should be applied, it is inevitable that varying amounts of mineral N will be present in the soil at the end of the cropping season. The fate of the unused N is a major concern to farmers and to those concerned with environmental implications.

5. OPPORTUNITIES TO EXPLOIT RESIDUAL NITRATE IN SUBHUMID REGIONS

Amounts of N applied or mineralized, in excess of crop needs, may accumulate in the soil or become lost to varying degrees by leaching or denitrification. Downward movement of nitrate occurs only when water infiltration exceeds the soil water storage capacity (Allison 1973). When water inputs exceed evapotranspiration, some downward movement of nitrate is inevitable, although the balance usually favours nitrate retention during most of the growing season (Allison 1973).

In areas where percolation of water through the root zone between crops seldom exceeds 10 cm, large amounts of N (applied and derived from the soil) accumulate within the root zone. An example is given in Fig.5 (Herron et al 1968). In this Nebraska study, 3 years of continuous maize followed alfalfa, and no more than 84 kg N/ha was required for maximum maize yield. At this N rate, relatively little accumulation was evident to a depth of 180 cm after 3 years. Data of this kind (Herron et al 1971) prompted the Nebraska workers to include nitrate measurements to rooting depth in the soil testing programme as a basis for N fertilizer recommendations (Olson, personal communication).

In other areas where limited rainfall occurs between crops and excessive N application is prevelent, e.g. irrigated sugarbeet in Idaho (Carter et al 1976) and Colorado (Ludwick et al 1976), nitrate measurements in the soil profile have been proposed as a guide to fertilizer N recommendations. Under such conditions, residual nitrate often supplies a substantial portion of the N needs of the succeeding crop (Fig. 6). In the deep loessial soils of the subhumid plains area of the United States, effective rooting depth may extend to 3m or more. In such cases, deep sampling to measure residual nitrate for advisory purposes is required (Schuman et al 1975).

6. NITRATE LEACHING IN HUMID REGIONS

Where annual percolation of water usually exceeds 10 cm, the residual value to the succeeding crops of N remaining at harvest is less consistent and, therefore, less predictable. In the Netherlands, van der Paauw (1962) found, for example, that winter rainfall (Nov-Feb) in excess of 10 cm was directly correlated with residual nitrate losses during a 14 year period in which winter rainfall varied from 10 to 40 cm. Several excellent field studies conducted in the humid regions have shown little evidence of nitrate leaching from the root zone when rates of applied N were nearly optimum, Gast et al 1974; McGregor et al 1974; Nelson and McGregor 1973; Olsen et al 1970, although the potential for substantial losses existed with N applications above the optimum (Fig. 7). Residual nitrate carry-over from one crop to the next should not be ignored, however, even in the humid

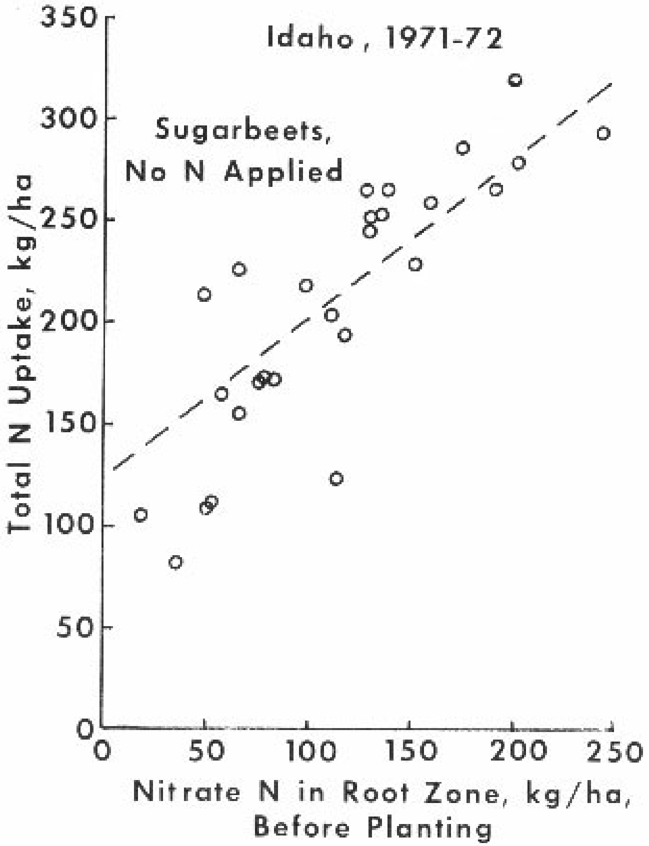


Fig. 6 Residual nitrate N in root zone before planting in relation to N uptake by irrigated sugarbeet in southern Idaho (Stanford *et al* 1977)

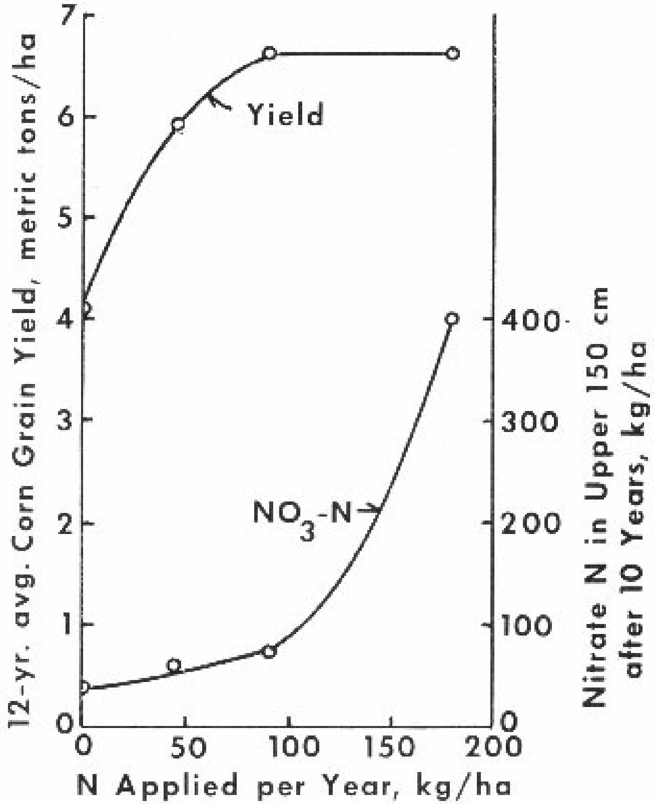


Fig. 7 Long term average maize yield response to applied N fertilizer and residual NO_3^--N in the soil following 10 years of annual N application

regions (White and Pesek 1959). Yet, in the major maize producing areas of midwestern U.S.A. where residual N carry-over varies widely, neither residual nor mineralizable N are evaluated as a guide to fertilizer N recommendations. Even in higher rainfall areas of eastern U.S.A. the carry-over of residual nitrate is extremely variable since it depends on winter precipitation.

7. DENITRIFICATION

Not much is currently known about the practical significance of denitrification in agriculture that was not already known at the beginning of the present century (Allison 1973). Although additional facts regarding pathways, mechanisms and other factors involved have been reported in recent years, the economic significance of gaseous N losses from soils remains a mystery. Allison (1973) suggested that denitrification losses would tend to increase with rising use of N fertilizers. There is no experimental evidence, however, to support this assumption.

The conditions under which denitrification will occur and the sequence of enzymatic (biological) transformations ($NO_3^- \Rightarrow NO_2^- \Rightarrow NO \Rightarrow N_2O \Rightarrow N_2$) involved have been well documented through research. Low oxygen (less than 1-2%), available carbon supply, and favourable pH (5 to 8) enhance rapid denitrification at temperatures near the optimum (30 - 35°C) (Broadbent and Clark 1965; Nommik 1956). Under submerged rice or in poorly drained, waterlogged soils, conditions are often conducive to denitrification, but more generally the extent of denitrification is uncertain. Even in relatively well aerated soils, denitrification may occur in anaerobic microsites giving rise to gradual losses that are difficult to quantify (Allison 1973; Broadbent and Clark 1965).

It has been claimed that use of fertilizer N is related to the incidence of skin cancer, caused indirectly by increased evolution of N_2O. The basic argument is that N_2O, a relatively unreactive gas, reaches the stratosphere where it is photochemically converted to NO_x, a reactive product. This form of N then reacts with ozone, O_3, to form O_2 (Crutzen 1974). Since ozone acts as a shield blocking entrance of UV rays to the earth's surface, its destruction is believed to be positively correlated with the incidence of skin cancer.

Research to find: (a) how much N_2O is currently evolved from the earth and oceans, (b) what factors influence the N_2O/N_2 ratio of the gases evolved during denitrification, (c) whether N_2O production and fertilizer N consumption are positively correlated would seem to be justified, if only to gain a better understanding of the N cycle in agriculture.

In our investigations on denitrification, we discovered that disappearance of nitrate under anaerobic conditions may involve a secondary pathway that leads to NH_4^+-N production (see broken curve, Fig.1) (Stanford *et al* 1975a). Using nitrate labelled with ^{15}N in the presence of glucose we found that the $^{15}NH_4^+$ produced gradually became incorporated in organic cellular material. After 24 hours of anaerobic incubation, 25 to 40 percent of the added labelled nitrate had reverted to NH_4^+ and organic N (Stanford *et al* 1975a,b). The significance of these findings to nitrogen conservation in agriculture is yet to be determined. Nevertheless, results challenge the prevalent view that denitrification N(NO_3^- N_2O and N_2) accounts for essentially all anaerobic nitrate dissimilation in soils.

8. ESTIMATING OPTIMAL FERTILIZER N REQUIREMENTS

Sound fertilizer N recommendations must take into account the internal N requirement of the crop for a projected attainable yield, the N supplying capacity of the soil and the efficiency or recovery of N supplied from soil and fertilizer.

The internal N requirement for attainable yield has been defined for a number of crops. The N percentage in total dry matter (N % TDM) associated with a broad range of attainable yields appears to be nearly constant. With maize, for example, the optimum N % TDM, *ca.* 1.2, appears to be independent of variety, location and cultural practices (Stanford 1966, 1973). Approximate optimal N % TDM values for certain other important crops are listed as follows: rice, 0.9–1.2 (Broadbent and Reyes 1971; De Datta and Kerim 1974; Sanchez *et al* 1973); wheat, 1.25% (Stanford and Hunter 1973); sugarbeet (including root), 1.6% (Carter *et al* 1976); potato (including tubers), 1.7% (Stanford 1966); and for sugarcane (2 yr crop), 0.2% (Stanford and Ayres 1964).

The amount of fertilizer N, N_f, required for a specified internal crop requirement, N_c, where N supplied from the soil is N_s and fractional recovery of N_f is denoted as E_f, may be expressed as follows: $N_f = (N_c - N_s)/E_f$ (Stanford 1973). Estimates of N_c are derived from projected attainable yields and associated N uptakes. The components of N_s are: (a) mineralized during the cropping season (N_m) and (b) residual mineral N in the root zone at planting time (N_a). Assuming that recoveries of measured or estimated N_m and N_a are similar, then their combined efficiency may be expressed as E_s, and $N_f = [N_c - E_s(N_m + N_a)]/E_f$. If apparent recoveries of N_m and N_a differ, then $N_f = (N_c - E_m N_m - E_a N_a)/E_f$. The latter approach was used with reasonable success to estimate N_f in a 2 year field study with sugarbeet (Stanford *et al* 1977).

REFERENCES

Allison, F.E. Soil organic matter and its role in crop production. Amsterdam,
1973 Elsevier.

Bandel, V.A., Dzienia, S., Stanford, G. and Legg, J.O. N behaviour under no-till
1975 vs. conventional corn culture I. First-year results using unlabelled N
fertilizer. Agron. J. 67: 782-786.

Bennett, O.L., Stanford, G., Mathias, E.L. and Lundberg, P.E. Nitrogen
1975 conservation under corn planted in quackgrass sod. J. Environ. Qual.
4: 107-110.

Broadbent, F.E. and Clark, F.E. Denitrification. *In* Soil nitrogen. Agronomy
1965 10: 344-359. Madison, Wisc. Amer. Soc. of Agronomy.

Broadbent, F.E. and Reyes, O.C. Uptake of soil and fertilizer nitrogen by rice
1971 in some Philippine soils. Soil Sci. 112: 200-205.

Carter, J.N., Westermann, D.T. and Jensen, M.E. Sugarbeet yield and quality as
1976 affected by nitrogen level. Agron. J. 68: 49-55.

Crutzen, P.J. Estimates of possible variations in total ozone due to natural
1974 causes and human activities. Ambio. 3: 201-210.

De Datta, S.K., and Kerim, M.S.A.A.A. Water and nitrogen economy of rainfed rice
1974 as affected by soil puddling. Soil Sci. Soc. Amer. Proc. 38: 515-518.

Frere, M.H. Nutrient aspects of pollution from cropland. *In* Control of Water
1976 Pollution from Cropland, Volume II, Chapter 4. Agricultural Research
Service, USDA, and Office of Research and Development, EPA.

Gast, R.G., Nelson, W.W. and MacGregor, J.M. Nitrate and chloride accumulation
1974 and distribution in fertilized tile-drained soils. J. Environ. Qual.
3: 209-213.

Herron, G.M. *et al.* Residual mineral N accumulation in soil and its utilization
1971 by irrigated corn (*Zea mays* L.). Agron. J. 63: 322-327.

Herron, G.M. *et al.* Residual nitrate nitrogen in fertilized deep loess-derived
1968 soils. Agron. J. 60: 477-482.

Jenny, H. Soil fertility losses under Missouri conditions. Missouri Agric. Exp.
1933 Sta. Bull. 324.

Laws, W.D. Farming systems for soil improvement in the Blacklands. Texas Res.
1961 Found. Bull. 10.

Legg, J.O. and Allison, F.E. A tracer study of nitrogen balance and residual
1967 nitrogen availability with 12 soils. Soil Sci. Soc. Amer. Proc.
31: 403-406.

Ludwick, A.E., Reuss, J.O. and Langin, E.J. Soil nitrates following four years
1976 of continuous corn and as surveyed in irrigated farm fields of central
and eastern Colorado. J. Environ. Qual. 5: 82-86.

McGregor, J.M., Blake G.R. and Evans, S.D. Mineral nitrogen movement into
1974 subsoils following continued annual fertilization for corn. Soil Sci.
Soc. Amer. Proc. 38: 110-113.

Nelson, W.W. and MacGregor, J.M. 1973 Twelve years of continuous corn fertilization with ammonium nitrate or urea nitrogen. Soil Sci. Soc. Amer. Proc. 37: 583-586.

Nommik, H. 1956 Investigations on denitrification in soil. Acta Agr. Scand. 6: 195-228.

Olsen, R.J. *et al.* 1970 Fertilizer nitrogen and crop rotation in relation to movement of nitrate nitrogen through soil profiles. Soil Sci. Soc. Amer. Proc. 34: 448-452.

Paauw, F. van der. 1962 Effect of winter rainfall on the amount of nitrogen available to crops. Pl. Soil 16: 361-380.

Sanchez, P.A., Ramirez, G.E. and Calderon, M.V. de. 1973 Rice response to nitrogen under high solar radiation and intermittent flooding in Peru. Agron. J. 65: 523-529.

Schuman, G.E. *et al.* 1975 Nitrate movement and its distribution in the soil profile of differentially fertilized watersheds. Soil Sci. Soc. Amer. Proc. 39: 1192-1197.

Stanford, G. 1966 Nitrogen requirements of crops for maximum yield. *In* Agricultural anhydrous ammonia: technology and use. W.H. McVicker, ed. Madison, Wisc. Soil Sci. Soc. Amer.

Stanford, G. 1973 Rationale for optimum nitrogen fertilization in corn production. J. Environ. Qual. 2: 159-166.

Stanford, G and Ayres, A.S. 1964 The internal nitrogen requirement of sugarcane. Soil Sci. 98: 338-344.

Stanford, G. *et al.* 1977 Residual nitrate and mineralizable soil N in relation to N uptake by irrigated sugarbeets. Agron. J. 69: 305-308.

Stanford, G. and Hunter, A.S. 1973 Nitrogen requirements of winter wheat (*Triticum aestivum* L.) varieties 'Blueboy' and 'Redcoat'. Agron. J. 65: 442-447.

Stanford, G. and Smith, S.J. 1972 Nitrogen mineralization potentials of soils. Soi Sci. Soc. Amer. Proc. 36: 465-472.

Stanford, G. *et al.* 1975a Denitrification and associated nitrogen transformations in soils. Soil Sci. 120: 147-152.

Stanford, G., Legg, J.O. and Staley, T.E. 1975b Fate of ^{15}N-labelled nitrate in soils under anaerobic conditions. Proc. 2nd Int. Conf. on Stable Isotopes (Klein, E.R. and Klein, P.D., eds.). Argonne, Illinois, Argonne National Laboratory.

Triplett, Jr., G.B. and Van Doren, Jr., D.M. 1977 Agriculture without tillage. Sci. Amer. 236: 28-33.

White, W.C. and Pesek, J. 1959 Nature of residual nitrogen in Iowa soils. Soil Sci. Soc. Amer. Proc. 23: 39-42.

Paper 4 POTASSIUM EFFICIENCY IN TROPICAL AND SUBTROPICAL CONDITIONS

H. Beringer

Büntehof Agricultural Research Station, Hannover, Federal Republic of Germany

1. INTRODUCTION

Two sets of interrelated factors, natural conditions and socio-economics, determine the efficiency of applied fertilizer. The cropping system is specially important where manpower is abundant but land is scarce and capital for the purchase of inputs is limited. Under such circumstances agriculture becomes labour intensive, more than one crop is grown per year to enhance income, good use is made of incident light, and by providing an almost permanent cover for the soil, erosion and nutrient losses are reduced. The ecosystem will, however, deteriorate if resources used by the plant are not restored by fertilizers.

2. DYNAMICS AND AVAILABILITY OF K

Nutrients reach the root surface by three principal mechanisms (Oliver and Barber 1966):

i. interception, whereby nutrients absorbed in the water film of soil colloids can pass to an adjacent root surface. This process, formerly known as "contact exchange", plays only a minor role in the nutrient supply to the plant.

ii. mass flow, driven by the water saturation deficit between the atmosphere and the soil. The extent of this deficit determines transpiration intensity. Nutrients dissolved in the soil water are transported to the roots by the flow, and the higher their concentration the better the needs of the plant are met. About 80% of the Ca and Mg requirements of a crop are so supplied.

iii. diffusion, which plays the major role in the P and K nutrition of the crop. The concentration of P and K in the soil solution is rather low. Absorption of K by the plant reduces this concentration and a gradient is built up between the soil solution and the pool of exchangeable K and the K reserves respectively (Fig.8).

The different fractions containing K in the soil are in equilibrium with each other if no crop is grown on the soil. The parent minerals, like micas and feldspars, on the left side of the diagram, have a high content of firmly bound K. On the righthand side the concentration of K in the soil solution is rather low, but the dissolved K is highly mobile. The amount of K which is or can become available to the plant is determined by size of the pools (i.e. the quantity) and the rate at which these pools release potassium (i.e. the intensity). It is important to recognize that the diffusion coefficients as indicators of K mobility are several orders of magnitude higher for the dissolved and exchangeable K than for non-exchangeable K and the K in the reserves (Nye 1972). If maximum crop yields are aimed at, the amount of plant available K must always be high enough to satisfy peak requirements. However, if the fertilizer input is oriented towards maximum use of the K reserves, the low flux rate of K from these reserves could sometimes limit yield.

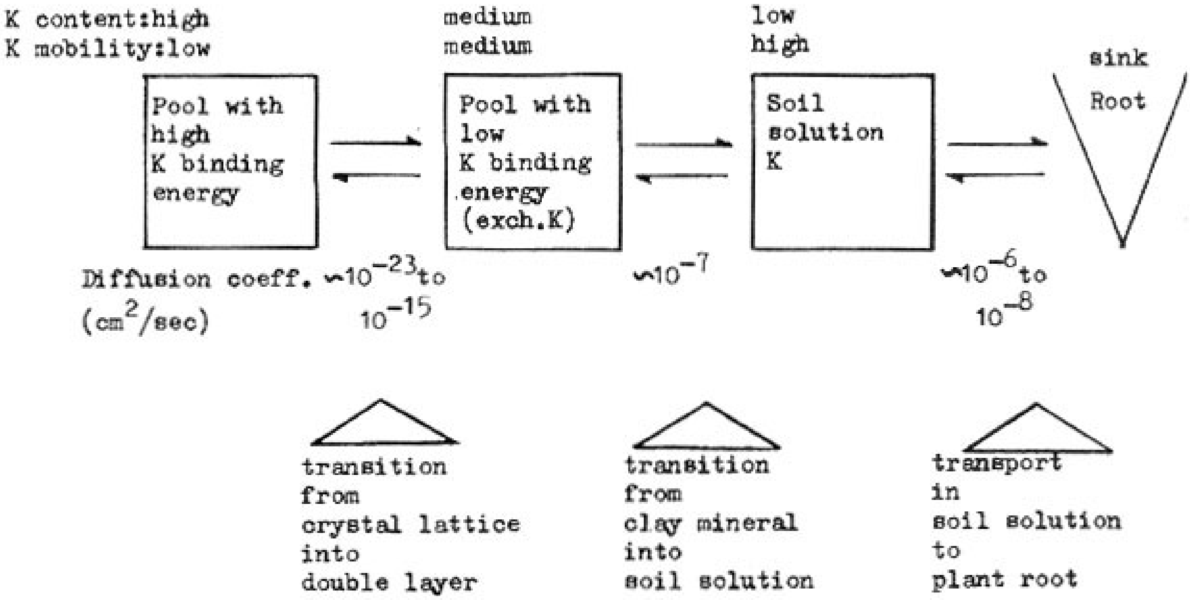


Fig. 8 Simplified diagram of K **dynamics in soil**

Generally the fraction of exchangeable K in the top soil is used as indicator of plant available potassium, but the correlation between soil exchangeable K and crop yield and K uptake by the plant respectively is not necessarily good (Mengel 1975). Data from fertilizer trials on rice in India (Grimme 1976) have shown that a higher response to 90 kg K/ha was obtained on soils with a medium K status than on soils poorer in K, contrary to expectations from Mitscherlich's law.

2.1 Influence of Clay on K Availability

The K dynamics in a soil are controlled by the clay fraction. Whereas K is bound unspecifically on the organic cation exchange sites and it is easily desorbable, the clay content and the type of clay minerals vary from soil to soil. In 2:1 clay minerals like montmorillonite and illite cations are adsorbed at planar, edge and interlattice positions. Considering the ratio of K:Ca in these different positions with the K/Ca ratio in an equilibrium solution, the specificity of these positions to bind K is expressed by the Gapon coefficient. The high coefficient for interlattice sites (>1000) compared with coefficients of 2 for the planar and 200-1000 for the edge positions indicates clearly the well-known fixation of K by illites. **Kaolinitic**, i.e. 1:1, clay minerals have only planar sites at which ions are easily exchangeable. Depending therefore on the clay composition and clay content, fertilizer K in the low K rice soils of India (Gimme 1976) could have been bound more firmly and was thus less available. Consequently, the determination of exchangeable K as a basis for the prediction of fertilizer efficiency must be supplemented by other criteria, among which the most promising is the soil solution from which the plant absorbs its nutrients.

Testing K uptake from several soils Nemeth and Forster (1976) found a good correlation with the K concentration in the soil solution ($r = 0.89^{***}$). In comparison exchangeable K was poorly correlated with K uptake. Only when soils were grouped according to their clay content did the correlation become better. This is because a given amount of exchangeable K is distributed over fewer clay particles in a sandy soil than in an alluvial soil. As there is a strong positive correlation between the degree of K saturation of the inorganic exchange capacity and the K concentration in the soil solution (Nemeth and Grimme 1973), soil tests for available K must always consider the inorganic CEC in addition to exchangeable K. Boyer (1972) correspondingly recommended that a soil should contain sufficient exchangeable K to saturate at least 2% of the CEC with K. Below 0.2 meq exch. K/100 g soil, most tropical soils are certainly deficient in K. The threshold below which responses to applied K can be expected is generally between 0.15 and 0.35 meq K/100 g soil.

The influence of the type of clay minerals on the relation between exchangeable K and K concentration in the soil solution is shown in the data of Table 4. All soils tested were of similar pH (5.0 - 6.0) and clay content (~20%). K concentration in the soil solution increased with increasing exchangeable K in all the samples, but whereas in the red soil from Nigeria and the relict red soil 15 - 18 mg exchangeable K corresponded to 1.05 - 1.2 meq K/1, 17 mg exchangeable K in the grey-brown podzolic soil derived from loess yielded only 0.4 meq K. This is caused by the prevalence of kaolinite in the red soils and by the occurrence of 2:1 clay minerals in the latter soil. Accordingly applied K fertilizer will raise the K concentration to a larger extent and will be more efficient in stimulating plant growth on a kaolinitic soil. On the other hand soils with illite minerals have a higher K buffering capacity and will release K for a longer period of time. This is shown in Fig.9 where rye grass has been repeatedly cut on the relict red soil and the grey-brown podzolic, both having been fertilized with K to comparable exchangeable K levels. Whereas on the kaolinitic red soil dry matter production was high (72 g) at the first cut and dropped progressively to 13 g in the fourth cut, yields on the grey-brown podzolic were more uniform. This indicates the higher K buffering capacity in the grey-brown podzolic. It is

Table 4 RELATION BETWEEN (A) EXCHANGEABLE K AND (B) K ADDITIONS ON THE K CONCENTRATION IN THE SOIL SOLUTION OF SOIL TYPES WITH COMPARABLE CLAY CONTENT

A)

	Red soil ultisol (Nigeria)		Relict red soil oxisol (Germany)		Grey-brown podzolic (alfisol) (Germany)		
Exch.K(mg/100 g)	12	15	10	18	10	17	30
K in soil solution meq/1	0.75	1.05	0.80	1.20	0.2	0.4	1.2

B)

	K addition (mg/100 g soil)	K concentration in soil solution
Relict red soil	0	0.80
	10	1.60
	20	2.60
Grey-brown podzolic	0	0.2
	10	0.25
	20	0.35
	40	1.10

Source: Nemeth and Grimme (1974)

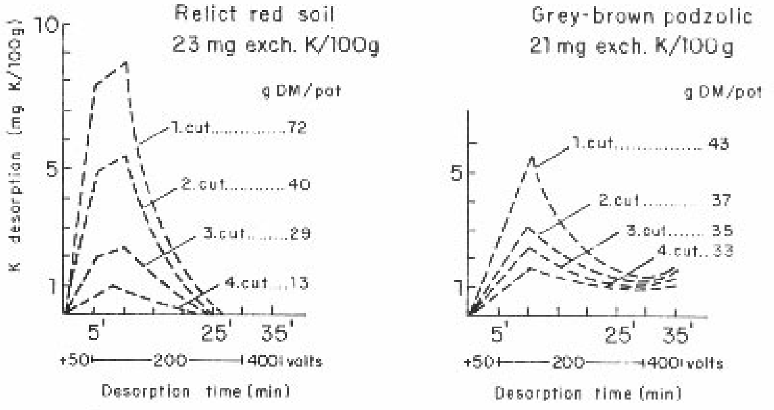


Fig. 9 Dry matter production of consecutive ryegrass cuts and changes in K concentration of soil solution (Nemeth and Grimme 1974)

thus clear that the parameter exchangeable K is insufficient to characterize the K buffering capacity of soils differing in clay content and clay mineralogy.

Many attempts have been made in the past to describe the K dynamics of a soil by laboratory methods. Haylock (1956) used repeated extractions with chemicals. Based on the Gapon equation Beckett (1972) developed the concept of the intensity/quantity relationship. Although this greatly stimulated research, the analytical work is laborious. One of the more recent developments is the electro-ultrafiltration method (Nemeth 1972). A soil suspension is exposed to an electric field of increasing strength. The ions desorbed from the soil at the indicated voltages are collected at 5 min intervals. The amount of K desorbed in the first and second 5 min periods is correlated with K concentration in the soil solution, whereas the 30 - 35 min fraction allows an evaluation of the long-term K supply rate. Comparing the two soils it is clear that the kaolinitic red soil originally had a high K concentration in the soil solution which was severely depleted by the continuous ryegrass cropping. Furthermore, this red soil is very poor in K reserves. In contrast the grey-brown podzolic had a lower K concentration in the soil solution but higher K buffering capacity, as indicated by the amounts of K desorbed at 400 v (30 - 35 min fraction) and by the dry matter production of the grass.

2.2 Influence of Soil Moisture on K Efficiency

The concept that the diffusive flux of K in the soil is the most important criterion for the potassium supply to the plant root implies that a required diffusive flux can be achieved either by a high K concentration if soil moisture is low or by a lower concentration if many soil pores are filled with water. It can be assumed that soil moisture is adequate during the rainy season in tropical areas so perhaps explaining why soils low in exchangeable K may respond little to K fertilizers.

During dry spells a crop, particularly if potentially high yielding or passing through a phase of high K demand, will suffer from K stress because of a low K concentration in the soil solution and lack of soil moisture. In a model experiment by Grimme et al (1971) a cation exchanger was used to simulate the root. Fig. 10 shows that when the soil is moist the depletion of K (as indicated by decreases in exchangeable K) is higher and the foraging area of the root is larger. Although the soil of Fig.3 was reduced only from pF 1.8 to pF 3.2 which is well within the range of good water supply, diffusive flux into the ion exchanger decreased by 44% from 0.51 to 0.29 meq/cm^2/ day. This is a substantial reduction of availability and may be critical in cases of marginal K status when the K supply is just sufficient under optimum water conditions.

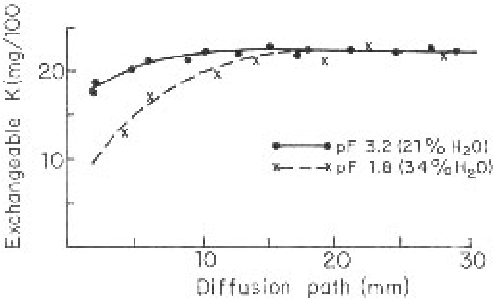


Fig. 10 Exchangeable K contents after one week of diffusion in a soil at different soil moisture levels in relation to distance from an absorbing surface

In avoiding such stresses fertilizers are valuable. In Holland, increases in yield of potatoes following application of K at 400 kg/ha were highly correlated (r = 0.85***) with the number of rainless days (Van der Paauw 1958). This clearly demonstrates that limiting soil moisture has to be compensated by higher K concentrations in the soil solution to ensure good availability of K and high yields. Similarly, under submerged conditions the K uptake by rice plants was higher from both the exchangeable and non-exchangeable K fractions, but the soil K was exhausted more rapidly (Biswas 1974) and yield could only be maintained by applying K.

2.3 K Status of Tropical and Subtropical Soils

It is generally assumed that tropical and subtropical soils are not deficient in K at a low level of farm management (Jones and Wild 1975). This is partly due to low yields and small exports of K from the field and partly to the recycling of K in shifting cultivation (Nye and Greenland 1960). Nevertheless, certain soils from Ghana (Table 5) are rather low in exchangeable K (0.15 meq/100g) and therefore in K buffering capacity. In the rain forest, or when clay contents are low and kaolinite is prevalent, the intensity i.e. the K availability is quite good. Thus the K supply might initially be sufficient for plant growth but would soon be depleted, especially were all other growth factors to be improved. Another consequence of the high K mobility will be greater leaching of K under heavy rainfall. The less weathered savanna soils on the other hand are slightly richer in exchangeable K, the K intensity is lower and the quantity of potentially available K higher. Similar results for Malaysian soils have been reported by Triagalingam and Grimme (1976). Of 12 soils tested, nine contained less than 0.16 meq exchangeable K/100 g of which more than 60% was easily desorbed, i.e. highly available.

Table 5 INFLUENCE OF CLAY CONTENT AND VEGETATION ON K DYNAMICS IN SOILS OF GHANA. MEANS OF 48 SAMPLES

Variable	No. of Soils	Exch.K meq %	Intensity $(M/1)^{1/2}$ x 100	Quantity meq %	$\frac{\text{Quantity}}{\text{Intensity}}$ x 100
Clay < 10 %	12	0.15	0.59	0.18	36
10-20 %	17	0.24	0.60	0.35	75
> 20 %	19	0.25	0.32	0.25	105
Forest	14	0.16	0.63	0.22	57
Forest/savanna	8	0.16	0.36	0.20	49
Savanna	26	0.23	0.46	0.27	80
Range of SE		0.01-0.20	0.01-0.1	0.02-0.05	5-19

Occurence of clay minerals (the figures refer to number of soils)

	X-ray pattern				
	none	identifiable	weak	medium	strong
Montmorillonite	-	26	17	2	3
Illite	21	23	4	-	-
Kaolinite	-	3	-	16	29

Source: Acquaye (1974)

3. RESPONSE OF CROPS TO K FERTILIZERS

All the foregoing aspects of K dynamics affect K fertilizer requirements and K efficiency in warm climates.

3.1 A Need for Long-Term Fertilizer Trials

The results of a 5 year fertilizer experiment are given in Table 6. Remarkable yield increases were obtained by application of 140 kg N/ha, the efficiency of which was 2.93 t/ha in the first year but dropped to 1.54 t/ha in the fifth year, clearly because the P and K reserves in the soil became yield-limiting. Applied P and K resulted initially in only small yield increases, but in time their efficiency increased. This reached a maximum for P in 1971 and fell again in the NP treatment owing to lack of K. Potassium was the most efficient in the final year leading to a yield increase of 1.4 t/ha over the yield from NP. In 1968, 1 kg of fertilizer K produced 6 kg grains whereas in 1972 23 kg grains/kg were obtained. Efficiency of K can therefore be estimated only in long term fertilizer trials. The required duration is determined by the K reserves of the soil and the K requirements of the crop species; the rooting pattern and the capacity of the root to explore the soil for K; the yield potential, and the K return by nonmarketable plant residues.

Table 6 EFFECT OF NPK ON ADDITIONAL GRAIN YIELD (T/HA) OF FLOODED RICE GROWN FOR FIVE SUCCESSIVE YEARS (DRY SEASON DATA, AVERAGE OF 3 EXPERIMENT STATIONS IN THE PHILIPPINES AND OF 3 CULTIVARS

	kg/ha						
N	P_2O_5	K_2O	1968	1969	1970	1971	1972
0	0	0	3.20	2.20	3.28	3.63	3.26
140	0	0	+2.93	+3.02	+1.67	+1.67	+1.54
140	60	0	+ .33	+ .48	+ .90	+1.13	+ .53
140	60	60	+ .38	+ .32	+ .77	+ .64	+1.40
kg grain/kg NPK			14	15	13	13	13
kg grain/kg K_2O			6	5	13	11	23

Source: Kammler and Malicornet (1976)

3.2 Split Application of K Fertilizers

The good mobility of K but poor K buffering in kaolinitic tropical soils implies that split applications may be superior to single doses. This indeed has been found for rice (Fernando 1961; Esakkimuthu et al 1975; Misra et al 1976). The results of three field trials with rice on sandy loam soils low in N,P and K status are given in Table 7. Increased numbers of panicles and grains per panicle in the treatments with split applications suggest that a single basal dressing could not meet the K demand at critical periods. As a result grain yield was increased by 6 q/ha in the split treatments but probably also partly because of improved disease and pest tolerance (Trolldenier 1969).

Table 7 EFFECT OF SPLIT DRESSINGS OF K ON RICE YIELD AND DISEASE ATTACK (MEANS OF 2 SEASONS AT 3 SITES)

50 kg/ha K_2O	Grain yield Q/ha	Panicles /m	Grains /panicle	% Plants affected by S.B.1/	BLB 2/
Basal	40.0	354	69	4.0	28
1/2 at transplanting 1/2 three weeks later	44.5	369	72	2.8	21
1/3 at transplanting 1/3 at tillering 1/3 at panicle init.	46.0	372	78	1.8	13

1/ Stem borer

2/ Bacterial leaf blight

Source: Misra et al (1976)

3.3 Influence of Agronomic Practices

The efficiency of each nutrient is improved by having a well balanced total nutrient supply and all other growth factors at their optima. There is a great need to optimize planting date, plant population etc. in improving fertilizer efficiency (Allan 1971, Werblow 1975). Few experimental data relate to the efficiency and cycle of nutrients in mixed or multistorey cropping. Data by Dalal (1974) reveal a K uptake of 90 kg/ha by alternating rows of maize and pigeon pea in comparison with 61 and 44 kg/ha by pure stands of maize and pigeon pea respectively. Kanwar (1975) stated that a farmer producing 6 t rice and 6 t wheat/ha per year annually removes 276 kg N, 55 kg P (125 kg P_2O_5) and 329 kg K (396 kg K_2O) per ha. Such heavy exports of K_2O rapidly exhaust the K reserves, especially of soils with high K mobility but low K buffering. Yet intensive cropping supported by balanced fertilizer application could ultimately raise soil fertility, not least by improvement of the physical condition.

Future experiments will have to show how far such cropping systems can mobilize K reserves, but wherever the diffusive flux of K is suboptimal maximum yields will not be attained because the rate of release of non-exchangeable K is too slow. The long term task is not only to find out how far nutrient reserves in the soil can be depleted to save fertilizer inputs, but also to learn how to make full use of the yield potential of ecological cropping systems and improved genotypes and how to maintain or even increase soil fertility.

4. CONCLUSIONS

Rainfall, the varying nutrient requirements of crops and standards of farm management affect fertilizer recommendations and efficiency of applied fertilizers.

Soil analyses should combine the determination of potentially available nutrients with measurement of the intensity of nutrient release to the roots. Exchangeable K should be expressed both as meq/100g and as a percentage of the CEC so that knowing the kind of prevailing clay mineral fuller information is available on the extent of fixation and release of K. Easily available K and potentially available K reserves should be quantified by two or more methods.

REFERENCES

Acquaye, D.K. Factors determining the potassium supplying power of soils in
1974 Ghana. Proc. 10th Coll. Int. Potash Inst., Berne pp. 51-70.

Allan, A.Y. Fertilizer use on maize in Kenya. FAO Soils Bull. 14: 10-25
1971

Beckett, P. Critical cation activity ratios. Adv. Agron. 24: 379-408
1972

Biswas, C.R. The potassium supplying capacity of several Philippine soils
1974 under two moisture regimes. Potash Rev. Subj. 4, 57th suite

Boyer, J. Soil potassium. In Soils of the humid tropics, pp. 102-135
1972 Washington Nat. Acad. Sci.

Dalal, R.C. Effects of intercropping maize with pigeon peas on grain yield
1974 and nutrient uptake. Exp. Agric. 10: 219-224

Esakkimuthu, N., Krishnamoorthy, S and Loganathan, S. Influence of nitrogen
1975 and potassium and method of application of potassium on yield and
nutrient uptake in rice. J. Ind. Soc. Soil Sci. 23 (4): 452-457

Fernando, H. Raising rice yields in Ceylon. Proc. Ceylon Ass. Adv. Sci. 17
1961 (2): 74-98

Grimme, H. Some factors of potassium availability. Ind. Soc. Soil Sci., Bull.
1976 10, 144-163

Grimme, H., Nemeth, K and v. Braunschweig, L.C. Some factors controlling
1971 potassium availability in soils. Int. Symp. Soil Fert. Eval. New
Delhi, Proc. 1: 33-43

Haylock, D.F. A method for estimating the availability of non-exchangeable
1956 potassium. Rapp. VI. Cong. Int. Soil Sci., Paris, Vol.B, 403-408

Jones, M.J. and Wild, A. Soils of the West African savanna. Commonw. Agric.
1975 Bur. 246 pp.

Kanwar, J.S. Assessement of potassium fertilization in the tropics and sub-
1975 tropics Asia. Proc. 10th Cong. Int. Potash Inst., Budapest.
pp. 261-282.

Kemmler, G and Malicornet, H. Fertilizer experiments - the need for long-
1976 term trials. Int. Potash Inst. Berne, 34p.

Mengel, K. Die Faktoren der Kaliverfügbarkeit und deren Bedeutung für die
1975 Ertragsbildung. Landw. Forsch. 31/1: 45-58

Misra, H.C., Misra, B and Padmi, S.C. Response of jaya rice to split application
1976 of potassium. Ind. Potash J. 1(3): 24-28

Nemeth, K. The determination of desorption and solubility rates in the soil by
1972 means of electroultrafiltration. Proc. 9th Coll. Int. Potash Inst.,
Berne, pp. 171-180

Nemeth K and Grimme, H. Effect of soil pH on the relationship between K
1973 concentration in the saturation extract and K saturation of soils. Soils Sci. 114: 349-354

Nemeth, K and Grimme, H. Kaliumdynamik bei Roterden mit kaolinitischer
1974 Mineralzusammensetzung im Tonanteil und deren Bedeutung für die Ertragsbildung. Mitt. Dtsch. Bodenkundl. Ges. 20: 194-200

Nemeth, K and Forster, H. Beziehungen zwischen Ertrag und K-Entzug von
1976 Ackerbohnen (Vicia faba) sowie verschiedenen K-Fraktionen von Böden. Bodenkultur 27: 111-119

Nye, P.H. Localised movement of potassium ions in soil. Proc. 9th Coll. Int.
1972 Potash Inst., Berne, pp. 147-155

Nye, P.H. and Greenland, D.J. The soil under shifting cultivation. Commonw.
1960 Agric. Bur. 156 pp.

Oliver, S. and Barber, S.A. An evaluation of the mechanisms governing the
1966 supply of Ca, Mg, K and Na to soybean-roots. Soil Sci. Soc. Amer. Proc. 30: 82-86

Paauw, F. van der. Relation between the potash requirements of crops and
1958 meteorological conditions. Pl. Soil 9: 254-268

Thiagalingam, K. and Grimme, J. The evaluation of the K status of some
1976 Malaysian soils by means of electroultrafiltration. Planter, Kuala Lumpur, 52: 83-89

Trolldenier, G. Cereal diseases and plant nutrition. Potash Rev. Int. Potash
1969 Inst., Berne, Subj. 23, 34th suite

Werblow, U. Grenzen des Einsatzes ertragssteigernder Produktionsmittel im
1975 Baumwollanbau der Zentralafrikanischen Republik. Tropenlandwirt 76: 40-51

Paper 5

AVAILABILITY OF SECONDARY AND MICRONUTRIENTS TO CROPS

M. Sillanpää

Institute of Soil Science, Agricultural Research Centre, Vantaa, Finland

1. INTRODUCTION

On the basis of the amounts in which different elements are required by plants and of their functions the elements are classified into different categories. Some authors, especially recently, have distinguished only two groups, i.e. macronutrients (N, P, K, Mg, Ca, S) and micronutrients (other nutrients), while most research workers have been using the following three categories: (a) primary or major nutrients, N, P and K, which are required in relatively large amounts, (b) secondary elements or nutrients, comprising Si, Ca, Mg and S because of their relative abundance in both soils and plants, (c) trace elements (minor elements, microelements or micronutrients) which exist only in small amounts in ordinary soils and plants. Their proportions are usually given in parts per million (ppm). Sometimes the name "nutrient" is used only for those elements which have been proved to be essential for plant growth or for the nutrition of animals to distinguish them from other, non-essential elements.

More than half a dozen trace elements, including B, Cl, Cu, Fe, Mn, Mo, Zn and possibly Co are known or suspected to be essential for the normal growth of plants. Some of these (Cl, Co, Cu, Fe, Mn, Mo, Na and Zn) are also essential for animal nutrition. Other trace elements required by animals are Cr, I, Se and perhaps F. Deficiencies of Ba and Sr have been found in certain conditions to cause growth or other abnormalities but whether they are essential is still doubtful.

2. OCCURRENCE OF TRACE ELEMENTS

The amounts of trace elements removed yearly with normal crop yields (Mn 500, Zn 250, Cu 50, Mo 10 and Co 1 g/ha; approximate data collected from various sources) represent only a very small proportion, generally less than one percent, of the total amounts of the various trace elements present in soils. Thus, it is clear that the total amounts, even in the most serious deficiency cases, far exceed the requirements of crops, but the total amount is seldom a reliable index of availability to the plant.

Besides the mineralogical composition of the parent material, the total amounts of trace elements present in soils depend on the type and intensity of weathering and on climatic and other factors predominating during the process of soil formation.

The relative resistance to weathering of various rocks and minerals apparently has a great influence on both the texture and the trace element content of soils. Fine textured soils and the finer fractions in other soils are likely to have been derived from the more easily weathered minerals, which are also the main source of trace elements. Coarse textured soils and coarse fractions are derived from minerals, such as quartz, which are resistant to weathering and have a low micronutrient content. The lower total trace element contents of coarse rather than fine textured soils have been reported by several authors. Organic soils, especially pure peats, are another group of soils in which the total contents of most trace elements are low.

Trace elements are bound in different ways in soils and the demarcation between different forms is diffuse. For example, the following forms may occur: (a) Trace elements in the soil solution. (b) Exchangeable ions bound by the electric charges of soil particles. These ions form a plant-available fraction of trace elements, similar to that of exchangeable K, Ca and Mg. The trace elements are, however, more firmly bound and less available. (c) Trace elements complexed with organic material. Most trace elements are typical heavy metals, which are able to form complexes with ligands derived from soil organic material or from biological residues in the soil. The availability to plants varies. (d) Precipitated trace elements. The concentrations of Fe and Mn are high enough to allow precipitation. This fraction is to some extent plant-available. (e) Trace elements occluded during development of new solid phases in which they are not principal constituents. This is a long term equilibrium reaction about which little is known. (f) Constituents of soil minerals. These trace elements are released during weathering. Ions which have entered the crystal lattice of clay minerals belong to this group. The availability of the last mentioned is strictly limited.

3. FACTORS AFFECTING AVAILABILITY OF TRACE ELEMENTS

The availability of different trace elements to plants and the factors affecting it, vary considerably from one trace element and medium to another. Availability is not only influenced by the total amount of the element in the soil but also by factors such as pH, texture, organic matter, clay minerals, redox potential and interrelation of the elements.

3.1 Soil pH

Soil pH can markedly affect the availability and consequently the plant uptake of trace elements. Reducing the acidity reduces the solubility and uptake of Al, Co, Cu, Fe, Ni, Sn, Zn, and particularly of Mn and increases that of Mo and S. Cases have also been reported in which the ability of plants to utilize trace elements decreases with decreasing acidity (increase in pH) to a minimum at pH 5.2-6.5, while utilization at higher pH remained constant or even increased.

An example of the influence of soil pH raised by liming on the trace element content of plants is given by the following data (Mitchell 1957):

Rate of applied $CaCO_3$ (t/ha)	Soil pH	Element content (ppm in oven dry materials)							
		Mixed pasture				Red clover			
		Co	Ni	Mo	Mn	Co	Ni	Mo	Mn
0	5.4	0.28	1.83	0.42	125	0.22	1.98	0.28	58
14.4	6.1	0.19	1.34	1.54	111	0.18	1.40	1.48	41
27.1	6.4	0.15	1.08	2.14	72	0.12	1.10	1.53	40

The effect of pH on the solubility and plant availability of different trace elements is often more varied than that shown above. Apparently, there are also differences in the influence of pH on th uptake of native and applied trace elements, the latter being usually more affected. Among the actual trace elements Mo is the only one whose availability increases with increased soil pH.

3.2 Soil Texture

Little is known about soil texture as a factor affecting availability, but coarse textured or sandy soils tend to be associated with low total trace element contents and symptoms of deficiencies in crops.

3.3 Organic Matter

The influence of soil organic matter on the availability of trace elements has been widely studied and contradictory results have been reported. The view was held earlier that the absorption of trace elements by organic matter may sometimes be sufficient to cause deficiency, but more recent work does not support this view and the influence of organic compounds on inorganic soil constituents is not clearly defined.

On cropping, organic soils are among those most often found to be deficient in one or several trace elements. In some cases analyses show a high content (ppm) of trace elements in peat soils, but when the plants grown on peat are also analysed the content may be lower than in plants grown on other soils. This has been attributed, maybe too often, to low availability or high fixation of trace elements in organic soils whereas the actual reason may lie in the low total content. To understand these contradictory results it must be realised that the dimension or unit in which the trace element content is given is of prime importance and should not be overlooked when interpreting the results. For example, if two soils, a mineral soil with a bulk density (or volume weight) of 1.5 and a peat soil with an extremely low bulk density of 0.1, are analysed and both show an equal content of 100 ppm of a certain trace element when expressed in the usual way on weight basis, the result is completely different if expressed on volume basis, as shown below.

Soil	Bulk density	Trace element content as expressed	
		on weight basis (ppm)	on volume basis (mg/litre of soil)
Mineral	1.5	100	150
Peat	0.1	100	10

Thus, in this extreme example, the 100 ppm in the peat soil actually corresponds to only one fifteenth of that of the mineral soil.

It is apparent that plants are able to adsorb many forms of organic matter-bound trace elements and that many of the trace element deficiency cases found in peat soils are not due to the low availability but to the inadequate total trace element sources in these soils.

3.4 Miscellaneous Factors

Other factors which may cause considerable differences in the availability of trace elements to plants are microbiological activity in soils, soil drainage and oxidation-reduction conditions, weather conditions and seasonal variation. Because of the mutual interactions between these factors, the extent of their single effects is often uncertain.

Microbiological activity is largely dependent on all the abovementioned factors as well as on the chemical composition of soil, pH, quantity and quality of soil organic matter, etc. There is some evidence that Zn deficiency may sometimes be directly caused by the soil micro-organisms competing with the plants for the small quantities of the available Zn present. More indirectly, micro-organisms may affect the availability of trace elements by releasing ions during the decomposition of organic matter, by immobilization of ions through incorporation into microbial tissue, by oxidizing elements to less available forms, by reduction of oxidized forms and by indirect transformations such as changes in pH or oxidation potential.

Clearly the availability of Mn and Fe is more affected by oxidation and reduction than that of other trace elements, but reduction caused by high moisture content or flooding can also increase the availability of S, Cu, Mo, Ni, Zn, Pb, V and Co in some cases (Mn, Fe, Mo, S) up to toxic levels. The low availability of Mn and Fe in oxidized conditions is usually explained in terms of the lower solubility of the trivalent as compared with the reduced divalent form. However, oxidation-reduction processes are usually accompanied by changes in soil pH, which may complicate the picture, as well as interactions between Mn and Fe and other elements.

The availability of many trace elements has been found to fluctuate with seasonal variations. It is difficult, however, to point out any general trends in availability due to weather changes because of the complexity of factors simultaneously involved. High soil temperature has often been found to be associated both with high uptake of trace elements and with low soil moisture, the latter being often shown to be responsible for low availability. Also microbiological activity is largely controlled by temperature and may alter the availability according to the state of oxidation-reduction, type of micro-organism, organic matter, etc. Excessive phosphorus fertilization has been found to reduce the availability of Cu and Zn, increase that of Mn and have variable effects on the uptake of B and Mo. Several possible explanations have been offered for the Zn or Cu deficiency so induced, including the immobilization of the trace element within the plant by abnormal amounts of P being present, precipitation by P within the conducting tissue of the plant shoot, possible P-Zn antagonism within the root and reactions occurring outside the physiologically active roots so reducing the uptake of Cu and Zn.

4. CORRECTION OF TRACE ELEMENT DEFICIENCES

For correcting trace element deficiencies in the field, the most commonly adopted practices are perhaps the soil applications of soluble salts such as borax, cobalt chloride, copper sulphate, ferrous sulphate, manganous sulphate or oxide or manganese ammonium phosphate, sodium molybdate or zinc sulphate containing the trace element in question. Common mineral fertilizers usually contain minute quantities of trace elements but recently additions of certain trace elements into NPK fertilizers have become more common.

Salts of trace elements may also be used as a foliar spray, especially when the soil applications are ineffective, as for example in the case of Fe in limed or calcareous soils, where the soluble ferrous sulphate quickly ionizes in the soils, becomes bound to other ions or oxidizes into the less soluble ferric form and loses its effectiveness.

In cases where both soil applications and foliar sprays have given unsatisfactory results, chelates have been used to correct trace element deficiencies. Since the introduction of EDTA (ferric potassium ethylenediamine tetra-acetate) in 1951 great advances have been made in the use of chelating agents, not only with Fe but also with other trace elements that are deficient such as Cu, Mn and Zn.

Chelates are highly stable and although some of the chelates are quite soluble, the trace element in a chelate does not ionize or precipitate in the soil but is held in a soluble complex form which is available for absorption by the root. In chelates the trace element is protected from fixation and the chelating molecule including the trace element may enter the plant. The chelated metals are only slowly exchangeable with other cations, but highly water soluble chelates may be subject to some loss by leaching and may also be decomposed by microbial activity. Chelates are usually not toxic to plants.

Chelates have also been used as foliar sprays but the results, in general, have not been as satisfactory as by soil treatments, perhaps owing to the decomposition of chelates by sunlight. One of the factors limiting the use of chelates is their high price.

REFERENCE

Mitchell, R.L. Trace element content of plants. Research (London) 10: 357-362 1957

Paper 6 SOIL MANAGEMENT WITH RESPECT TO LIMING, MANURING AND OTHER SOIL AMENDMENTS IN EAST AFRICA

S.O. Keya

Department of Soil Science, Faculty of Agriculture, University of Nairobi, Kenya

1. INTRODUCTION

Soil amendments provide a means of raising the productivity of good farm land or utilization of those marginal soils where extremes of acidity, alkalinity or physical characteristics limit plant growth. The productive soils of East Africa are generally acid, and low in available N, P and S and minor element deficiencies or toxicities are common. The low pH of these soils results in a preponderance of exchangeable Al, manganese toxicity and P fixation. It is for these reasons that liming has been adopted to raise the CEC, increase the supply of Ca and reduce the Al and Mn toxicity.

2. CONVENTIONAL SOIL AMENDMENTS

2.1 Lime

Responses to liming have not been as marked on tropical soils as on temperate zone soils. The addition of Ca to soils with low CEC may cause nutrient imbalance and lower the availability of micronutrients (Ignatieff 1949). The unpredictable response to liming probably emphasizes the difference between tropical soils rich in sesquioxide and the soils of the temperate regions dominated by **2:1 clays**. The oxide surface displays a constant surface potential while the 2:1 clays exhibit a constant surface charge (Mekaru and Uehara 1972). Ignatieff and Page (1958) showed that wheat and pyrethrum in Kenya responded to liming when the soil pH was below 5, but responses were unlikely when the pH was above 5.2. Other experiments at five sites around Kitale, Kenya, indicated that application of 500 kg/ha of Ca did not increase the yield of maize although exchangeable calcium was as low as 2 meq/100 g (Laycock and Allan 1976).

In Tanzania and Uganda economic responses from applied lime have not been obtained with food crops such as maize and potato. However, in some acidic and especially sandy soils, responses have been obtained with sweet potato, rice and sisal in Kenya and Tanzania. In Uganda, responses were obtained with beans at Kawanda (Stephens 1967) and with sorghum at Serere (Wadsworth 1965, cited by Foster 1970). Maize planted on land reclaimed by draining the Nyanza swamp in western Uganda where the soil pH was below 3.5 failed completely in the absence of lime.

Foster (1970) conducted 84 factorial trials on continuously cultivated soils in various districts of Uganda and obtained 18 significant responses. He concluded that groundnuts are likely to respond to lime one year after its application, if the soil exchangeable calcium is below 6 meq/100 g. Cotton, sweet potato and beans did not respond to lime in 23 trials where the soil pH was above 5.25, but significant responses were obtained in eight out of 18 trials where soil calcium was below 6 meq/100 g and soil pH below 5.25. His findings that cereals are likely to respond to lime if the pH is below 5.25 concurred with those from Kenya by Ignatieff and Page (1958).

The materials used to raise the soil pH have been mainly calcium oxide, calcium magnesium carbonate and magnesium oxide applied at the rate of about 5 t/ha. Recently Uriyo and Singh (personal communication) were able to raise the pH of a Tanzania oxisol (nitosol) from 5.5 to 7.0 by an application of 5 t/ha of sepiolite (calcium magnesium silicate) of which there are large deposits in northeastern Tanzania. They obtained a significant yield increase with a test crop of maize.

At its 13th meeting, the East African Specialist Committee on Soil Fertility and Crop Nutrition reviewed the progress on liming experiments during the last 30 years and resolved to discourage further research on the subject but proposed that liming should aim at neutralizing toxic Al without raising the CEC or pH.

2.2 Farmyard Manure

In contrast to lime it is clear that farmyard manure improves fertility. Long term manurial experiments at Serere, Uganda, by Jameson and Kerkham (1960) showed that farmyard manure applied at 6 and 12 t/ha every five years increased the the yield of all crops except sweet potato and had a residual effect for 20 years. Leaving the land fallow for some three years did not restore soil fertility but an application of 25 t/ha of farmyard manure every 3 years was adequate to maintain soil fertility under continuous cropping at Serere.

Grimes and Clarke (1962) in Kenya showed that in a rotation of sweet potato, maize and cassava, a large response to farmyard manure was obtained by an annual application of 4 t/ha. They also found that artificial fertilizers were as effective as farmyard manure in sustaining crop yields. In Bukoba, Tanzania, Evans and Mitchell (1961) reported that an application of 5 or 10 t/ha of farmyard manure significantly increased the yield of maize on a leached sandy soil.

2.3 Interaction between Lime and Farmyard Manure

Although Foster (1970) did not find any consistent interaction between lime and other fertilizer treatments in Uganda, Le Mare (1972) working in Tanzania found that productivity could be maintained by using compost, superphosphate, ammonium sulphate and lime. Compost increased pH, exchangeable K, Ca and Mg. Lime applied at the rate of 3.5 t/ha 32 months before planting increased pH and exchangeable Ca and decreased exchangeable Mn. Anderson (1970) working with acid soils of Tanzania also recorded a beneficial effect of lime, P and K on yield of groundnuts.

2.4 Plant residues

Under continuous arable cropping, the soil suffers deterioration resulting in reduced infiltration. As at IITA, Ibadan, Nigeria, work is in progress at Morogoro, Tanzania, on the reclamation of such soils by the use of organic mulches. With the object of improving the soil structure and permeability, no tillage is practised and trash is left on the surface. The seed is directly sown. In addition to the activities of microorganisms in the semi-humid environment of Morogoro, termites feeding on the surface litter leave behind faecal pellets and aerate the soil with their tunnels. The process of improvement is therefore a natural one, stimulated by management. The use of a grass mulch is a standard recommendation for coffee culture in East Africa and the benefit certainly goes beyond water conservation.

3. OTHER SOIL AMENDMENTS

3.1 Filtermud

Soil salinity occurs in some parts of East Africa and restricts the growth of crop plants. Experiments conducted by Kinyali (1976) at Arusha Chini, Tanzania, using filtermud (a byproduct of white sugar manufacture) as a soil dressing showed that it was possible to grow sugarcane where the pH was 8.7 and EC above 4 mmho/cm. Not only did the cane setts planted on the treated soil germinate and become established faster but the cane yield was also more than doubled. The effect of filtermud may be due to its high potassium content (about 13 meq/100g). It may also aid in the formation of stable soil aggregates. The increased aggregation improves aeration, water movement and increased root development, changes which were noticeable three months after its application. Large quantities of filtermud are available at sugar factories.

3.2 Ash

Kitchen ash is produced in many East African households and is valued by the backyard tobacco grower and gardener. Another source of ash is bagasse which is used as fuel in sugarcane factories. In Africa ash has been claimed to raise the soil pH (de Geus 1967, cited by Kalpage 1976). Probably the effect of burning crop residues and of the bush fires that are so common in Africa is to supply plant nutrients which would otherwise be immobilized prior to mineralization. Zake (1974), in glasshouse experiments using two red sandy clay loam soils from Buganda Catena and Amaranthus and soyabean as test crops, found that application of ash produced better yields than the $CaCO_3$ treatment and in certain cases $CaCO_3$ depressed yields.

3.3 Calcium Silicate

It has been suggested that calcium silicate might be superior to the traditional liming materials since it would help to reduce P fixation in acid soils. However, it is the SiO_3 and not the SiO_2 which is active in reducing P fixation. "Kensil", mined in Kenya, which at one time was thought to be rich in $CaSiO_3$ is predominantly $CaSiO_2$.

3.4 Organic Matter

Urban expansion in East Africa provides a growing potential source of organic manures and pretreated dried sewage is being used in the parks in Nairobi. Coffee pulp is an agricultural waste available in limited quantities.

Green manuring by the ploughing under of succulent leguminous crop plants has not gained acceptance in Africa, nor has the inoculation of legumes with Rhizobia been fully exploited although it is probably the cheapest and most economic of improvement measures. Inoculants are not readily available, and being imported and subject to deterioration may not be suitable or fully effective.

4. SUPPLY AND DISTRIBUTION OF SOIL AMENDMENTS

Supplies of animal manure are scarce at all times and of low nutrient composition which deteriorates further on storage. Large quantities of plant residues for compost making or mulching are also usually lacking, 1 ha of permanent grassland being required to mulch 1 ha of coffee annually (Pacine and Jones 1954). Transport of bulky or heavy loads by carrying on the back or head is a severe limitation imposed by most farms being inaccessible to motor vehicles or by prohibitive transport costs. The fuller integration of animal and crop production systems is necessary so that the animals can not only be fed and produce manure on the farm but can also lighten the burden of manual labour and transport.

REFERENCES

Anderson, G.D. Fertility studies on a sandy loam in semi-arid Tanzania.
1970 II. Effect of phosphorus, potassium and lime on yield of groundnuts. Exp. Agric. 6: 213-222.

Evans, A.C. and Mitchell, H.W. Soil fertility studies in Tanganyika, I.
1961 Improvement to crop and grass production on a leached sandy soil in Bukoba. E. Afr. Agric. For. J. 27: 189-196.

Foster, H.L. Liming continuously cultivated soils in Uganda. E. Afr. Agric.
1970 For. J. 36: 58-69.

Grimes, R.C. and Clarke, R.T. Continuous arable cropping with the use of manure
1963 and fertilizers. E. Afr. Agric. For. J. 28: 74-80.

Ignatieff, V. Efficient use of fertilizers. FAO Agric. Stud. No.9.
1949

Ignatieff, V and Page, H.J. (eds) Efficient use of fertilizers. FAO Agric.
1958 Stud. No.43.

Jameson, J.D. and Kerkham R.K. The maintenance of soil fertility in Uganda.
1960 I. Soil fertility experiments at Serere. Emp. J. Exp. Agric. 28: 179-192.

Kalpage, F.S.C.P. Tropical soils, classification, fertility and management.
1976 London, Macmillan.

Kinyali, S.M. Reclamation of affected soils for sugar cane production. Proc.
1976 East Afr. Agric. For. Res. Org. Annu. Sci. Con. Muguga, 26-28 October 1976.

Laycock, D and Allan, A.Y. Fertilizer, cultural and husbandry trials. U.K. Min.
1976 Overseas Dev. and Kenya Min. Agric. Maize Agronomy Research Project. Final report Part II.

Le Mare, P.H. A long term experiment on soil fertility and cotton yield in
1972 Tanzania. Exp. Agric. 8: 299-310.

Mekaru, T. and Uehara, G. Anion adsorption in ferruginous tropical soils. Soil
1972 Sci. Soc. Amer. Proc. 36: 296-300.

Pereira, H.C. and Jones, P.A. Field responses by Kenya coffee to fertilizers,
1954 manures and mulches. Emp. J. Exp. Agric. 22: 23-36.

Stephens, D. The effects of different nitrogen treatments and of potash,
1967 lime and trace elements on cotton, on Buganda clay loam soil. E. Afr. Agric. For. J. 32: 320-325.

Zake, J.Y.K. Comparison of ash and calcium carbonate as liming materials in
1974 some Uganda soils. Paper presented at the 13th Meeting of the East African Specialist Committee for soil fertility and crop nutrition, Nairobi, Sept. 1974.

Paper 7

ROLE OF SOIL TESTING FOR IMPROVED NUTRIENT EFFICIENCY

A. Finck

University of Kiel, Germany

1. INTRODUCTION

Plants obtain their mineral nutrients from the soils and under natural conditions plant growth may be limited by a nutritional minimum growth factor. In agriculture the aim is the production of high crop yields and therefore the limiting main factors have to be improved by supplementing the natural soil supply with fertilizers. Since fertilizers are neither cheap nor abundant, they must be used economically.

The common mistakes in fertilizer use to be avoided are:

(a) neglect of the basic soil conditions required for optimum conditions of soil and fertilizer nutrient use, (b) insufficient NPK fertilization for high production, (c) neglect of the supply of secondary and trace elements, (d) unnecessary surplus of fertilizers leading to pollution.

For precise fertilization the optimum fertilizer requirement should be based on diagnostic methods. The best test is the fertilizer experiment, but it is expensive and slow. Therefore common diagnostic methods (soil and plant testing) are required, and the purpose of this paper is to describe the principles of soil testing as a basis for fertilizer recommendations.

2. SOIL TESTING FOR ASSESSMENT OF GENERAL GROWTH CONDITIONS

A high efficiency of soil nutrient use is only obtained when the basic conditions of soil fertility have been met, e.g. optimum soil reaction. pH testing is a basic requirement in order to avoid soil acidity, to obtain optimum availability of soil nutrients which are strongly dependent on pH and to obtain optimum soil structure.

The combination of optimum nutrient availability and good structure often presents difficulties on medium and heavy soils insofar as for a good soil nutrient supply a lower pH range is preferable, whereas for optimum structure a higher one would be better. The optimum pH range is not yet established for many soil and growth conditions. This accounts for different opinions on optimum liming. However, the occasional lack of response to liming can often be explained by inadequate nutrient supply, to clarify which requires detailed soil testing.

Soil testing for pH and the lime requirement, despite many theories involved, is reliable and comparatively simple (McLean 1973).

3. SOIL TESTING FOR NUTRIENT AVAILABILITY

3.1 Forms of Nutrients in Soils and the Estimation of the Available Fraction

From the plant nutritional point of view several forms of nutrients in soils can be distinguished, although not always easily separated by laboratory methods (Table 8).

Table 8 RELATIONSHIP BETWEEN MOBILITY AND AVAILABILITY OF NUTRIENT FORMS IN SOIL

	Water soluble nutrients	Exchangeable nutrients	Nutrient reserves	
Chemical mobility	Highly mobile	Partly mobile	Easy to mobilize	Difficult to mobilize
Availability	Very easily available	Easily available	Moderately available	Almost unavailable

Methods for the determination of available nutrients are designed to estimate all or part of the total available fraction. Fig.11 shows a selection of methods for extracting different parts of the available range.

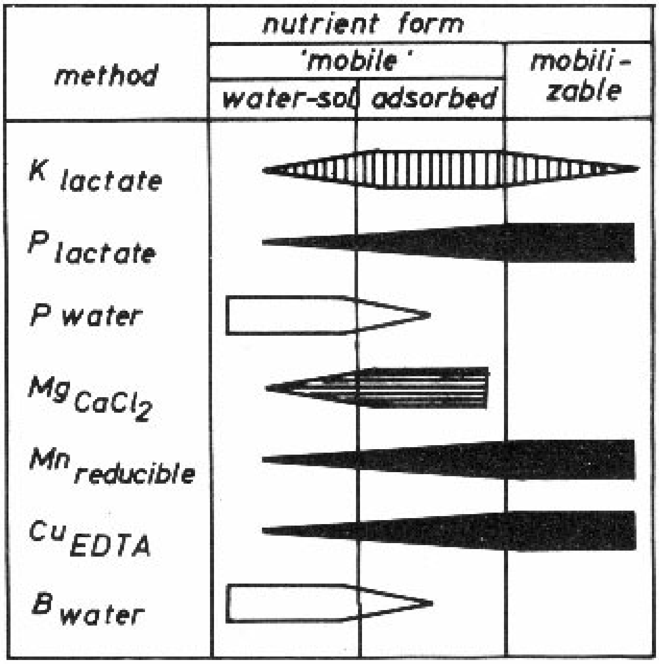


Fig. 11 Methods for extracting different fractions of available nutrients (Finck 1970)

The different forms of nutrients are interrelated. Plants take up nutrients from the soil solution (water soluble form) which represents the intensity factor (Corey and Schulte 1973). The maintenance of a high intensity, however, depends (via the exchangeable form) on a high content of easily mobilizable reserves (capacity factor) and on the rate of transfer from one fraction to the other.

In a scientific investigation all these fractions and factors can be determined with great accuracy, e.g. for P recently by Dalal and Hallsworth (1976). However, soil testing for farmers should be simple as well as reliable. A good method should combine the intensity and capacity factor (including the rate factor), although normally the emphasis has to be put on one of them.

3.2 Selection of the Best Method

The choice of a method depends on the special behaviour of the nutrient in soil and on the production level.

For cationic nutrients with a considerable exchange fraction, for example, this fraction is likely to give a fair estimate of the available fraction, especially if the reserves are relatively low.

At low production and fertilization levels plants mainly use soil nutrients and the test methods must place emphasis on the reserves that can easily be mobilized. Even the total reserves have been used as an index (extraction with hot conc. HCl). The importance of the reserves as an index for available nutrients increases with the temperature, since at 30 - 40° C the mobilization rate is about 4 - 6 times higher than at annual average temperature of 10° C (Finck 1963).

At high production level high yielding plants are used and the nutrient supply of the soil is high. Under these circumstances annual plants take up nutrients mainly from easily available forms.

In view of the complexity of determining 'available' nutrients it is not surprising that there are many extraction methods. More than 50 methods have been proposed for Mn and almost as many for P.

The methods for available nutrients can be divided into biological and chemical methods. The chemical methods either extract mainly the water soluble or exchangeable nutrients or the mobilizable reserves.

Examples of 'water soluble' methods are those for B and some for P. The results represent mainly the intensity factor. Disadvantages are the small and sometimes variable contents leading to sampling and analytical difficulties. In order to include part of the capacity factor, an extraction ratio of 1 : 60 is chosen for P and hot water for B.

Several 'exchangeable' methods are used for available K and Mg. The interpretation can be based on content of exchangeable nutrients in soil or expressed as percentage of the exchange complex.

Methods for mobilizable 'reserve' nutrients can be divided according to the extractants: i.e. extraction by inorganic acids, organic acids, alkaline solutions, complex reagents (for heavy metals), reducing reagents (for 'redox' elements), physico-chemical methods (e.g. exchange resins, electro-ultrafiltration) and isotope methods.

3.3 Calibration of Methods

The best method for the estimation of the available portion of a nutrient cannot be selected by logical reasoning alone and it must be emphasised that 'logical reasoning is quite unreliable as a guide to the truth in biological research'(Beveridge, cited by Finck 1960). Therefore the methods have to be evaluated (calibrated) in order to select the best one for a given soil and production condition.

The main standards for calibration are the relative yield and plant nutrient contents. The relative yield is obtained from fertilizer experiments in which the nutrient tested is the main factor and solely responsible for the yield obtained. The result is expressed in curves for different soils and crops. An example is shown in Fig.12.

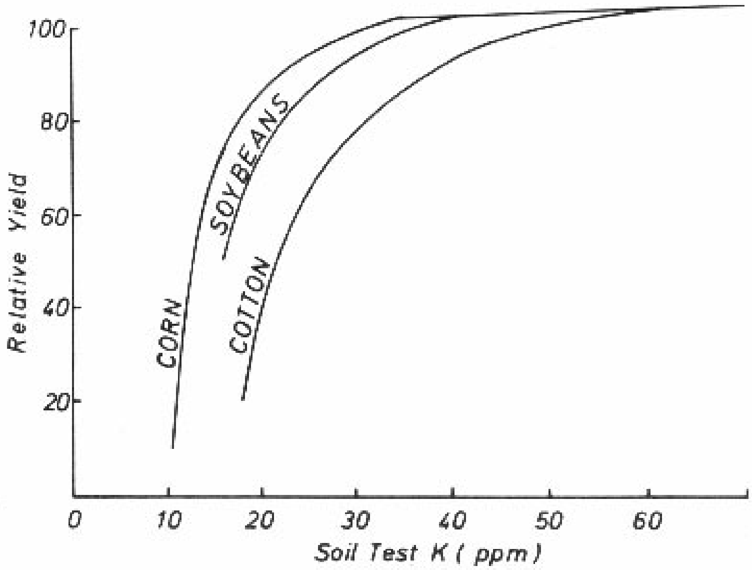


Fig. 12 Relationship between soil test K and relative yields of crops (Cope and Rouse 1973)

The nutrient contents of plants can be used if fertilizer experiments are difficult to carry out, as often is the case for trace elements. Within the range of latent deficiency and optimum supply, the nutrient contents of plants reflect the amounts of available nutrients in the soil and can therefore be used as an index of calibration. This procedure is quite reliable if certain precautions are observed (Finck 1976).

The comparison of test standard and soil nutrient is made statistically and the results are expressed as r^2 values (the r value often used is much less adequate and less intelligible). Soil methods should have r^2 values of more than 60 or 70% in order to be useful.

As an example, data for available manganese are presented in Table 9.

Table 9 CALIBRATION OF SOIL TESTS FOR AVAILABLE MANGANESE IN EGYPT (CORRELATION WITH Mn CONTENT OF SOYABEANS)

Method	r^2 (%)
1 n NH_4- acetate	13
0.1 n phosphoric acid	28
1 n Na-acetate (pH 5.5)	30
0.05 m Na-EDTA	34
0.1 m Na-pyrophosphate	67
0.2% hydroquinone in NH_4-acetate	51
0.05% "	63
0.025% "	69

Source: Metwally et al 1973

4. INTERPRETATION OF SOIL TEST DATA

The data on available nutrients in the soil supplied by a reliable method provide an estimate of the crop response (Hauser 1973). In order to obtain fertilizer recommendations from the soil test data, the following information is required: (a) relationship between soil data and relative yield, (b) the amount of fertilizer nutrient required to make good the difference between a certain relative yield and the maximum yield (data supplied by fertilizer experiments). The relation between soil data and fertilizer amounts can be plotted directly on a continuous curve or calculated via fertility classes.

An example of direct and continuous interpretation (including the economic aspect) is presented for P in Fig.13. For convenience in use, the amounts of fertilizer are grouped in classes.

Table 10 shows the relationship between soil nutrient status, crop yields and fertilizer requirements. The goal of fertilization is the range of optimum supply without getting far into the range of luxury uptake. At optimum supply a normal fertilizer dressing corresponding to the losses (mainly the nutrients removed by crops) has to be applied. Data for amounts of nutrients removed by crops were given by Ignatieff and Page (1968), de Geus (1973) and Finck (1977).

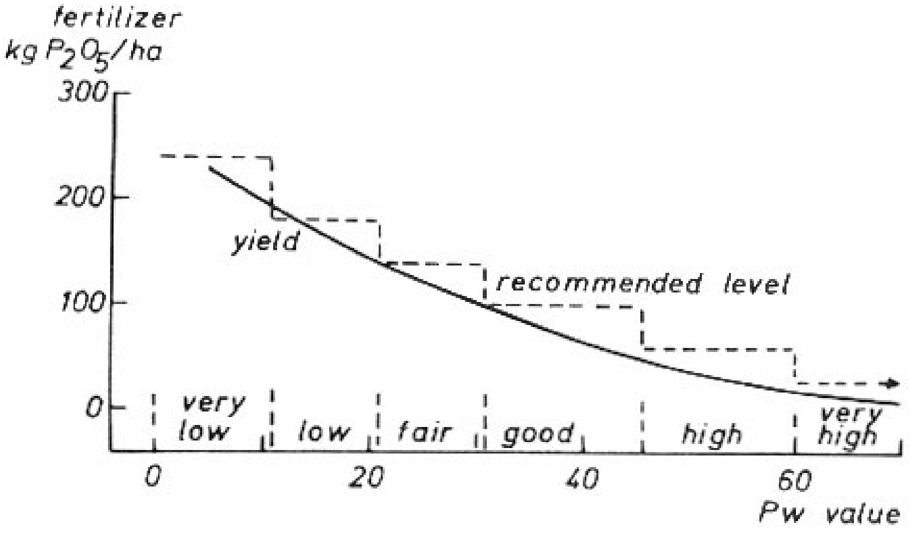


Fig. 13 Relationship between water soluble P in soil and economic optimum amount of P fertilizer for potatoes (Ris and Van Luit 1973)

Table 10 RANGE OF SOIL NUTRIENT STATUS IN RELATION TO CROP YIELD AND FERTILIZER REQUIREMENT

Soil nutrient status	Crop yield	Fertilizer requirement
Severely deficient	Low	Heavy, or special measures to be taken
Slightly deficient	Moderate	To be increased to say 50% above normal
Optimum supply	Good	Normal rate to replace losses
Luxury supply	Good	Reduce to half normal rate or less
Small surplus	Moderate	None
Large surplus	Low	Counter measures required

4.1 Available Nitrogen

The estimation of available N is less well developed compared with P and K. The most important problem is the estimation of the first N dressing to be applied at sowing time or in the spring, taking into account the amount of N present already in the soil. In the Netherlands it is suggested that the amount of nitrate should be determined to a depth of 1m and that this amount of N should serve as the base for the fertilizer rate (Ris 1974). Thus if 120 kg N are required for wheat in the spring and if there are 80 kg in the soil only 40 kg have to be added as fertilizer. This procedure not only saves mineral N, but also prevents unnecessary losses and the side effects of pollution.

5. ALLIED PROBLEMS

5.1 The Upper Supply Limit of Nutrients

In intensive agriculture fertilizers are sometimes applied in large amounts. In consequence the available nutrient content of the soil rises to five or ten times the normal amount. Soil testing, therefore, is also becoming a means of avoiding waste. The establishment of the upper limit requires considerable calibration work.

For lactate soluble P, for example, values of above 120 ppm P give maximum cereal yields. Therefore soils containing more than 120 or even 200 ppm P need no additional P for some years.

5.2 Toxicity of Nutrients

A new function of soil testing is developing with regard to environmental problems. The accumulation of nutrient or other elements in the soil may endanger crop yields and the health of the consumer. Toxic elements may be introduced by plant protection products and the prolonged use of city waste or fertilizers containing trace elements. If the toxicity limits for plants are established by correlation of plant and soil data, toxicity limits for available nutrients in soil can be established.

5.3 Soil Testing and Stress Conditions

Plants are subjected to many stresses and fertilization under such conditions presents special problems. Since the adverse effects of stress can often be decreased by the better supply of some nutrients, special fertilization becomes increasingly important (Finck 1977). A surplus of some nutrients in soil may not increase the yield, but may increase the resistance of plants to adverse climatic and biological conditions.

Testing saline soils for salinity is a basic requirement, but the nutrient status also needs special consideration. Owing to antagonistic effects, however, the data indicated by soil testing need a different interpretation and have to be supplemented by plant analysis data. Since fertilization of saline soils should avoid any unnecessary addition of fertilizer salts and yet add the nutrients required, precise diagnostic methods play an even more important role than on non-saline soils.

It is possible with appropriate fertilizer dressings, based on soil and plant tests, to suppress the uptake of Na and increase the formerly depressed uptake of essential nutrients to the benefit of the crop yield.

5.4 Soil and Plant Analysis

Soil testing and plant analysis in combination often gives the best information on the nutritional status, and the interpretation of the data is easier since the limiting values for a given plant are fairly uniform everywhere. However, plant analysis requires more technical expenditure, whereas soil analysis is normally easier to perform.

Limiting values (concentrations required for optimum supply) have been established for many crops (Chapman 1966, Walsh and Beaton 1973, Reisenauer 1976, Bergmann and Neubert 1976).

One great disadvantage of soil analysis for available nutrients is the diversity of limiting values for all kinds of different soils. They have to be established in any area before soil testing can be interpreted. Therefore in areas of unknown soil conditions soil testing is difficult to apply whereas plant analysis often can give immediate information.

REFERENCES

Bergmann, W. and Neubert, P. Pflanzendiagnose und Pflansenanalyse. Jena,
1976 Fischer.

Chapman, H.D. Diagnostic criteria for plants and soils. Univ. of California.
1966

Cope, J.T. and Rouse, R.D. Interpretation of soil test results. In Walsh,
1973 L.M. and Beaton, J.D. eds. Soil testing and plant analysis, pp.35-54, Madison, Soil Sci. Soc. Amer.

Corey, R.B. and Schulte, E.E. Factors affecting the availability of nutrients
1973 to plants. In Walsh, L.M. and Beaton, J.D. eds. Soil testing and plant analysis, pp.23-33. Madison, Soil Sci. Soc. Amer.

Dalal, R.C. and Hallsworth, E.G. Evaluation of the parameters of soil
1976 phosphorus availability factors in predicting yield response and phosphorus uptake. Soil Sci. Soc. Amer. Proc. 40: 541-546.

Finck, A. Principles and problems of the chemical estimation of the supply of
1960 available soil manganese. Pl. Soil 13: 39-46.

Finck, A. Tropische Böden. Hamburg, Parey.
1963

Finck, A. Pflanzenernährung in Stichworten, Kiel, Hirt.
1976

Finck, A. General aspects of fertilization in tropical and subtropical
1977 agriculture. Plant Research and Development (in press) Tübingen.

Finck, A. Mineraldüngung gezielt. AID-Broschüre Nr. 401, Bonn.
1977

Geus, J.G. de Fertilizer guide for the tropics and subtropics. 2nd ed.
1973 Zurich, Centre d'Etude de l'Azote.

Hauser, G.F. Guide to the calibration of soil tests for fertilizer recommendations.
1973 FAO Soils Bull. No. 18.

Ignatieff, V. and Page, H.J. Efficient use of fertilizers. FAO Agric.
1968 Stud. No. 43.

McLean, E.O. Testing soils for pH and lime requirement. In Walsh, L.M. and
1973 Beaton, J.D. eds. Soil testing and plant analysis, pp.77-95. Madison. Soil Sci. Soc. Amer.

Metwally, A.I., El-Damati, A.H. and Hamdy, A.A. Evaluation of different
1973 chemical extractants for the determination of available soil manganese in calcareous soils. Egypt. J. Soil Sci. 13: 79-96.

Reisenauer, H.M. Soil and plant testing in California. Div. Agric. Sci. Univ.
1976 Calif. Bull. No.1879.

Ris, J. Stikstofbemestingsadviezen voor bouwland. Stikstof 78: 168-173.
1974

Ris, J, and van Luit, B. The establishment of fertilizer recommendations on the
1973 basis of soil tests. Paper Indt. of Soil Fertility, Haren (Netherlands).

Walsh, L.M. and Beaton, J.D. Soil testing and plant analysis. Madison, Soil
1973 Sci. Soc. Amer.

Paper 8 RECENT RESEARCH AND ADVANCES IN CHARACTERIZATION OF GENOTYPIC DIFFERENCES IN ION UPTAKE AND ION ASSIMILATION EFFICIENCY

F. van Egmond

Department of Soils and Fertilizers, Agricultural University, Wageningen,
the Netherlands

1. INTRODUCTION

Genotypic variability which occurs to a greater or lesser extent within plant species gives an opportunity to breed cultivars which meet in various ways the growers requirements. The numerous reports of genotypic differences in ion uptake, ion utilization or the secondary effects of these processes, indicate that improvement of ion uptake and ion assimilation efficiency is possible.

The genotypic differences reported range from: $(Na^+ + K^+)$-activated ATPases in sugarbeet, K uptake in grapes, iron uptake and assimilation in soyabeans, maize and tomato, the nitrate reductase in maize and wheat, the nitrate concentration in smooth leaved and savoy leaved spinach, to the salt sensitivity of tomato etc. (Alleweldt and Pollak 1976, Barker *et al* 1974, Brown 1967, Brown *et al* 1971, Hageman 1975, Kylin and Hansson 1971, Rao 1976, Rush and Epstein 1976, Weiss 1943).

Two topics will be dealt with in this paper: (a) the nitrate uptake and assimilation efficiency of wheat, and (b) the efficiency of utilization of iron by soyabeans.

2. NITRATE UPTAKE AND ASSIMILATION BY WHEAT

After the straw strength of wheat had been improved, so reducing the risk of lodging at high N rates, it was said that the nitrogen response was improved. Kramer (1977), however, distinguished between nitrogen response and nitrogen tolerance. The N response is the increase in production per additional unit of applied N, while the N tolerance is the rate above which additional N decreases production. It was mainly the genotypic differences in straw strength that contributed to the improvement of the N tolerance. The more closely the maximum N tolerance is reached, the more timely it is to try to improve the N response of wheat without reducing the maximum N tolerance.

Physiological or biochemical markers are required by the plant breeder for his work on attempting to improve the N response of wheat. In the N flowsheet shown in Fig.14, the most interesting features are the nitrate absorption by the roots, the nitrate reduction in roots and shoots, and the translocation of reduced N to the ear. In making a choice, a knowledge of uptake kinetics must be used to characterize genotypic differences. For example, the relationship between NO_3^- concentration in the root medium and NO_3^- uptake rate at important points in Feekes' scale could be calculated for wheat genotypes grown under standard and well defined climatic conditions. From the results obtained in these studies, $K_{\text{Michaelis Menten}}$ and V_{max} could be calculated as important physiological markers of NO_3^--uptake.

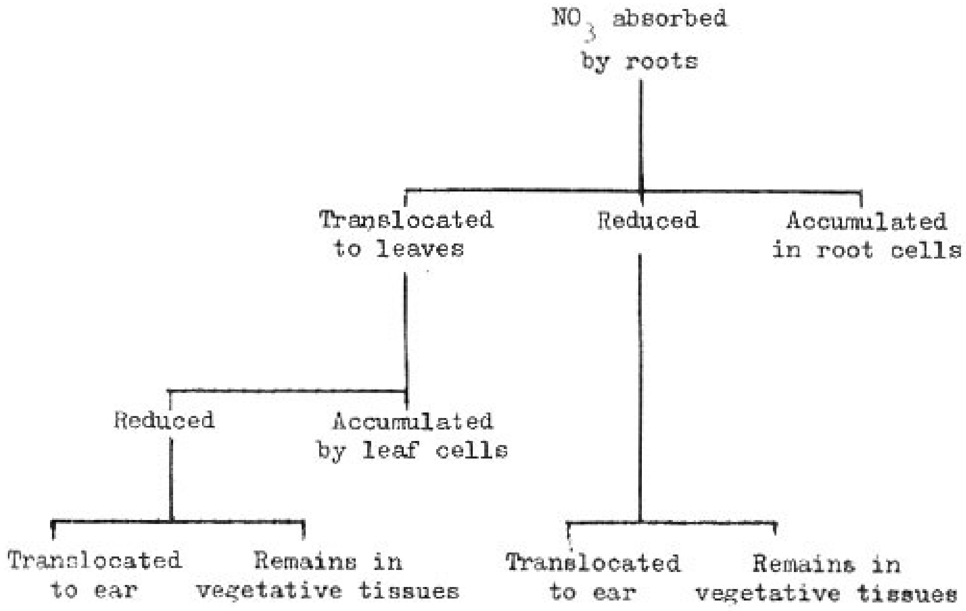


Fig. 14 Nitrogen flow in the plant

Attempts have been made to use in vitro nitrate reductase activity as an indicator of the superior performance of a crop genotype. Success reported for this single criterion has been only limited. As can be expected with any complex system, no single criterion has been found to play a regulatory role important enough to serve as a marker for the efficiency of nitrate use. Recent results show that in wheat, for example, there is genetic diversity in ability to take up, accumulate and reduce nitrate (Ras 1976).

From a theoretical point of view markers of nitrate reduction in root versus shoot can be expected to be of importance. In higher plants solar energy is intimately involved in nitrate assimilation. The intermediate reduction product NO_2^- (nitrite) can be photoassimilated in green leaves by accepting electrons, most probably at the level of ferredoxin. This means that nitrite (NO_2^-) is assimilated even more directly than carbon dioxide (CO_2). Penning de Vries (1975) pointed out that as light saturation is approached, nitrite (NO_2^-) may increase photosynthetic efficiency by allowing electron flow through photosystem II, when photosynthesis rate is limited by the ambient concentration of CO_2. The entire nitrate assimilation pathway also operates without photoassimilatory coupling, e.g. plants reduce NO_3^- to NH_4^+ in the dark or in their roots. There is evidence that nitrate assimilation can occur in either the root, the shoot or in both (Minotti and Jackson 1970). Since reduction in roots presumably is more costly to the plant in terms of energy (photoassimilation of NO_3^- impossible) reduction of NO_3^- in the root must be evaluated as an aspect of efficiency of NO_3^- utilization. Apart from nitrate reductase in the leaf, the ratio of nitrate reductase in shoot to nitrate reductase in root may be an important marker of N assimilation efficiency.

Relative to translocation of N to the ear, studies with rice, wheat and oats have shown that genotypes, with an equal grain production but of differing protein content, differ in N translocation efficiency to the ear. The genotypes with the highest protein content in the grain transport more leaf N to the ear. The efficiency of translocation of N to the grain can be used as a marker for higher protein content of cereals. In this respect the net harvest index for protein can be used.

EFFICIENCY OF IRON UTILIZATION BY SOYABEANS

Fe deficiency originates from an absolute lack of iron, but is usually induced by factors which influence soil and plant availability. A well known example of induced iron deficiency is lime induced chlorosis.

Plant species and genotypes can differ in their ability to absorb and translocate iron, or they may be divided into efficient and inefficient utilizers of iron. According to Brown and Chaney (1971) the plant factors that contribute favourably to efficiency of iron utilization are: exudation of H^+ into the root medium, reduction of Fe^{+++} to Fe^{++} at the root surface, accumulation of citrate in the root for transport of Fe as Fe-citrate and a concomitant decrease of P in the rootsap.

Venkatraju (1971) observed that Fe deficiency in sunflower induced an excretion of H ions into the nutrient medium. This excretion was accompanied by a decreased anion uptake and an increase in carboxylate accumulation in the plant. In contrast to this, in an Fe inefficient genotype of maize, Fe deficiency did not result in H ion excretion even though the deficiency is known to increase carboxylate accumulation, and for soyabeans it is known that genotypes can differ very much in their efficiency of iron utilization.

As differences in H or OH ion excretion by plant roots are a result of the way the ionic balance of plants operates, some attention must be paid to this topic. Plants grown on nitrate as the nitrogen source produce large amounts of OH^- in the NO_3^--assimilation process (Dijkshoorn 1962). To regulate in this case the pH in shoot and root tissue the plant disposes of the OH^- ions in ways such as the following: (a) direct excretion of OH^- in the rooting medium, (b) neutralization of OH^- by malic acid after activation of PEP-carboxylase, (c) neutralization of OH^- by e.g. malic acid in the shoots, phloemtransport of malates to the roots and decarboxylation of malate followed by exchange of NO_3^- for OH^- or HCO_3^- (Egmond 1974, Houba *et al* 1971). For more details a recent paper of Raven and Smith (1976) is recommended. The currently popular Ben Zioni Lips model, especially as modified by Kirkby (1974), is very useful as a working model.

In grasses and cereals some 50-60% of the negative charge originating from NO_3^--assimilation appears in the nutrient medium. In buckwheat, tomato, sugarbeet and spinach the OH^- or HCO_3^- excretion is considerably lower; after translocation to the shoot nitrate is assimilated and oxalate, malate and citrate and the carboxylates of sodium, calcium and magnesium accumulate in the shoots. The release of HCO_3^- or OH^- excretion by plant roots supplied with nitrate can be calculated from whole plant analysis data as follows:

Uptake of anions = Uptake of cations + OH excretion, or approximately

$(NO_3$ + organic N + H_2PO_4 + SO_4 + organic S) = (K + Na + Ca + Mg) + OH excretion

as 1 eq. NO_3 assimilated = 1 mol of organic N, and according to Dijkshoorn and van Wijk (1967) organic S = 0.054 organic N on ion equivalent basis.

We then write A + 1.054 (organic N) = C + OH excretion

OH excretion = 1.054 (organic N) - (C-A) or when organic S is neglected OH excretion $\simeq$ (organic N) - (C-A).

The interspecies and genotypic differences in OH excretion by the roots is used as the basis of a working hypothesis for the response of plants to Fe stress (Egmond and Aktas 1977). They suggested that plants which normally excrete low levels of OH ions into the nutrient medium respond to iron stress by shifting the ionic balance in favour of H ion excretion so that iron stress is alleviated; these are the Fe efficient plants. Plants which normally excrete very high amounts of OH ions also shift their ionic balance in the same direction as a result of iron stress, but although lowering the OH ion excretion they still excrete net OH ions. Iron availability is then not increased; these are the Fe inefficient plants.

From plant analysis the OH excretion of the roots is calculated with the equation mentioned above, while the H ion excretion by plants supplied with nitrate N and not supplied with iron is calculated in a comparable way by: H ion excretion $\simeq$ (C-A) - (organic N).

The results of the experiments showed that in general the working hypothesis was a right one (Egmond and Aktas 1977) but there was a remarkable exception for the two soyabean genotypes 'Hawkeye' and T203. This exception is shown in Fig.15. In this Figure the effect of Fe stress on the OH ion excretion of the tested plants is presented in four ways. Every first column shows the effect of iron stress on the OH ion excretion. In every second column this is divided into the effects on anion and cation uptake. Every third column gives the effect of Fe stress on the amount of nitrate reduced, A and C. The last column gives the effect of Fe stress on the organic N and (C-A) or carboxylate. In the case of the Fe efficient 'Hawkeye' the rate of OH ion excretion gradually declined and on the 12th day of the experiment H ion excretion began. In contrast, the Fe inefficient T203 increased the rate of OH ion excretion gradually with developing Fe stress. It should be emphasized that none of the other plants tested behaved in the same way as the soyabean genotype T203. This means that in contrast to the other plants tested the low availability of iron in the root medium is accentuated by Fe deficiency in the T203 genotype.

As stated before, plants grown on nitrate as the nitrogen source produce large amounts of OH^- in the NO_3^--assimilation process. Clearly this OH production which is related to NO_3^--assimilation, drops to zero when the NO_3^- reserves are depleted by the plant. In conformity with this it is often shown that plants which are insufficiently supplied with nitrate later excrete H ions into the root medium (Dijkshoorn <u>et al</u> 1968, Houba <u>et al</u> 1971). When the plant has depleted the the nitrate N reserves the equation: H ion excretion $\simeq$ (C-A) - (organic N) can be simplified to H ion excretion $\simeq \Delta$(C-A) whereby Δ(C-A) is the carboxylate production by the plant after N depletion. From this it is expected that the extent and duration of iron stress is closely linked to the amount of nitrate supplied to the plant. Or, it is expected that the plants recover sooner from iron stress the less N is supplied to the plant. In a pot experiment with T203 and 'Hawkeye' soyabeans grown on a calcareous soil, well known for its lime induced chlorosis problem, the following nitrogen doses were supplied:

N_1 = 0.5 g N as nitrate, which is only enough for some weeks of growth.

N_2 = 1.0g N as nitrate, which might be depleted at the end of the experiment.

N_3 = 1.5 g N as nitrate, which the plants will not deplete during the experiment.

The Fe efficient genotype 'Hawkeye' grew well on all N treatments, although at 43 days after sowing the N_1 plants became light green, obviously because of depletion of the nitrate reserves. On the other hand, for the first 25 days the Fe inefficient genotype T203 was iron deficient (clear visual symptoms) in all treatments, the worst treatment being the highest rate of nitrogen (1.5 g N). Gradually, however, the N_1 plants recovered from Fe deficiency during the experiment and at 43 days after sowing the T203 N_1 plants were almost free from visual symptoms of Fe deficiency.

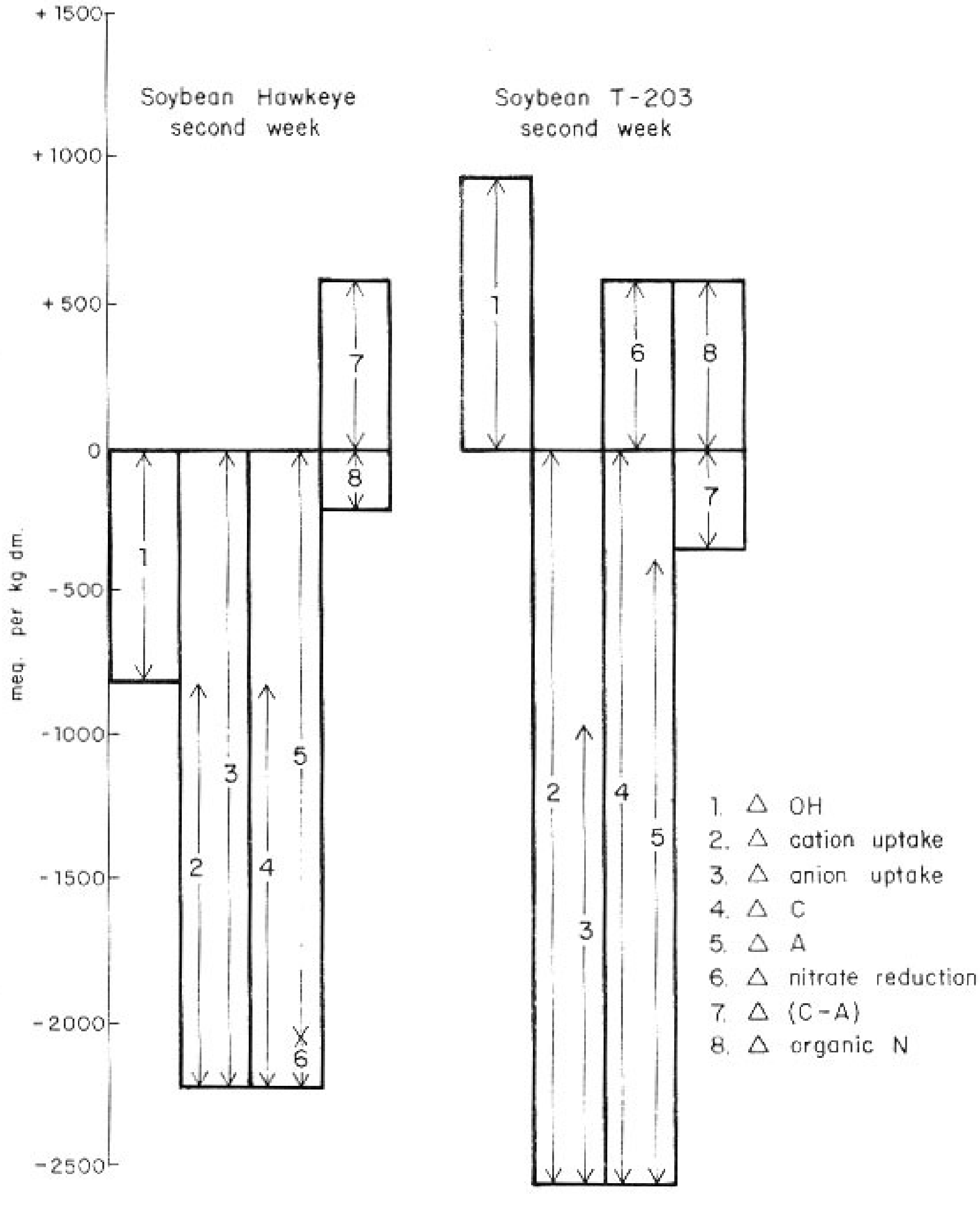


Fig. 15 Differences between the results of the complete and no-iron treatments

In Fig.16 the net H or OH ion excretion of the plant roots up to the final harvest date is plotted against the amount of N supplied. In this figure the nitrogen effect is clearly demonstrated; with increasing supply of nitrate the OH ion excretion increases. The genotypes differ in that the OH ion excretion per unit of N is much larger for T203 than for 'Hawkeye'. Moreover, it is shown that with the lowest N dose both genotypes acidify their rhizosphere, which acidification must have started after depletion of N.

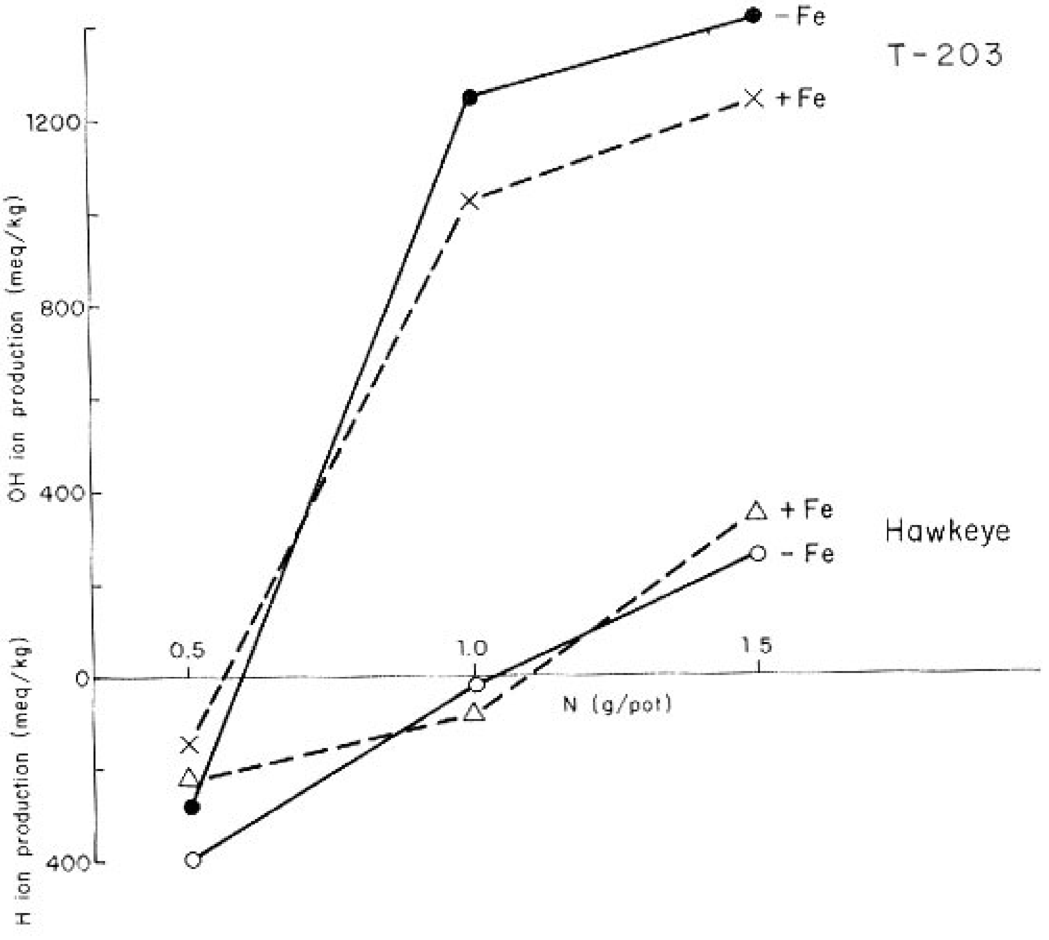


Fig. 16 The effect of applied nitrate on the OH^- or H^+ production of the plant

REFERENCES

Alleweldt, G. and Pollak, V. Die Sortenspezifität der K-aufnahme. In A.
1976 Cottenie (ed) 4th International Colloquium on the Control of Plant
Nutrition, Gent, pp. 314-326.

Barker, A.V., Maynard, D.N. and Mills, H.A. Variations in nitrate accumulation
1974 among spinach cultivars. J. Amer. Soc. Hort. Sci. 99: 132-134.

Brown, J.C. Differential uptake of Fe and Ca by two corn genotypes. Soil Sci.
1967 103: 331-338.

Brown, J.C. and Chaney, R.L. Effect of iron on the transport of citrate into
1971 the xylem of soybeans and tomatoes. Plant Physiol. 47: 837-840.

Brown, J.C., Chaney, R.L., and Ambler, J.E. A new tomato mutant inefficient
1971 in the transport of iron. Physiol. Plant. 25: 48-53.

Dijkshoorn, W. Metabolic regulation of the alkaline effect of nitrate
1962 utilization in plants. Nature 194: 165-167.

Dijkshoorn, W., Lathwell, D.J. and de Wit, C.T. Temporal changes in
1968 carboxylate content of ryegrass with stepwise change in nutrition.
Pl. Soil 29: 369-390.

Dijkshoorn, W. and van Wijk, A.L. The sulphur requirements of plants as
1967 evidenced by the sulphur-nitrogen ratio in the organic matter. A
review of published data. Pl. Soil 26: 129-157.

Egmond, F van. The ionic balance of the sugarbeet plant. Thesis Wageningen,
1974 also: Agric. Res. Rep. 832.

Egmond, F. van and Aktas, M. Iron-nutritional aspects of the ionic balance
1977 of plants. Pl. Soil (in press).

Hageman, R.H. Nitrate and nitrate reductase as factors associated with yield and
1975 protein production of cereal crops. Univ. Ill. Coll. of Agric. Spec.
Pub. 36.

Houba, V.J.G., Egmond, F van, and Wittich, E.M. Changes in production of
1971 organic nitrogen and carboxylates (C.A.) in young sugarbeet plants in
nutrient solutions of different nitrogen composition. Neth. J. Agric.
Sci. 19: 39-47.

Kirkby, E.A. Recycling of potassium in plants considered in relation to ion
1974 uptake and organic acid accumulation. In J. Wehrmann (ed) Proc.
7th Int. Colloq. Plant Anal. Fertilizer Problems, Hannover, 557-568.

Kramer, Th. Verbetering van de stikstofbenutting bij granen door veredeling.
1977 Lezing gehouden in het kader van de ITAL stikstofdag 1977, Wageningen.

Kylin, A and Hansson, G. Transport of sodium and potassium, and properties of
1971 (sodium+potassium) - activated adenosine triphosphates: Possible
connection with salt tolerance in plants. In Potassium in biochemistry
and physiology. Bern, International Potash Institute.

Minotti, P.L. and Jackson, W.A. Nitrate reduction in the roots and shoots of
1970 pea seedlings. Planta 95: 36

Penning de Vries, F.W.T. Use of assimilates in higher plants. In Cooper, J. ed.
1975 Photosynthesis and productivity in different environments. Cambridge
University Press.

Rao, K.P. Some physiological and biochemical aspects of nitrogen assimilation
1976 in barley and wheat. Thesis. University of California, Davis.

Raven, J.A. and Smith, F.A. Nitrogen assimilation and transport in vascular
1976 land plants in relation to intracellular pH regulation. New Phytol.
76: 415-431.

Rush, D.W. and Epstein, E. Genotypic responses to salinity. Differences between
1976 salt-sensivitive and salt-tolerant genotypes of the tomato. Plant
Physiol., 57: 162-166.

Venkatraju, K. Regulieringsmechanismus der Aufnahme von Eisen durch
1971 Sonnenblumenpflanzen bei Angebot schwerlöslicher Eisen-Verbindungen.
Thesis Berlin. D 83 nr 10.

Weiss, M.G. Inheritance and physiology of efficiency in iron utilization in
1943 soybeans. Genetics 28: 253-268.

Paper 9

CROPPING SYSTEMS FOR EFFICIENT FERTILIZER USE

D.J. Greenland

Department of Soil Science, University of Reading, U.K.

1. INTRODUCTION

One general factor common to all crop production systems should first be recognized. The better the crops grow, the greater will be the efficiency with which nutrients are utilized. Thus those systems which best reduce pest and disease incidence, and which have cropping sequences adjusted to take best advantage of the climate and soil conditions, will always do better than less well adapted systems. Similarly, legumes given proper nutrition, fix N at higher rates than they do when other nutrients are in short supply, or when the soil is too acid for them to make optimum growth. Thus the most important effect of a cropping system on fertilizer efficiency is through its effect on the health and vigour of the various crops.

Cropping systems also influence the efficiency of fertilizer use through their effects on the processes of fertilizer loss. These processes include leaching, erosion, volatilization and irreversible conversion to non-plant available forms. In this paper cropping systems will be taken to include systems for the production of tree crops and forage crops, since by combining arable crop production with perennials such as trees and pastures the efficiency of fertilizer use may be considerably improved.

It is impossible to review all aspects of all cropping systems in a short paper, and so attention will be given to some aspects of examples from temperate, subtropical and tropical agriculture.

2. EFFICIENCY OF FERTILIZER USE IN TEMPERATE ZONE CROP PRODUCTION SYSTEMS

2.1 Arable Farming

Many balance sheets for plant nutrients in temperate zone arable cropping systems have been published (Cooke 1967). The longest standing experiments for which good data are available are those initiated at Rothamsted in 1852. With commendable foresight these experiments were initiated with N, P and K applied at rates up to 144, 33.5, and 135 kg/ha respectively which are still realistic at the present time. Over the period of 120 years or so the proportions of N, P and K recovered in cereal crops are approximately 35%, 20% and 20% (Rothamsted Experimental Station 1968) but vary considerably. There has been little change or a decrease in soil N contents on the continuous cereal experiments, and therefore the lost N is presumed to have been leached or volatilized. The P and K are still in the soil, but in forms in which they are not immediately available to plants, although some at least is in equilibrium with the soluble and labile forms and so contributing to crop yields (Rothamsted Experimental Station 1968).

In comparison with cereals, recovery of fertilizers by root crops (particularly sugarbeet) in the United Kingdom is considerably better (Johnson 1976), perhaps because they occupy the ground for a longer period of time.

If crops are planted in the autumn and fertilized before the winter rains and the rapid spring growth, considerable losses of fertilizer can occur (Kuipers 1962, Devine and Holmes 1963). Recoveries of spring applied N are much higher. This may partly account for the generally greater efficiency of root crops in recovering fertilizer as these crops tend to be fertilized rather later in spring, make their most active growth later in the summer, and are harvested later than cereals.

Although recoveries of P and K by the crop to which they are applied are often low, there is ample evidence to show that in arable rotations the total recoveries are considerably higher because subsequent crops in the rotation benefit from them (Table 11). Thus Cooke (1967) summarized much U.K. work as follows:

> "1. The large residues accumulated in soil from long periods of manuring with phosphorus and/or potassium fertilizers have been found useful to crops in all the experiments done.
>
> 2. There are large residual effects from the large dressings of compound fertilizers that are commonly used for cash root crops in Britain; they greatly increase yields of following cereals.
>
> 3. Large dressings of nitrogen fertilizers used for root crops have considerable residual effects on following cereals.
>
> 4. Residues of all three nutrients (N,P,K) applied as fertilizers cause general increases in yield and often lessen the need for fresh fertilizer."

Table 11 FERTILIZER RECOVERIES IN CONTINUOUS WHEAT AND ROTATION EXPERIMENTS, ROTHAMSTED, U.K.

	Continuous Wheat		Wheat-kale-barley-grass-potatoes 5 year rotation	
	Period	Nutrient recovery	Period	Nutrient recovery
N	1852 - 61 1966 - 67	22 (37) 36 (64)	1956 - 70	43
P	1852 - 71 1966 - 67	14 (33) 21 (35)	1956 - 70	29
K	1852 - 91 1966 - 67	29 (52) 14 (35)	1956 - 70	54

Source: Johnston (1968), Widdowson and Penny (1972).

Figures are nutrient in harvested part (a) less nutrient in harvested part when no fertilizer applied (b) as per cent of applied fertilizer (c) i.e. $\frac{a-b}{c}$ x 100. Figures in parentheses are $\frac{a}{c}$ x 100. Results are means for periods shown, for all crops and cut grass.

Wheat received N 144 kg/ha, P 33.5 kg/ha, K 90 kg/ha annually. In the rotation experiment the mean annual fertilizer application over the 5 year period of the rotation was N 70 kg/ha, P 27.3 kg/ha, K 143 kg/ha. Original publications should be consulted for full details.

Cook and Davies (1957) who reviewed much American work also found that for temperate areas the residual effects of N, P and K in arable rotations were considerable. Olson (1972) also concluded that while total recoveries of nitrogen in arable cropping systems in America were of the order of 50%, recovery could be improved by including sod crops or deep taprooted legumes to soak up mineral nitrogen which in some areas accumulates in the subsoil. Efficiency is also greater if nitrogen fertilizers are applied only after the root system of the crop is established, but this may not be the most convenient or the most productive time at which to apply it.

In addition to appropriate timing of the fertilizer application, recovery is likely to be affected by the way in which the root system of the crop develops. In a well structured soil, root growth is optimal but if the soil is compacted so that root development is restricted, recovery is less efficient (Phillips and Kirkham 1962, Kubota and Williams 1967, Lupton et al 1974). Zero tillage and minimum tillage techniques have generally been found to necessitate rather higher fertilizer application rates than cropping systems utilizing conventional ploughing and harrowing (Beaumer and Bakermans 1973). However, it is probable that efficiency measured over a period of several years will be at least as high as in conventional land preparation methods, as the fertilizer not recovered immediately in the crop remains in the soil. The initial higher requirement is necessary only to establish new equilibrium conditions and until the better structural condition created by faunal activity on no tillage systems is established (Cannell and Finney 1973).

.2 Grassland Farming

Although results published for N recovery from fertilizers applied to grassland show a wide range, they tend to be higher than for arable crops grown in similar conditions, and may be as high as 85% for N (Williams and Jackson 1976).

It is probable that the most important factor is the continuous presence of the crop in the soil. Very low levels of nitrate in soils under permanent grassland have been widely observed (Russell 1973). Although the reasons are still not established unequivocally, there is no dispute that nitrate levels are low under grass. Because only nitrate and nitrite (which is not found in significant amounts) are readily mobile in soils, the absence of nitrate implies that leaching and volatilization losses due to microbial dissimilation of nitrate are negligible. When a net release of N does occur, roots are always present to absorb it quickly. In non-alkaline soils nitrate is always the dominant anion, and leaching of cations depends on the amounts of nitrate in the soil. Thus cation leaching as well as loss of N as nitrate is controlled.

Losses of fertilizer N from pastures may be greater when heavy fertilizer dressings are used (600 kg/ha/year of N is often an economic rate in the U.K.) but data obtained by Hood (1976) indicated that even when N was applied at 750 kg/ha to a grazed pasture leaching losses accounted for only 5% of that applied. Studies of the concentration of nitrous oxide in pastures receiving high rates of N fertilizer by Dowdell and Webster (1976) and Burford (personal communication) indicate that the losses by denitrification are probably also low.

When legumes are included in the pasture, it is undesirable to use heavy dressings of N because these repress the legume components and encourage the grasses, and the N fixation by the remaining legumes is depressed. Nevertheless in Europe it has become customary to use grass dominant pastures and heavy N dressings, as among other reasons, it is easier to ensure rapid dry matter production in the early spring, when winter feeding stuffs may be scarce, than if reliance is placed on pasture legumes. However, in terms of dry matter produced per total fertilizer units applied, the legume based pastures are probably more efficient than heavily fertilized grassland.

Although the soil-pasture system is very retentive of nutrients, a source of loss arises from the concentration of nutrients in animal excreta. Losses of N occur through volatization of ammonia in urine patches (McGarity and Rajaratnam 1973, Denmead et al 1974) and by denitrification from animal slurry (Burford et al 1976). Losses of K by leaching may also occur on some soils (Davies et al 1962) although Cooke (1971) concluded that grazed grasslands are seldom deficient in K, the return of K through the animal making good the large amounts accumulated in the grass. If the grass is cut and fed to animals elsewhere substantial losses of K arise, and K fertilizers are needed if the production level is to be maintained.

3. EFFICIENCY OF FERTILIZER USE IN PASTURE—WHEAT ROTATION SYSTEMS OF THE SEMI-ARID, SUBTROPICAL ZONE

This production system is probably one of the most efficient in terms of fertilizer requirement, in that very little input is needed. It involves a succession of two to four years of pasture, followed by two or three crops of cereals, usually wheat. The fertilizer input is restricted to superphosphate, supplemented where necessary by trace elements; the N requirement comes from the rhizobia associated with the legumes, usually subterranean clover, grown in the pasture, and the system is sometimes described as the "super and sub" system.

Because it is practised in semi-arid areas leaching losses are low, and consequently there is little or no need for K or lime, and the N fixed by the pasture is largely available to succeeding wheat crops. Although good responses to P are obtained, little (ca 10%) of that applied is recovered in the first crop grown after application (Woodroffe and Williams 1953) but again high residual values occur (Piper and de Vries 1964, Donald 1964, Smith 1964) even though most Australian soils are low or very low in natural reserves of phosphate (Wild 1958) and "fix" much of the applied phosphorus.

An important role of the P and S applied is in building the organic matter content of the soil (Williams and Donald 1957). Fertility build-up in most soils cultivated in this way is an essential part of the success of the system (Greenland 1971) and the contribution of the fertilizer to this process should be regarded as part of its function. The accumulated organic P does not mineralize as readily as the N and S (Williams and Lipsett 1961) and so is not "available" but the organic matter of which it forms part improves the structure of the soil and hence water entry and storage which are critical aspects in relation to cereal production. Efficiency of use of N is closely related to water availability and for a given quantity of applied N yields rise in proportion to rainfall. The stimulation of N fixation by the P and S applied to clover based pasture is a major factor in the effectiveness of the system. About 8 kg of N are estimated to be fixed from the air for each kg of P applied (Williams and Donald 1957).

4. SYSTEMS OF ARABLE CROPPING OF SOILS OF THE HUMID TROPICS

In the tropics the problems associated with the development of efficient cropping systems become more difficult. This is due to the pronounced seasonality of the climate, the intensity of the rainfall, and the characteristics of the soils. Early planting at the onset of the rains is usually critically related to yield, and timing of fertilizer application becomes more important than in gentler climates. The high proportion of rainfall which leaches through the soil is expected to cause greater losses of fertilizers by leaching; the high proportions of Fe and Al oxides in these soils are often stated to be likely to lead to high rates of P fixation and hence inefficient recovery of applied P; the high erosivity of the rain is likely to lead to surface run-off carrying applied fertilizer with it and removing nutrients concentrated in surface soils. The year-round high temperatures and high humidity are very favourable for microbiological activity, and development of pathogens can be extremely rapid, as well as processes such as denitrification.

Three cropping systems have so far proved successful in the humid tropics, namely paddy rice production, tree crop production, and small farmer natural fallow rotation systems. These systems are successful because they do not cause a soil erosion hazard. Attempts to translate agricultural practices developed for intensive arable production in the temperate zone to the humid tropics have largely failed, because they are not adapted to the more severe constraints of the tropical climate. However, recent work at the International Institute of Tropical Agriculture in Ibadan, Nigeria, has shown that a system based on mulch-zero tillage techniques and inter- and relay- cropping should enable sustained intensive arable production to be maintained in these areas (Greenland 1975).

4.1 Fertilizer Efficiency in Paddy Rice Production

The recovery of fertilizer N in crops of rice tends to be low but can be improved by attention to method and timing of application and water management (Sanchez 1972). Results obtained using nitrogen-15 have shown that placement at 15 cm can increase recovery of applied N in the grain to as much as 40% (IAEA 1970). Losses are greatest under conditions of intermittent, as opposed to continuous, flooding because of the formation of nitrate when oxygen becomes available in the soil, and the subsequent denitrification of the nitrate when the soil is flooded (Patrick et al 1967).

Responses to P are less common in rice than are responses to other nutrients, probably due in part to the generally higher availability of soil P in flooded land. Perhaps most important is the fact that not only is soil phosphate more available but also P in rock phosphate, and at least in acid soils recoveries of P from applied rock phosphate can be as good as those from superphosphates (Engelstad et al 1974). Substantial improvements in efficiency of fertilizer use by rice have been obtained with the introduction of the new rice varieties, with shorter straw and better root characteristics.

4.2 Fertilizer Efficiency in Other Arable Production Systems in the Humid Tropics

The traditional natural fallow rotation system of arable crop production in the subhumid and humid tropics depends on the accumulation of nutrients in natural fallow vegetation, and their release on burning, to maintain soil fertility. Recovery of the nutrients released from the vegetation by crops is normally very low, but provided the roots of the natural vegetation previously present are not killed, loss from the soil-vegetation system is small and the nutrient cycle between natural vegetation and soil is largely maintained. It normally takes several years for the vegetation to redevelop adequately, and so the intensity of land use permitted by such systems is low, although efficiency is high in terms of crop production per unit of nutrient and energy input.

Serious problems, however, start to arise if pressure on the land increases, so that the period when the vegetation redevelops is shortened and the cropping period extended. Productivity then falls disastrously owing to failure to replenish nutrient reserves, and the increasing importance of soil erosion and other factors associated with prolonged cultivation periods. Nutrient losses due to erosion have recently been quantified for an Alfisol in southern Nigeria by Lal (1976) and are substantial, particularly since the greatest concentration of nutrients in soils of these areas is in the immediate surface.

Yields on these soils can be maintained if nutrients are supplied by fertilizers (Kang 1974) and erosion is controlled. Because of the severe erosivity of the climate of the lowland humid tropics, erosion control demands that a soil cover be maintained throughout the year. Mechanically constructed works are liable to failure, even when designs based on those found satisfactory in less erosive conditions are used. Combination of arable crops with trees or other perennials, or proper use of multiple cropping can, if the dry season is not too prolonged, provide the necessary cover. Alternatively or additionally, all crop and weed residues can be used as mulches to give the necessary soil protection (Lal 1976).

Efficiency of fertilizer use in such systems might be expected to be low because of (a) severe leaching (b) high fixation rates (c) competition between crop uptake and assimilation by microorganisms which are involved in decomposition of the mulch (d) poor crop, and particularly, root growth due to initial soil acidity, or acidity developed following continued use of fertilizers (e) multiple cropping.

i. Leaching

Good quantitative data on leaching of fertilizers applied to arable crops in humid tropical conditions are still needed. Data obtained under tree crops (Godefroy et al 1970, Bolton 1968) rather confirm the expectation of serious leaching losses, although apparent recoveries (neglecting the soil contribution) of N,P and K are broadly similar to those obtained in temperate zone agriculture, which implies that the problem in the humid tropics is at least no more serious than in temperate areas.

ii. Fixation

The myth of poor phosphorus responses due to high fixation rates in "tropical soils" dies hard. For instance, as recently as 1973 and in a publication of the U.S. National Academy of Sciences, Olson and Engelstad (1973) state that "Fixation is especially rapid and strong on ferralitic soils (oxisols)" and "Fixation of applied increments of phosphorous is far more serious in certain tropical soils than soils of temperate regions". It may be true of volcanic ash soils, those developed on highly basic rocks and others with high free alumina contents, but is quite untrue of the majority of soils in the tropics, Russell (1973) states "It is worth noting that most tropical soils behave as typical temperate soils". There is ample evidence from long term fertilizer trials to establish that applied P gives rise to substantial residual responses, a result recently reconfirmed at IITA (Kang 1974). Kamprath (1967) reviewed briefly "fixation" of phosphorus in red soils of the warm and hot humid regions. In spite of apparent high fixation rates very substantial residual responses are obtained and in North Carolina even seven to nine years after the initial application of superphosphate to the strongly P fixing red Ultisol good residual effects are found.

In Northern Australia Arndt and McIntyre (1963) found that the residual value of rock phosphate after 7 years was 60 to 70% of that in the initial year. Cooke (1967) concluded that "there is much evidence that in many soils "ordinary" dressings of phosphate fertilizers leave residues that benefit later crops, just as they do in temperate soils".

iii. Competition in assimilation

When mulches are used to protect the soil from erosion, competition for nutrients between microorganisms involved in decomposition of the mulch material and plant roots is likely to arise. This is usually most pronounced with respect to nitrogen. However Greenland and Nye (1960) found that rice and maize straw applied to an alfisol in Ghana caused only a very limited tie up of fertilizer N and more recently Kang (1975) at Ibadan in Nigeria found that provided adequate rates of N are used, there is no difference in requirement with and without a mulch applied. More information on this topic is required, but results currently available do not suggest that the mulches will lead to a serious reduction in fertilizer efficiency.

iv. Reduced efficiency associated with high acidity

In the perhumid areas of the tropics soil pH may be as low as 4. Crop growth and response to fertilizer may then be limited by Al toxicity, and deficiency of Ca and Mg. Responses to N P K fertilizers will be small unless the acidity is first corrected. Small rates of lime (less than 3 t/ha) often give substantial responses, but higher rates may cause yield depressions because of induced deficiencies of trace elements (Spain et al 1975, Juo 1975). Responses to liming when the pH of the soil is greater than 5 appear to be less common than might be expected, and N P K responses are not then dependent on interaction with lime. However, application of nitrogen fertilizers for several years can cause substantial acidification, and the efficiency of N P K will diminish. Abruna et al (1959) have given examples from South America and Jones and Wild (1975) examples from West Africa.

v. Effects of inter- and relay-cropping on efficiency of fertilizer uptake

The number of experiments on fertilizer efficiency on intercropping and relay-cropping experiments are inadequate to make useful generalizations. Oelsligle et al (1976) posed the question "What, if any, are the increases in utilization efficiency of the different nutrients when compared to sole cropping?" and from their review of the available literature concluded that if the timing of application was appropriate and adequate rates were used, recovery of fertilizer would "surely increase" compared with fertilization of sole crops.

Sanchez (1976) has also reviewed nutrient uptake in multiple cropping systems. Results from many parts of the tropics show that when legumes are included in the intercrops they can improve N uptake by associated cereal or other crops, and the efficiency with which fertilizer N is used, provided that they are utilized in the cropping scheme in such a way that they do not compete seriously with the associated crop or crops for water or sunlight. Clearly, timing of application is important, but there is too little information on this topic. The compatibility of root systems is another important topic which requires study, to assist in developing rational management systems. Indigenous relay intercropping systems undoubtedly incorporate a great deal of empirical knowledge, and merit careful consideration when endeavouring to replace them by more productive systems (Okigbo and Greenland 1976).

5. CONCLUSIONS

Cropping systems, as well as timing, method of application and forms of fertilizer, can influence fertilizer efficiency. Although there are many factors which cause various practices to have different relative importance in different areas, the importance of having an actively growing root system present whenever fertilizers are applied appears to be generally true. In the tropics this is particularly important, and appropriate relay intercropping practices are likely to lead to the most efficient recoveries. Proper timing is probably more generally important than placement. Residual responses in both tropical and temperate regions are generally high, and efficiencies of recovery should not be assessed on the basis of recovery in the crop to which the fertilizer is applied alone, but on the recovery in the several crops utilized in the cropping system. There is a need for further long term studies of fertilizer efficiency in different cropping systems, particularly in the tropics. The most serious irreversible losses of fertilizer and other nutrients arise from erosion, and not fixation. Mulches provide the simplest method of erosion control, and their effects on nutrient recovery merits further study.

REFERENCES

Abruna, F., Pearson, R.W. and Elkins, C. Quantitative evaluation of soil reaction
1959 and base status changes from field applications of residually acid forming N fertilizers. Soil Sci. Soc. Amer. Proc. 22: 539-542.

Arndt, W. and McIntyre, G.A. The initial and residual effects of superphosphate
1963 and rock phosphate for sorghum on a lateritic red earth. Aust. J. Agric. Res. 14: 785-795.

Beaumer, K and Bakermans, W.A.P. Zero tillage. Adv. Agron. 25: 77 - 123.
1973

Bolton, J. Leaching of fertilizers applied to a latosol in lysimeters. J.
1968 Rubber Res. Inst. Malaya, 20: 274-284.

Burford, J.R., Greenland, D.J. and Pain, B. Effects of heavy dressings of
1976 slurry and inorganic fertilizers applied to grassland on the composition of drainage waters and the soil atmosphere. In Agriculture and water quality, MAFF. Tech. Bull. 32, pp. 432-443.

Cannell, R.Q. and Finney, J.R. Effects of direct drilling and reduced cultivation
1973 soil conditions for root growth. Outl. Agric. 7: 184-189.

Cook, R.L. and Davies, J.F. The residual effect of fertilizer. Adv. Agron.
1957 9: 205-261.

Cooke, G.W. The control of soil fertility. London, Crosby Lockwood.
1967

Cooke, G.W. Potassium for grassland. In Potassium and systems of
1971 grassland farming. Proc. 1st Colloquium, Potassium Inst.

Davies, E.B., Hogg, D.E. and Hopewell, H.G. Extent of return of nutrient
1962 elements by dairy cattle; possible leaching losses. Trans. Comm. IV and V, Int. Soc. Sci., New Zealand, pp.715-720.

Denmead, O.T., Simpson, J.R. and Freney, J.R. Ammonia flux into the
1974 atmosphere from a grazed pasture. Science, 185: 609-610.

Devine, J.R. and Holmes, M.R.J. Field experiments comparing ammonium nitrate,
1963 ammonium sulphate and urea, applied repetitively to grassland. J. Agric. Sci., 60: 297-304.

Donald, C.M. Phosphorus in Australian agriculture. J. Aust. Inst. Agric. Sci.,
1964 30: 75-105.

Dowdell, R.J. and Webster, C.P. Denitrification and leaching of nitrogen
1976 fertilizers. In Agriculture and water quality. MAFF Tech. Bull. 32, pp. 163-173.

Engelstad, O.P., Jugsujinda, A.and De Datta, S.K. Response by flooded rice to
1974 phosphate rocks varying in citrate solubility. Soil Sci. Soc. Amer. Proc. 38: 524-529.

Godefroy, J., Muller, M. and Roose, E. Estimation des pertes par lixiviation
1970 des elements fertilizants dans un sol de bananeraie de Basse Cote d'Ivoire. Fruits 25: 403-420.

Greenland, D.J. Changes in the nitrogen status and physical condition of soils
1971 under pastures, with special reference to the maintenance of the fertility of Australian soils used for growing wheat. Soils Fertil. 34: 237-251.

Greenland, D.J. Bringing the green revolution to the shifting cultivator.
1975 Science, 190: 841-844.

Greenland, D.J. and Nye, P.H. Does straw induce nitrogen deficiency in tropical
1960 soils? Trans. 7th Int. Cong. Soil Sci., Madison, 3: 478-485.

Hood, A.E. The leaching of nitrates from intensively managed grassland at
1976 Jealott's Hill. In Agriculture and water quality. MAFF Tech. Bull.
32, pp. 201-221.

I.A.E.A. Rice fertilization. Tech. Rep. Ser. No.108. IAEA, Vienna.
1970.

Johnston, A.E. The plant nutrients in crops grown on Broadbalk. Annu. Rep.
1968 Rothamsted Exp. Sta. Pt. II, pp.50-62.

Johnston, A.E. Additions and removals of nitrogen and phosphorus in long term
1976 experiments at Rothamsted and Woburn. In Agriculture and water
quality. MAFF Tech. Bull. 32, pp.111-144.

Jones, M.J. and Wild, A. Soils of the West African savanna. Tech. Comm.,
1975 No.55, pp.246. Commonw. Bur. Soils, Harpenden, U.K.

Juo, A. Soil chemistry. Annu. Rep. Int. Inst. Trop. Agric. Ibadan, Nigeria,
1975 pp. 11-15.

Kamprath, E.J. Residual effects of large applications of phosphorus on high
1967 phosphorus fixing soils. Agron. J. 59: 25-27.

Kang, B.T. Soil fertility. Annu. Rep. Int. Inst. Trop. Agric. Ibadan, Nigeria,
1974 pp. 44-51.

Kang, B.T. Soil fertility. Annu. Rep. Int. Inst. Trop. Agric. Ibadan, Nigeria,
1975 pp. 16-21.

Kubota, T. and Williams, R.J.B. The effects of changes in soil compaction and
1967 porosity on germination, establishment and yield of barley and globe
beet. J. Agric. Sci. 68: 227-233.

Kuipers, S.F. Factors determining the nitrogen fertilization of arable land.
1962 Stikstof 6: 3-19.

Lal, R. Soil erosion on an alfisol in Western Nigeria. IITA Monograph No.1.
1976

Lupton, F.G.H. et al Root and shoot growth of semi-dwarf and taller winter
1974 wheats. Ann. Appl. Biol. 77: 129-144.

McGarity, J.W. and Rajaratnam, J.A. Apparatus for measurement of losses of
1973 nitrogen in gas from the field and simulated field environments.
Soil Biol. Biochem. 5: 121-131.

Oelsligle, D.D., McCallum, R.E. and Kang, B.T. Soil fertility management in
1976 tropical multiple cropping. In Papendick R. et al eds. Multiple
cropping, pp. 275-292. Madison, Amer. Soc. Agron.

Okigbo, B.N. and Greenland, D.J. Intercropping systems in tropical Africa.
1976 In Papendick, R. et al., eds. Madison, Amer. Soc. Agron.

Olson, R. Maximizing the utilization efficiency of fertilizer N by soil and crop
1972 management. FAO Soils Bull. 16, pp.34-52.

Olson, R. and Engelstad, O.P. Soil phosphorus and sulphur. In Soils of the
1972 humid tropics, pp. 82-101. Washington, Nat. Acad. Sci.

Patrick, W.H., Quirk, W.A., Peterson, F.H. and Faulkner, M.D. Effect of
1967 continuous submergence and alternate flooding and drying on growth,
yield and nitrogen uptake by rice. Agron. J. 59: 418-419.

Phillips, R.E. and Kirkham, D. Soil compaction in the field and corn growth.
1962 Agron, J. 54: 29-34.

Piper, C.S. and de Bries, M.P.C. The residual value of superphosphate on a
1964 red brown earth in South Australia. Aust. J. Agric. Res. 15: 234-
272.

Rothamsted Experimental Station. The Broadbalk wheat experiment. Annu. Rep.
1968 Part II.

Russell, E.W. Soil Conditions and Plant Growth. 10th ed. London, Longmans.

Rusell, J.S. Nitrogen fertilizer and wheat in a semi-arid environment.
1967 Aust. J. Exp. Agric. Anim. Husb. 7: 453-462.

Sanchez, P. Nitrogen fertilization and management in tropical rice. N.
1972 Carolina Agric. Exp. Sta. Tech. Bull. No.213, p.31.

Sanchez, P. Properties and management of soils in the tropics. Wiley-
1976 Interscience, New York.

mith, A.N. Aluminium iron phosphates in soils. J. Aust. Inst. Agric. Sci.
1964 31: 110-126.

Spain, J.M., Francis, C.A. , Howeler, R.H. and Calvo, F. Differential species
1975 and varietal tolerance to soil acidity in tropical crops and
pastures. In Soil management in tropical America, pp.308-329. Raleigh,
N. Carolina State Univ.

Widdowson, F.V. and Penny, A. Yields and N, P and K contents of the crops
1972 grown in the Rothamsted Reference experiment, 1956-70. Annu.
Rep. Rothamsted Exp. Sta. Part II, pp. 111-130.

Wild, A. The phosphate content of Australian soils. Aust. J. Agric. Res.
1958 9: 193-204.

Williams, C.H. and Donald, C.M. Changes in organic matter and pH in a podsolic
1957 soil as influenced by subterranean clover and superphosphate. Aust.
J. Agric. Res. 8: 179-189.

Williams, C.H. and Lipsett, J. Fertility changes in soils cultivated for
1961 wheat in southern New South Wales. Aust. J. Agric. Res. 12: 612-629.

Williams, T.E. and Jackson, M.V. The recovery of fertilizer N in herbage and
1976. soil. In Agriculture and water quality, MAFF Tech. Bull. 32, pp.145-
152.

Woodroffe, K. and Williams, C.H. The residual effect of superphosphate in
1953 soils cultivated for wheat in South Australia. Aust. J. Agric. Res.
4: 127-150.

Paper 10

CROP PERFORMANCE AND SOIL NUTRIENT POTENTIAL

O. Talibudeen and M.B. Page

Rothamsted Experimental Station, Harpenden, U.K.

1. SOIL NUTRIENT POTENTIAL

A review (Talibudeen 1974) of the definition of the chemical potential of a plant nutrient in the soil, soil nutrient potential (SNP), showed that for all practical purposes it can be represented by the activity (or concentration in dilute solutions) in the soil water in equilibrium with the soil (static or dynamic). It is also convenient when comparing crop/soil environments to consider this equilibrium activity or concentration in energy units (i.e. $\Delta G_i = -RT\ln A_i$ in solution culture and $\Delta G_i = -RT\ln AR_o$ in soil culture, where AR_o is the equilibrium activity ratio (Beckett 1972)) Because it (a) facilitates the use of the 'activity-ratio' or '-product' concept where nutrient ions are involved in exchange/adsorption/precipitation processes in the soil, (b) enables a more rigorous comparison to be made of soil nutrient status under various environmental conditions (e.g. various competing or interacting ions, chelating molecules and temperatures), (c) makes it feasible to put the nutrient extracting abilities of various crops and chemical extractants on a common energy scale, and (d) allows the needs of the growing plant to be assessed on a common scale through its various development stages under changing environmental conditions. (The units of concentration, activity ratio and energy are conventionally molarity, (molarity)$^{1/2}$ and calories per mole or joules per mole.)

2. SOIL NUTRIENT POTENTIAL AND CROP PERFORMANCE

2.1 A Concept

Ideally a SNP should be the average value in the root zone under the environmental conditions prevailing in the soil. These 'environmental conditions' integrate the effects on SNP of pH, temperature, the partial pressures of oxygen, carbon dioxide and water (and in the context of modern agriculture, perhaps ammonia) and the various chemical components of the soil complex. To relate SNP to crop performance, measurements would need to be averaged over a particular stage of development.

In relating SNP to crop growth, the most common yardsticks used to define plant performance are dry matter yield (FY)(of a particular plant part) and nutrient uptake (NU) into the shoots. In recent years, a more fundamental plant index of root absorbing power (RAP) has been suggested and measured in the laboratory for a few plants with root systems of ideal shape, e.g. cylinders with no root hairs (Fried and Shapiro 1960, Nye 1966, Fried and Broeshart 1967). RAP has been shown, as one would expect and predict, to be related to the development stage of the plant, plant species and root age. To project this concept to the field requires simplifying assumptions and laborious measurements of roots. The latter do not include all active root components.

The effects of a wide range of SNP values, on FY and NU shown in Figure 1 allow the identification of mean values of several critical crop energy parameters for a particular development stage that can be derived experimentally by measuring the mean SNP over that stage:

i. The 'exhaustion' (or 'threshold' or 'uptake') potential, when PY and nutrient concentration (NC) in the plant increase slowly with SNP;

ii. the 'response' (or 'deficiency') potential, when PY and NC increase rapidly with SNP;

iii. the 'optimum' (or 'adequate supply') potential, when PY is maximum:

and

iv. the 'luxury-toxic uptake' potential, when PY decreases and NC increases with increasing SNP.

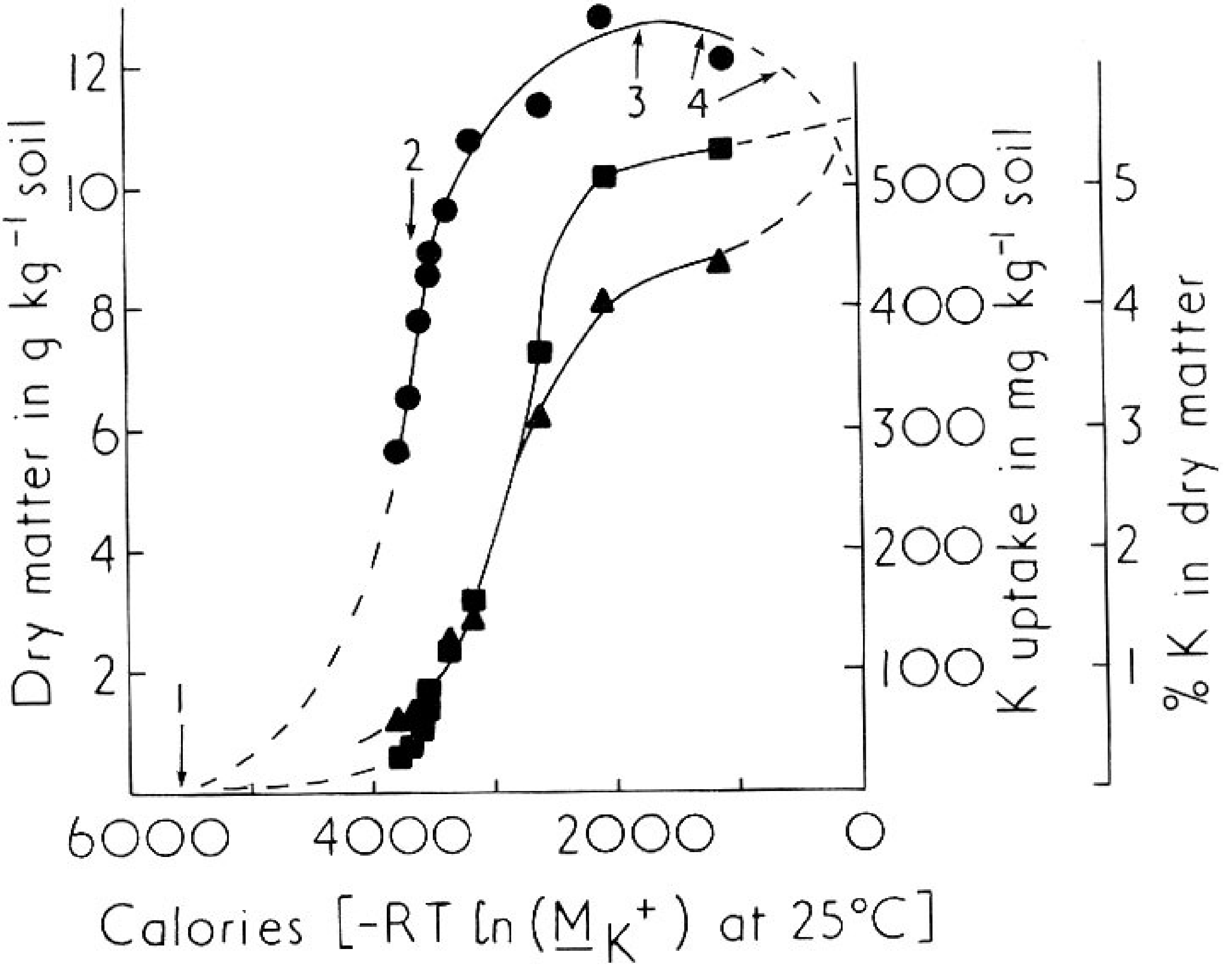


Fig. 17 Effect of soil potassium potential (cal/mole) on the growth characteristics of perennial ryegrass (S23) in a controlled environment. (1 exhaustion, 2 response, 3 optimum, 4 luxury and toxic potentials)

Dry matter ●—●: K uptake ■—■: % K in dry matter ▲—▲

2.2 Some Difficulties

The concept described above is undeniably an oversimplification but attempts to bridge the gap between the older ad hoc agronomic experimentation and the more recent sophisticated, fundamentally based models being developed and investigated in the laboratory. (The basic tenets of the latter are not yet of practical use to the agronomist.) Some difficulties in designing experiments for investigating this concept are now discussed.

The transitions between development stages are not likely to be distinct but could be evaluated by analysing the observed FY : SNP and NU : SNP curves at each stage. At various development stages, the SNP values giving maximum dry matter yields (ΔG_{opt}) may be different. Furthermore, the maximum growth of some part of a plant in the earlier stages may not result in maximum yield of the harvested part. For instance, excessive vegetative growth in some root crops results in poor root yields. Similarly, with wheat too much N in spring can lead to excessive tillering which reduces grain yield. In contrast, more N given during grain filling (when 'available' N in the soil is usually at a low level) often increases grain yield and invariably increases N concentration in the grain, suggesting particularly the need to maintain an optimum SNP during grain filling. So, to obtain maximum benefit at final harvest from native and applied nutrients in the soil, the SNP at each development stage should be such that the yield at final harvest is maximum and not necessarily ΔG_{opt} for that stage.

To take account of recognized nutrient interactions for a particular crop (e.g. N:K, N:P, K:Mg, Ca:P; pH (Al):P,K,Ca,Mg; trace element interactions), initial experiments would need to use 'optimum' basal levels of such interacting nutrients (other than the tested nutrient) based on previous experience. Subsequently, their effect could be investigated by factorially combining a few levels of an interacting nutrient into the main experiment set up to study the crop performance:SNP relationships. Such ideas develop naturally from the basic concepts of soil nutrient potential originally proposed by Schofield (1963) and his collaborators at Rothamsted during 1934-55, starting with soil water and concluding with P, K and lime potentials.

2.3 Procedures Used Hitherto

The methods used so far to derive one or more of these critical potentials are briefly described below:

2.3.1 Empirical approach A

The nutrient status of the soil (before growing the crop but after equilibrium with various levels of added fertilizer) is assessed by calculating the SNP from the composition of the equilibrium soil water (Schofield 1947). The yield response of the crop at final harvest is measured and, combined with SNP values, is used to assess the exhaustion, response and optimum potentials but not, so far, luxury-toxic potentials of the crop (Woodruff 1965). At best such estimates can only be approximate. By far the largest body of data for various crops (Beckett 1972) concerns SNP values covering a range between crop exhaustion and response. Such values, at least for higher plants, must be regarded only as average and approximate because SNP in the dynamic equilibrium between plant and soil changes during growth and also the critical values may not be the same for the various development stages. (The former reason is less true for nutrients involved in exchange/adsorption/precipitation reactions in the soil.) However, for a particular soil, they indicate the level to which SNP must be brought to produce a stated level of performance by a particular crop, given normal environmental conditions (Table 12).

Table 12 CRITICAL SNP VALUES FOR THE GROWTH OF VARIOUS CROPS AT 25°C (cal/mole)

Crop	Exhaustion	Response	Optimum	Reference
		(a) Potassium		
Grass and hey (unspecified)	-	-4500 (pH 7)	-	Schaffer et al 1962
Ryegrass	-4600, -5600 and -5400	-	-	Arnold 1962, Talibudeen and Dey 1968, Addiscott 1970
Wheat	-4700 and -4200	-3200 and -3700	-3400	Scheffer et al 1962, Feigenbaum and Hagin 1967
Winter rye and spring barley	-	-	-3400	Schaffer et al 1962
Oats	-3800	-	-	Acquaye et al 1967
Maize and Sorghum	-4300	-3800	-	Acqaaye et al 1967
Rice	-	-3700	-3000	Ramamoorthy and Paliwal 1965
Vetch and clover	-5000	-	-4400	Hagin and Dovrat 1963
Subterranean clover	-6200	-	-4600	Barrow 1966, Barrow et al 1977
Soyabean	-	-4010	-	Woodruff and McIntosh 1961
Alfalfa	-	-3900	-	Levin et al 1969
Potato	-4900	-3900 and -4200	-2500 and -2400	Schaffer et al 1962, Arnold et al 1968, Addiscott and Mitchell 1970.
Sugarbeet	-	-	-3000	Scheffer et al 1962
Oil palm	-	-3900	-3000	Tinker 1964
Cacao	-	-	-3900	Moss 1964
Banana	-	-	-3200	Moss 1964
Strawberry	-4000	-	-	Bradfield 1969
		(b) Magnesium		
Sugarbeet	-	-2300	-	Tinker 1967
Coconut	-2700	-	-	Nethsinghe 1962
		(c) Phosphate		
Unspecified crop (wheat)	-	-7600	-6900	Aslyng 1964

Table 13 CRITICAL CONCENTRATIONS AND THE EQUIVALENT CHEMICAL POTENTIALS (IN PARENTHESES) FOR THE GROWTH OF VARIOUS CROPS IN FLOWING NUTRIENT CULTURE SOLUTIONS

Crop	Exhaustion	Response	Optimum	Luxury	Reference
		(a) Potassium M x 10^6 (and $-RT\ln(M)$ at 25°C			
Ryegrass, Bromgrass	1 (8200)	8 (7000)	24 (6300)	1000 (4100)	Asher and Ozanne 1967
Oats, barley	1 (8200)	24 (6300)	1000 (4100)	-	
Subterranean clover, vetch	1 (8200)	8 (7000)	100 (5500)	1000 (4100)	
		(b) Phosphate M x 10^6 (and $-RT\ln(M)$ at 25°C)			
Bromgrass, clover	0.04 (10200)	0.2 (9200)	5 (7300)	25 (6300)	Asher and Loneragan 1967
Lupin	-	1 (8200)	5 (7300)	25 (6300)	
Potato	1 (8200)	-	40 (6000)	-	Houghland 1947
Wheat	1 (8200)	5 (7300)	10 (6900)	-	Sommer 1936, Teakle 1929
Barley	1 (8200)	2 (7800)	5 (7300)	-	Bingham 1951
Soyabean	1 (8200)	3 (7600)	5 (7300)	-	Parker 1927
Pea	2 (7800)	-	30 (6200)	-	Sommer 1936

2.3.2 Empirical approach B

Several workers have reported critical nutrient concentrations for the growth of various crops by maintaining their roots in flowing and aerated culture solutions containing the tested nutrient in a wide range of concentrations (up to one thousandfold). Critical concentrations of the nutrient are converted to energy units (i.e. chemical potentials) by calculating ionic activities by conventional methods for comparison with the corresponding SNP values (Table 13). These critical potentials seem to be smaller by at least 1-2 kcal/mole than those derived from SNP experiments. Perhaps this results from the better root systems developed in solution culture, although nutrient potentials in soil and solution culture are not strictly comparable.

2.3.3 Quantitative approach

For determining the exhaustion potential of a crop, this approach utilizes the relationship between the quantity (Q) of (exchangeable) nutrient ion in the soil and its 'potential' (I) to calculate the amounts of K required to be removed from it to decrease its potential to various predetermined values. Nutrient uptakes from the soil, maintained at various nutrient levels, are correlated with each of these calculated nutrient removals. Plotting these correlation coefficients against SNP for each soil treatment at various times gives a maximum r value at the exhaustion potential of the crop (Addiscott 1970a,b, Addiscott and Mitchell 1970) this potential being independent of the period of growth and the soil used, provided "non-exchangeable" forms of the nutrient are not substantially released. Values for the exhaustion potential for various crops can be derived in this way with a mean standard error of about ±10%. In addition to the degree of precision is the advantage that the extracting power of the crop can be equated to that of an appropriate conventional laboratory extractant by interpolating its SNP value on the quantity:potential curve for a soil (in a neutral electrolyte) corresponding with the amount of nutrient ion it can extract from the soil (Addiscott and Mitchell 1970).

Such a procedure, coupling soil nutrient availability to a particular crop to a specific extractant, is of value to the agricultural chemist.

2.4 Illustrative Results

The results described here are intended to illustrate the nature of the information available so far and are in no way exhaustive. Those on potassium are taken from an earlier review (Beckett 1972) and are grouped for various crops after converting activity ratio units into energy units, assuming a uniform soil temperature of 25°C.

2.4.1 Potassium

For the Gramineae, an optimum SNP of -3000 to -3400 cal/mole is observed for wheat, rye and paddy rice grown under quite different environments. Exhaustion potentials vary from -5500 cal/mole for ryegrass, -4300 for wheat, maize and sorghum to -3800 for oats. Response potentials are also reasonably uniform at about -3750 for wheat, maize, sorghum and rice, but those for grass and hay crops are lower at -4500 cal/mole at pH 7.

Legumes can grow at lower K potentials than the Gramineae, critical exhaustion and response potentials being -5600 (mean) and -4500 to -4000 cal/mole respectively.

The exhaustion and response potentials for potatoes are similar to those for the Gramineae although the optimum potential is higher at -2400 cal/mole. The optimum value for sugarbeet is -3000 although in the absence of sodium, this could be higher.

The requirements of tree crops in the tropics for optimum nutrition do not seem to differ much from the Gramineae on the energy scale, values of -4000 to -3000 cal/mole being obtained. However, observations are scarce.

2.4.2 Magnesium and phosphorus

See Table 12; there is too little published information for relevant comment.

3. IMPLICATION OF SOIL NUTRIENT POTENTIAL IN THE SUPPLY OF NUTRIENTS TO PLANTS

3.1 Equilibrium Conditions

The quantity (q) : potential (p) (or intensity or concentration) relationship of a soil is well-recognized and has been briefly referred to in relation to its importance in predicting nutrient supply by a soil. The adsorption isotherm is conventionally expressed as the amounts of nutrient in unit volumes of soil and equilibrium solution for which linear and curvilinear relationships are observed depending on the nature of the soil:nutrient interaction.

When linear, the slope, or buffering capacity, $b = dq/dc$, is constant and the amount of nutrient supplied over a concentration range c_1 to c_2 is easily calculated. When the q:c relationship is nonlinear, b can be calculated in several ways: (a) by the function $b = d\ (Rc^n)/dc$ where R and n are constants (Olsen et al 1962); (b) by deriving the buffer capacity parameter from a single Langmuir process equation of the type:

$$q = K_1c/(K_2 + c)$$

giving $b = K_2q^2/K_1c^2$ where K_1 and K_2 are constants, from which a 'supply parameter' $(K_1K_2)^{\underline{1}}-1/4(qc)^{\frac{1}{2}}$ is derived and which is shown to be highly significantly correlated with phosphate uptake by cotton (Khasawneh and Copeland 1973) with zinc uptake by wheat from four contrasting Indian soils (Sidhu et al 1977), and with zinc desorption by several extractants from an Indian soil (Sinha et al 1975); (c) by calculating a 'maximum buffering' capacity (MBC) for phosphate adsorption on soils by fitting high and low bonding energy Langmuir processes (Holford and Mattingly 1976a, Dalal and Hallsworth 1976) on the q:c relationship. The equilibrium buffering capacity (EBC) can then be obtained as before by differentiation:

$$EBC = k_1q'/(1+k_1c)^2 + k_2q''/(1+k_2c)^2$$

from which MBC is easily obtained for the condition $c \Rightarrow 0$). Highly significant correlations are obtained between phosphate uptake by ryegrass and EBC or MBC, especially the latter. As expected, this shows that the higher the buffer capacity, the lower the concentration c necessary and the larger the amount q required for a certain amount of phosphate uptake (Holford and Mattingly 1976b).

3.2 Dynamic Conditions

3.2.1 Nutrient flow through soil

Diffusive and mass flow are the mechanisms of the movement of nutrients to roots. The physical and chemical characteristics of the soil complex that affect diffusive flux are well known and identifiable quantitatively. This is achieved by studying the modification (by each soil complex) of the diffusion coefficient of the nutrient in free solution (Olsen et al 1965

$$D_{soil} = D_{soln}.f.\ \theta/b$$

where F is the tortuosity factor (i.e. the pore space for nutrient movement and its layout in the soil complex), θ the fractional volume of the pore space occupied by soil water and b (=dq/dc) the nutrient buffer capacity determined from the amounts of 'available' nutrient in unit volume of soil, q, and soil water, c, the latter being exponentially related to SNP. f and θ are interactive factors so that the tortuosity factor f decreases much more with decreasing θ, less so at lower θ values.

Clearly, measurements of such soil parameters can only be made with any acceptable precision in the laboratory and we are faced, for the foreseeable future, with considerable approximations in applying laboratory f and θ values in the field. However, for a similar transformation, a b value, averaged across the rhizosphere, is unlikely to change much if soil pH does not change. Little is known about the effects of changes in other soil factors, e.g. water content of the soil, on the factor b.

We also recognize that the mass flow component of nutrient flux through the soil must be affected to some extent by a tortuosity factor not too different to that for diffusive flux and that the buffer capacity of water in the soil is given by the water characteristic of the soil, i.e. the water 'content:potential' relationship. The gradients in the water SNP are created by evapotranspiration.

3.2.2 The root:soil interaction in nutrient flow

Within the last decade, efforts have been made to determine experimentally nutrient absorption rates by roots (Loneragen *et al* 1968, Wild *et al* 1974). This was foreshadowed by the postulation of carrier sites in roots (Epstein 1956) whose number depends partly on the nutrient concentration in the bathing solution (Hagon and Hopkins 1955, Wild *et al* 1974). It has also been demonstrated that the roots of various species have different concentrations of carrier sites (Noggle and Fried 1960). From the sophisticated, complex, experimental and mathematical models developed recently (Noggle and Fried 1960, Brewster and Tinker 1970, Baldwin *et al* 1973, Nye *et al* 1975) some conclusions can be derived which show an understandable similarity to work of twenty years earlier (Hagen and Hopkins 1955, Wild *et al* 1974):-

i. The unit absorption rate (UAR) of the nutrient by the root (in amount g/sec) decreases with the period of growth at low nutrient concentration in the bathing solution but is relatively constant at higher concentrations;

ii. UAR varies with species;

iii. Uptake is given by $(2\ a\alpha l).c$, where a is root radius, α, root absorption coefficient, l total active root length of the plant and c the nutrient concentration in the bathing solution, again related to SNP (Nye *et al* 1975);

iv. When these root characteristics are related to diffusive flux in the soil, we are presented with an "uptake-supply balance" index $(\alpha a/D_{soil}.b)$ for each plant:soil combination, also varying with development stages of the plant. These models have been and are being elaborated for mass flux, transpiration, competition between parallel and random roots, interferences with root hairs etc. Modifications by soil temperature, mycorrhizal hyphae, changes by the roots of environmental conditions in the rhizosphere, e.g. pH, chelation of ions etc. by exudates and decomposition products, would have to be introduced later.

REFERENCES

Acquaye, D.K., Maclean, A.J. and Rice, H.M. Potential and capacity of
1967 potassium in some representative soils of Ghana. Soil Sci. 103: 79-89.

Addiscott, T.M. Use of the quantity/potential relationship to provide a scale
1970a of the ability of extractents to remove soil potassium. J. Agric. Sci.
Cambridge 74: 119-121.

Addiscott, T.M. The uptake of initially available soil potassium by ryegrass.
1970b J. Agric. Sci. Cambridge 74: 123-129

Addiscott, T.M. and Mitchell, J.D.D. Potassium uptake by potatoes. J. Agric.
1970 Sci. Cambridge 74: 495-500.

Arnold, P.W. The potassium status of some English soils considered as a
1962 problem of energy relationships. Proc. Fertil. Soc. London 72: 25-43.

Arnold, P.W., Tunney, H. and Hunter, F. Potassium status: soil measurements
1968 and crop performance. Trans. 9th Int. Cong. Soil Sci 2: 613-620.

Asher, C.J. and Loneragan, J.F. Response of plants to phosphate concentration
1967 in solution culture: I. Growth and phosphorus content. Soil Sci.
103: 225-233.

Asher, C.J. and Ozanne, P.G. Growth and potassium content of plants in
1967 solution cultures maintained at constant potassium concentrations.
Soil Sci. 103: 156-161.

Aslyng, H.C. Phosphate potential and phosphate status of soils. Acta Agric.
1964 Scand. 14: 261-285.

Baldwin, J.P., Nye, P.H. and Tinker, P.B. Uptake of solutes by multiple
1973 root systems from soil III - A model for calculating the solute uptake
by a randomly dispersed root system developing in a finite volume
of soil. Pl. Soil 38: 621-625.

Barrow, N.J. Nutrient potential and capacity II. Relationship between potassium
1966 potential and buffering capacity and the supply of potassium to plants.
Aust. J. Agric. Res. 17: 849-861.

Barrow, N.J., Asher, C.J. and Ozanne, P.G. Nutrient potential and capacity III.
1967 Minimum value of potassium potential for availability to *Trifolium*
subterraneum in soil and in solution culture. Aust. J. Agric. Res.
18: 55-62.

Beckett, P. Critical cation activity ratios. Adv. Agron. 24: 379-412.
1972.

Bingham, F.T. Ph.D. thesis. California University.
1951

Bradfield, E.G. Quantity/intensity relations in soils and the potassium
1969 nutrition of the strawberry plant (Fragaria sp.). J. Sci. Food Agric.
20: 32-38.

Brewster, J.L. and Tinker, P.B. Nutrient cation flows in soil around plant
1970 roots. Soil Sci. Soc. Amer. Proc. 34: 421-426.

Brewster, J.L. and Tinker, P.B. Nutrient flow into roots. Soils Fertil.
1972 35: 355-359.

Dalal, R.C. and Hallsworth, E.G. Evaluation of the parameters of soil
1976 phosphorus availability factors in predicting yield response and
phosphorus uptake. Soil Sci. Soc. Amer. Proc. 40: 541-546.

Epstein, E. Annu. Rev. Plant Physiol. 7: 1-24
1956.

Feigenbaum, S. and Hagin, J. Evaluation of methods for determining available
1967 soil potassium based on potassium uptake by plants. J. Soil Sci.
18: 197-203.

Fried, M and Broeshart, H. The soil-plant system. Academic Press, New York.
1967

Fried, M. and Shapiro, R.E. Soil-plant relations in phosphorus uptake.
1960 Soil Sci. 90: 69-76.

Hagen, C.E. and Hopkins, H.T. Ionic species in orthophosphate absorption by
1955 barley roots. Plant Physiol. 30: 193-199

Hagin, J. and Dovrat, A. Note on methods for determination of available soil
1963 potassium. Emp. J. Exp. Agric. 31: 186-188.

Holford, I.C.R. and Mattingly, G.E.G. A model for the behaviour of labile
1976a phosphate in soil. Pl. Soil 44: 219-229.

Holford, I.C.R. and Mattingly, G.E.G. Phosphate adsorption and availability
1976b plant of phosphate (sic). Pl. Soil 44: 377-389.

Houghland, G.V.C. J. Agric. Res. 75: 1-18.
1947

Khasawneh, F.E. and Copeland, Jane P. Cotton root growth and uptake of
1973 nutrients: relation of phosphorus uptake to quantity, intensity,
and buffering capacity. Soil Sci. Soc. Amer. Proc. 26: 222-227.

Levin, I., Dovrat, A. and Mozes, G. Yield responses of irrigated alfalfa
1969 (Medicago sativa L.) to available soil P and K levels in different
fertilizer treatments in the Hula valley of Israel. Israel J. Agric.
Res. 19: 25-30.

Loneragan, J.F., Snowball, K. and Simmons, W.J. Response of plants to calcium
1968 concentration in solution culture. Aust. J. Agric. Res. 19: 845-
857.

Moss, P. A potassium relationships between soil solution and cacao bark.
1964 Nature (London) 201: 729-730.

Nethsinghe, D.A. Annu. Rep. Coconut Res. Sta. Ceylon. 14: 15-16.
1962.

Noggle, J.C. and Fried, M. A kinetic analysis of phosphate absorption by
1960 excised roots of millet, barley and alfalfa. Soil Sci. Soc. Amer. Proc. 24: 33-35.

Nye, P.H. The effect of the nutrient intensity and buffering power of a soil,
1966 and the absorbing power, size and root hairs of a root, on nutrient absorption by diffusion. Pl. Soil 25: 81-105.

Nye, P.H., Brewster, J.L. and Bhatt, K.K.S. The possibility of predicting
1975 solute uptake and plant growth response from independently measured soil and plant characteristics. I. The theoretical basis of the experiments. Pl. Soil 42: 161-170.

Olsen, S.R., Kemper, W.D. and Jackson, R.D. Phosphate diffusion to plant
1962 roots. Soil Sci. Soc. Amer. Proc. 26: 222-227.

Olsen, S.R., Kemper, W.D. and van Schaik, J.C. Self-diffusion coefficients
1965 of phosphorus in soil measured by transient and steady-state methods. Soil Sci. Soc. Amer. Proc. 29: 154-158.

Parker, F.W. Soil Sci. 24: 129-146.
1927

Ramamoorthy, B. and Paliwal, K.V. Comparison of some rapid methods of
1965 determining potassium availability of paddy soils. Soil Sci. 100: 425-427.

Scheffer, F. Ulrich, B. and Lisanti, L.E. 4th Agrochim. Symp. pp. 444-464.
1962

Schofield, R.K. Proc. 11th Int. Cong. Pure Appl. Chem. (London) 3: 257-261.
1947

Schofield, R.K. Collected papers. Natal University, Pietermaritzburg.
1963

Sidhu, A.S., Randhawa, N.S. and Sinha, M.K.
1977

Sinha, M.K. et al Chemical equilibria and quantity/intensity relationship of
1975 zinc in some acid soils of India. Geoderma 13: 349-362.

Sommer, A.L. J. Agric. Res. 52: 133-148.
1936

Talibudeen, O. The nutrient potential of the soil. Soils Fertil. 37: 41-45.
1974

Talibudeen, O.and Dey, S.K. Potassium reserves in British soils I. The
1968 Rothamsted classical experiments. J. Agric. Sci. Cambridge 71: 95-104.

Teakle, C.J.H. Plant Physiol. 213-232.
1929

Tinker, P.B. Studies on soil potassium IV. Equilibrium cation activity ratios
1964 and responses to potassium fertilizer of Nigerian oil palms. J. Soil Sci. 15: 35-41.

Tinker, P.B.H. The effects of magnesium sulphate on sugarbeet yield and its
1967 interactions with other fertilizers. J. Agric. Sci. Cambridge
68: 205-212.

Wild, A. et al. Comparison of potassium uptake by four plant species grown in
1974 sand and in flowing solution culture. J. Appl. Ecol. 11: 801-812.

Woodruff, C.M. The energies of replacement of calcium by potassium in soils.
1955 Soil Sci. Soc. Amer. Proc. 19: 167-171.

Woodruff, C.M. and McIntosh, J.L. Testing soil for potassium. Trans. 7th Int.
1961 Cong. Soil Sci. 1960. 3: 80-85.

Paper 11 METHODS OF FERTILIZER APPLICATION FOR INCREASING FERTILIZER EFFICIENCY

J. Velly

IRAT, GERDAT, Montpellier, France.

1. INTRODUCTION

In countries where fertilizers are widely used, means have usually been found of obtaining high fertilizer efficiency. There is a similar need in developing countries where the use of fertilizer is relatively recent and where natural conditions, such as rainfall and soil characteristics, tend to increase losses or cause poor utilization of nutrients. Recent increases in fertilizer prices have made efficient use of fertilizer even more necessary.

Most of the studies on this subject, carried out world-wide, have been devoted to N and P which differ markedly in their behaviour. Nitrogen can move rather freely in the soil and can be lost in many ways. Efforts have therefore been made to apply N at periods when the N needs of the plant are greatest so as to avoid, as far as possible, losses by leaching which are often heavy in the tropics. Phosphorus, however, moves little or not at all and can be fixed very strongly in many tropical soils. It has been considered necessary to place it as close as possible to the plant roots to promote its absorption, the risks of losses with water being very small, except by erosion.

In this paper, the results of experiments on both rice and upland crops are reviewed. Placement of fertilizers is discussed, as well as their application in split dressings. Different sources of the same element are compared since the first step towards increasing fertilizer efficiency is to ensure that the most active source is being used. The appendix deals with small items of agricultural equipment which can be used in developing countries to ensure that the fertilizer is placed as may be necessary.

This review is far from being comprehensive partly because of the great number of studies on the subject, but it should provide a fair idea of existing solutions, through appropriate methods of application, to the economically important problem of increasing the efficiency of mineral fertilizers.

2. NITROGEN IN RELATION TO CROP YIELDS AND UPTAKE

2.1 Lowland Rice

2.1.1 Forms of N

In Latin America (Sanchez 1972) the poor performance of nitrates and lack of difference between urea and ammonium sulphate as sources of N were general throughout the region, but in Mali (Poulain 1976) ammonium forms were better although for economic reasons urea was to be preferred.

In Thailand, four different slow release N fertilizers were compared with urea for a period of two years at five research stations using three varieties of rice (Suwanwaong and Sathdhani 1970), but yields did not differ significantly.

A number of organic compounds commercially available in Japan and containing slowly available N were referred to by Matsuo and Dewis (1970) as being seemingly promising, although their cost per unit of N was high. Guanyl urea, used in conjunction with a source of readily available N for the early stages of growth, was more effective than normal fertilizers.

Sulphur coated urea (SCU) was used in a four year programme aimed at increasing the efficiency of N applied to rice grown under intermittent flooding (Engelstad et al 1972). Such conditions are widespread (75%) in southeast Asia and lead to high losses of N resulting from nitrification during the dry periods being followed by denitrification or leaching of nitrate during periods of flooding. Trials in the glasshouse showed that the best results with SCU were obtained with delayed flooding or with alternate flooding and draining, the coating preventing dissolution of the granules and nitrification during the drained periods. The rate of release of N was slower under flooded than under drained conditions and under cyclical flooding compared with continuous flooding.

Field experiments in several countries have been used to compare SCU with urea supplied as basal or split dressings. Out of a total of 56 comparisons, 46 showed SCU to be superior to urea when both were applied as a basal treatment. In the Asian countries, 12 out of 19 comparisons showed SCU to be superior to split applications of urea, which in South America when all the urea was applied as a topdressing basally applied SCU was superior in 19 cases out of 26. These results indicated that N is lost from urea when flooding is not continuous.

Results of work in Peru with high yielding non-lodging varieties grown with intermittent flooding showed that basal applications of SCU were more efficient than urea or ammonium sulphate as topdressings (Sanchez et al 1973). Despite the 48% higher unit cost of N, the basal application of SCU was beneficial since there was a 40% reduction in the optimum rate of N and the need for precise timing of application was eliminated.

Similar experiments in African countries (IITA 1974) enabled no clear conclusions to be drawn, there usually being no difference between the different forms of N.

2.1.2. Timing and placement of N

Despite the wide range of conditions under which irrigated rice is grown, it has been found that in most countries an application of N at tillering or panicle initiation is better than a single dressing at planting (India, Mahapatra 1969; Japan, Murayama 1970; Mali, Poulain 1976; Latin America, Sanchez 1972; Peru, Sanchez and de Calderon 1971).

In the U.S.A. there has been evidence that correct timing is influenced by the variety grown, and that while late varieties have high N requirements at tillering and shortly before flowering, early varieties have a more uniform N requirement (Evatt 1964). The application of ammonium sulphate to dry soil was preferable to a wet soil, and when applied to a wet soil placement of the fertilizer in the reducing zone of the soil was advisable.

In many countries there are areas of rice where little or no control of water is possible and any N is therefore applied at planting or as circumstances may permit.

Placement at the appropriate depth is facilitated by the physical state of the fertilizer. The mud ball technique developed by the IRRI (1974) led to increased yields at a lower rate of applied N compared with topdressing, but the method requires an impracticably large number of balls (62 500 per hectare). Attention is being given to the production of urea in granular or briquet form by the International Fertilizer Development Center, Alabama, tests of which indicate parity with the mud ball technique (IRRI 1975).

2.1.3 Uptake of N

The uptake of N from fertilizer applied to rice serves as a discriminant between forms of N and methods of application, although more efficient uptake does not necessarily imply higher yields of grain. Studies by the joint FAO/IAEA Division of Atomic Energy on the use of ammonium sulphate labelled with ^{15}N (IAEA 1970a) showed that efficiency of use of N was highest on most soil types when placed at a depth of 5-15 cm at transplanting or broadcast on the surface two weeks before primordial initiation. When the pH was exceptionally high or low, depth of placement had no appreciable effect.

Urea behaved similarly to ammonium sulphate in respect to timing and placement, but fertilizers containing N in nitrate form were markedly less efficient and if they have to be used they should be applied late in the growing season shortly before primordial initiation.

Glasshouse studies by the joint FAO/IAEA Division of Atomic Energy suggested that the lower efficiency of surface applications is attributable to gaseous losses of N from the surface. Such losses on some soil types may be as high as 70%, and attempts to reduce them by using inhibitors such as N-Serve have failed.

2.2 Upland Cereals

2.2.1 Timing and placement of N

Three split applications of N at 40 kg/ha were more effective than a single application of 120 kg/ha to maize in Upper Volta (Poulain 1972) where the soils are deep, light textured and have good permeability.

In Madagascar (Velly et al 1972) 120 kg/ha of N applied prior to seeding maize were compared with the same amount in two split dressings (one-third at 3 weeks after emergence and two-thirds at flowering). The single basal dressing reduced the grain yield below that of control (no N) while the split dressings raised it by 1900 kg/ha. In a repeat experiment the following year, the basal dressing which was applied 3-4 weeks after seeding increased the yield by 2.7 t/ha over control and the split applications by 4.4 t/ha.

At Benin, Werts and Bowyer (1967) found that N applied to maize at 30 kg/ha 2 weeks after emergence was as effective as split applications, while in another year 15 kg/ha applied 2 weeks after emergence followed by 15 kg/ha at flowering increased the grain yield by 900 kg/ha.

Fox (1972), reporting the results of a series of experiments in Puerto Rico, concluded that post-planting applications of N to maize and sorghum were much more effective than preplanting applications in increasing grain yields.

Sanchez (1972) confirmed that in Latin America split or side-dressed applications of N to maize are more efficient than basal applications because leaching losses and wind competition are reduced.

2.2.2 Uptake of N by maize

Experiments carried out under contract with the joint FAO/IAEA Division using labelled fertilizer showed that under a wide range of conditions there was a great similarity between ammonium sulphate, ammonium nitrate and urea as sources of N (IAEA 1970b).

Uptake of N applied in bands at seeding was consistantly greater than when N was ploughed in before seeding. Side-dressed N was most abundant in the grain when it has been applied when the plants were 50 cm or more in height but before tasselling. After tasselling, fertilizer N efficiency decreased sharply. Differences between two and three split applications were small, and the most efficient treatment was usually half the fertilizer applied in a band at seeding and half side-dressed when the plants were 50 cm tall.

It should be noted that the results of these experiments mainly reflect the availability of fertilizer N to the plants; yields were often unaffected.

2.2.3 Uptake of N by upland rice

The uptake of N from labelled urea by upland rice was studied in the Ivory Coast by Chabalier and Pichot (1976). The effect was determined of split dressings of N at 60 and 120 kg/ha, applied half at planting and half at booting, on uptake of N by the plant and losses of N through leaching. Results are shown in Table 14.

Table 14 EFFECT OF RATE AND TIMING OF APPLICATIONS OF UREA TO RICE ON LOSSES OF NITROGEN FROM THE PLANT-SOIL SYSTEM

Fate of applied N	60 kg N/ha		120 kg N/ha	
	30 kg/ha at seeding	30 kg/ha at booting	60 kg/ha at seeding	60 kg/ha at booting
Found in plant (kg)	7	13	11	21
Immobilized in soil (0-25 cm((kg)	19	15	18	20
Mineral N in soil (0-25 cm) (kg)	1	1	2	1
Leached (kg)	0.5	0	3	0.5
Total accounted for (kg)	27.5	29	34	42.5
Losses (denitrification?) (%)	7	3	42	28

With a moderate application of N (60 kg/ha) losses of N were small, but not so at the higher rate (120 kg/ha). They were also smaller when N was applied at the booting stage and the plant was growing actively. Uptake of N by the plant was inversely related to losses.

2.2.4 Uptake of N by wheat

The wheat programme of the joint FAO/IAEA Division of Atomic Energy in Agriculture showed that applied N almost always had a pronounced effect on the yield of grain and also on the N content of the grain (IAEA 1974).

Split applications were better than a basal dressing at planting, N applied at tillering being used more efficiently. Early split applications were more effective in increasing grain yields, while later applications had more effect on the N content of the grain and less on yield.

There was little to choose between ammonium sulphate, ammonium nitrate and urea as sources of N, but frequently the mixing of ammonium N with phosphatic fertilizer increased the uptake of fertilizer P.

2.3 Response of Miscellaneous Crops to N

Cotton grown under irrigation in Madagascar gave a highly significant increase in yield of 700 kg/ha of seed cotton following a dressing of urea at 150 kg/ha applied 70 days after planting, whereas there was no response when applied at planting (Blanguernon 1967).

Deep placement (15 and 35 cm) of urea was compared with broadcast urea ploughed in before planting cotton on alluvial soils of northwest Madagascar in which water is available to the plant only by capillary rise from the water table. Placement at 15 cm deep increased the yield by 65 percent over that of control, compared with 30 percent when broadcast and ploughed in. Yields were not affected by different depths of placement (Cretenet 1967). Later trials on the same soils using mechanical equipment for deep placement showed that the best results were obtained by placement of half the N at 15 cm and half at 35 cm deep (Berger 1972).

Sanchez (1972), reviewing recommended methods of applying N to crops in Latin America, reported that for cassava half the N should be applied to the side of the planting furrow and half side-dressed at a later stage. For yams, delaying the application of N until three months after planting, when secondary shoots are then being produced, increased the yield by 50%. Potatoes did not appear to be affected by timing of N. Splitting the annual rate into equal amounts for application after each cut of forage or pasture was universally recommended.

3. PHOSPHORUS IN RELATION TO CROP YIELDS

3.1 Types of Phosphatic Fertilizer

Rock phospates of different origins were compared with superphosphate in a glasshouse experiment using four Nigerian soils of differing pH. On moderately to very acid soils the rock phosphates were equal or superior to superphosphate (IITA 1975).

A similar experiment in France (Traore 1976) compared six West African rock phosphates with Reno phosphate and superphosphate as controls. On the basis of dry matter production, all the phosphates were effective at pH 4.5 At pH 5.5, only superphosphate, Reno phosphate and Tilemsi (Mali) rock phosphate increased the yield significantly, whereas at pH 6.5 only superphosphate was active.

In the second year of an experiment in Nigeria comparing single superphosphate with Togo rock phosphate with and without added S, the rock phosphate with added S was as effective as superphosphate (Stockinger 1976). The beneficial interaction between Togo rock phosphate and sulphur was confirmed by Yawovi (1976) using three almost neutral Togo soils.

From these experiments it appears that rock phosphates could be used with advantage on many acid soils of the tropics.

3.2 Lowland Rice

3.2.1 Forms of phosphate

Judging from experiments reviewed by Davide (1964) any significant difference between different sources of P on lowland rice soils seems to be restricted to extremely acid or alkaline soils. Superphosphate was a good source on all but the very acid soils which were usually better suited to rock phosphate and bone meal.

In a series of experiments carried out by the TVA (Engelstad et al 1972) in India, the Philippines, Thailand, Sri Lanka and Colombia, it appeared that certain rock phosphates could replace the more costly acidulated phosphates, but to be effective the rock phosphate should contain not less than 15% of total P in the form of the citrate soluble fraction. Over 60% of the rice growing area in Malaysia and 78% in Thailand, for example, could be suitable for rock phosphate applications. Similar results have been reported by Velly and Roche (1973) in Madagascar.

3.2.2 Timing and placement of P

The TVA experiments (Engelstad et al 1972) showed general agreement that phosphate should be applied early, during the first two months of growth. This finding conforms with the recommendation in most countries of Asia that P should be applied as a basal dressing just before transplanting or seeding.

Although results from India were contradictory, it was found in Japan on volcanic ash soils with a high capacity to fix P that dipping the roots into a 1:5 paste of superphosphate and soil before transplanting was effective.

3.2.3 Uptake of P by lowland rice

The joint FAO/IAEA series of experiments on rice (IAEA 1970a) showed that the best way of applying superphosphate was on the soil surface at the beginning of the growth period, although late timing and split applications did not materially affect uptake. Flooding generally tended to increase the soil P supply but did not affect appreciably the availability of P from superphosphate. On rice soils in southeast Asia the increase in P availability on flooding was often relatively small. Ammonium sulphate stimulated the uptake of P from fertilizer placed at a shallow depth but not on the surface. The application of superphosphate to nurseries had no effect on the relative utilization of soil and fertilizer P after transplanting.

3.3 Use of P on Short-term Upland Crops

One of the main conclusions reached by Barber (1977) was that P must be applied early, young roots absorbing P much more rapidly than old roots. In a field experiment on maize, placement of the fertilizer in bands covering about one-tenth of the area of the field and ploughing it in was better than broadcasting and ploughing in or placement alongside the seed. Contact with the roots was also better than when fertilizer was close to the seeds and fixation was less than with broadcasting. This type of result is a function of the plant and fixation capacity of the soil; a different plant might require a different width of band, and on a soil with a low fixation capacity broadcasting and ploughing in might be better.

Placement and type of fertilizer are inter-related. In a glasshouse experiment with a Madagascar soil of high fixation capacity, Egoumenides and Pichot (1975) showed that the needs of a plant could be met either by placement of a rapidly soluble P source or by spreading and mixing a slowly soluble source such as rock phosphate. As it is impossible to saturate all the soil fixation capacity, it is necessary to ensure that enough is saturated so that intensity is no longer a limiting factor. The example of P fertilizer given by Barber (loc. cit.) clearly shows that the method of application is a compromise between the volume of soil in which the fertilizer is placed (and where the roots can find it) and the fixation capacity of the soil.

The foregoing to some extent clarifies divergent findings for different crops and soils. Sadaphel and Singh (1971) in India compared four methods of P application to sorghum: broadcast, band placement, alongside seed and half with seed and half as a foliar spray. Fertilizer applied close to the seed gave far higher yields than broadcasting, and slightly better yields than placement and half with seed and half as spray. Broadcasting was the least effective method. In Senegal, Pieri (1975) recommended that fertilizer for groundnuts and soyabeans be broadcast and ploughed in to promote rapid growth that is essential for efficient uptake of water and nutrients in semi-arid zones.

The foliar application of superphosphate in India has been reported by Barat and Das (1962).

Uptake studies by the joint FAO/IAEA Division of Atomic Energy in Agriculture have shown that under a wide range of soil and climatic conditions band application of mixtures of ammonium forms of N with superphosphate accelerated the rate of P uptake by maize. This did not occur with urea mixed with superphosphate. Mixing did not usually increase the rate of uptake of fertilizer N (IAEA 1970b).

Virmani (1971), comparing placement of labelled superphosphate 8 cm deep with broadcasting, found that placement resulted in higher grain yields and P content of grain and straw of wheat grown on two irrigated alkaline soils in India. Dissimilar results were reported for soyabeans in Senegal (Nicou 1974).

3.4 Use of P on Long-term Crops

The uptake of P by cocoa was studied by Massaux *et al* (1974) in Cameroon with the aid of ^{32}P labelled fertilizer. In a preliminary experiment on depths of placement it was found that phosphate must be placed within immediate reach of the roots as no P migration occurred. In a second experiment, in which P was placed at different distances from the tree and at various depths, it was found that uptake was greatest for a depth of 5 cm at a distance of 89 cm from the trunk. Because the root system is superficial, it can be recommended to spread the fertilizer over the surface of the ground covered by the crown of the tree commencing 80 cm from the trunk. The fertilizer can be covered with mulch but should not be buried.

Similar experiments have been carried out on coffee and passion fruit in Brazil by Malavolta and Neptune (1977) using labelled superphosphate. It appeared that the best method was to spread the fertilizer under the crown of the tree. Nevertheless, spraying the leaves with fertilizer was about three times more effective.

4. RESPONSE OF LOWLAND RICE TO K

With the exception of Japan, Taiwan and Korea, little K is used for rice. Considering the N-K balance in rice nutrition, von Uexküll (1970) concluded that the plants require a rather large N supply at tillering, the uptake of which too large a basal K application could reduce below the critical level. On the other hand rice plants require a considerable amount of K up to ripening, and timing of the application is therefore important. As a general rule, a small basal application should be followed by an application at maximum tillering and at primordial initiation. Responses to split applications can be expected on light soil and where the basal application of N is low.

Experiments by Velly (1973) over two successive crops in Madagascar showed that while 50 kg K/ha applied at transplanting increased the rice yield from 3697 to 5312 kg/ha, the same amount in split dressings at transplanting and panicle initiation further significantly increased the yield by 357 kg/ha.

5. CONCLUDING REMARKS

Despite differences in soils and climates, the evidence from experiments is generally in favour of split dressings of N, the first of which is less efficiently utilized and should therefore not be too generous. While the efficacy of the several sources of N differ little, ammonium nitrogen for irrigated rice should be placed in the reduced soil layer.

Care should always be taken to adjust N applications to the needs of the plant so that none is left unused in the soil and thus be liable to loss.

More use could perhaps be made of the naturally occurring mineral nitrogen in the soil. Work in West Africa by IRAT has shown that there is usually a peak in mineralization at the beginning of the rainy season and that 30 - 40 kg N/ha may be found in the top 40 cm of soil. Wherever crops can be planted early, use can be made of this N which would otherwise be lost by leaching with the first heavy rainfall of the season.

The best method for application of P is less clear than that for N. Soils vary widely in their capacity to fix P, and in practice a specific solution must be found in each case involving mainly the crop, placement and type of fertilizer. There is general agreement that P should be applied early.

Most experiments on placement of P have used a soluble source of P, usually superphosphate for which localized placement is normally the most efficient. A comparison of placed superphosphate with broadcast rock phosphate ploughed in would be of interest if the experiment were continued for several years so as to take account of changes in the availability of P from the two sources.

Phosphorus deficiency is rather widespread in West Africa but several of those countries have substantial deposits of rock phosphate. A better knowledge of their use could be rewarding.

The use of K presents four difficulties other than price and availability in the remoter regions. In a distant semi-arid zone, a crop of millet producing 1.5-2 t/ha could contain 65-85 kg of K in the straw, the replacement of which in fertilizer form would not be practicable. It is highly probable that K fertilization cannot be separated from the use of plant residues, for which easily manageable methods have yet to be found.

APPENDIX TO PAPER 11

It has been shown earlier that placement of fertilizers in pockets or bands often increased their efficiency. On small farms, without sophisticated machinery for the purpose, this operation is so laborious that fertilizers may be spread by the less effective method of broadcasting.

In consideration of this difficulty, the IRRI has developed relatively simple, sturdy hand operated tools for the injection and band placement of granulated fertilizer in rice fields. Figures 18 and 19 illustrate two different types of injector and Figure 20 shows a push-type implement for band placement, the local manufacture of which requires no high degree of technology.

Other push-type fertilizer distributors include the Planet Junior which can be used on arable land for band placement, while the Indian made "Sholapur" multi-purpose implement is representative of those designed for animal draught.

Many of these implements allow the simultaneous sowing of seed and application of fertilizer and can be adjusted for depths of sowing and placement as well as distance between the seed row and fertilizer band. Those designed for animal traction are able to sow and/or fertilize one or several rows at a pass, depending on the power available and the conditions in the field. However, with a large capacity implement capable of several rows at a time, sidebanding becomes impossible when the crop is tall, so that a one-row type needs to be used under such conditions.

Little emphasis is required on the general need to bring to the attention of farmers the results of research leading to recommended fertilizer placement techniques. Audio and visual methods must be supplemented with practical demonstrations to show that the recommendations are practicable and economic. Such demonstrations are only feasible if equipment appropriate to the size of holding and labour force has been introduced and is available. This step is essential if the more economical use of fertilizer is to be attained.

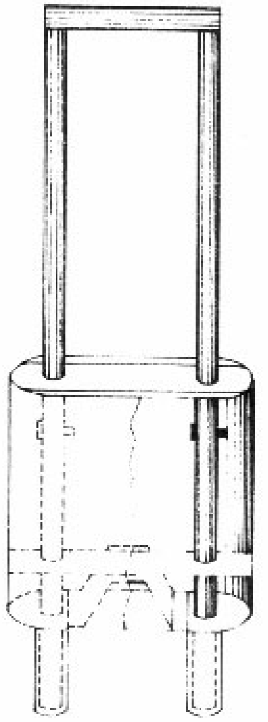


Fig. 18 Spot injector for granular chemicals (single rod)

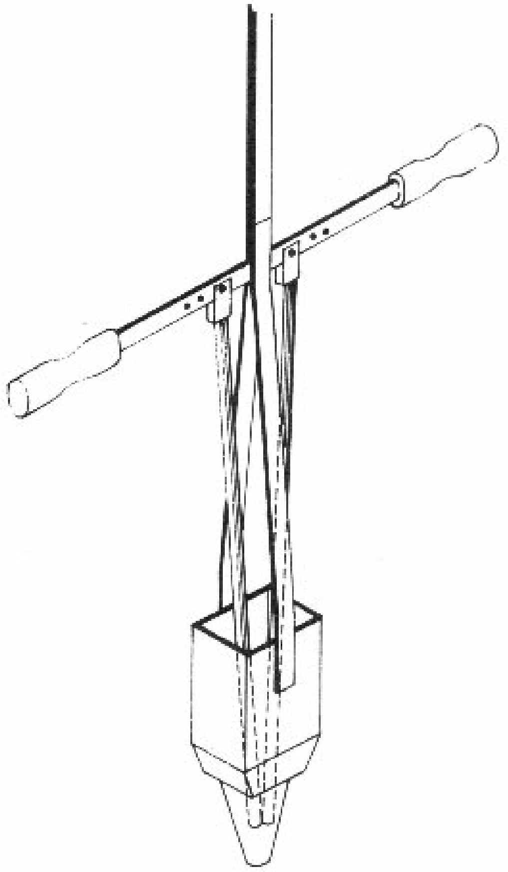


Fig. 19 Spot injector for granular chemicals (double rod)

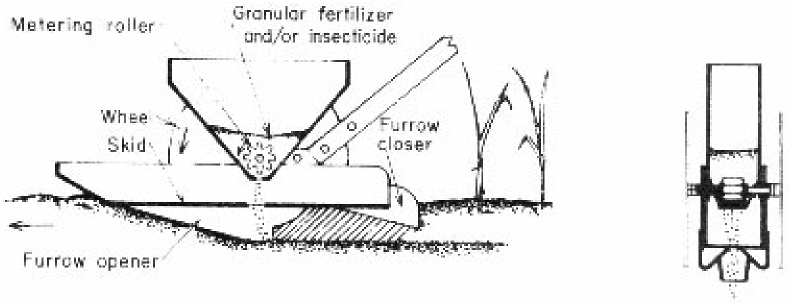


Fig. 20 Schematic drawing of push-type deep placement applicator for granular chemicals. The applicator opens a furrow, deposits the chemical below the soil surface and closes the furrow

REFERENCES

Barat, G.K. and Das, N.P. 1962 Soil and foliar application of urea and superphosphate. Indian J. Agric. Sci. 32 (1): 25-34.

Barber, S.A. 1977 Application des engrais phosphatés : méthodes, doses et époque d'application en fonction de l'état phosphorique des sols. Symposium ISMA sur l'importance du phosphore en agriculture. Paris.

Berger, M. 1972 La fertilisation azotée des sols de décrue du N.O. de Madagascar. Coton et fibres tropicales. 27(2): 259-262.

Blanguernon, F. 1967 Action de l'azote en culture cotonnière irriguée (sectuer Fiherenana - Madagascar). Colloque sur la fertilité des sols tropicaux. Tananarive pp.635-638.

Chabalier, P.F. and Pichot, J. 1976 N Fertilizer utilisation in a two-year rotation (rice - maize/cotton) in Central Ivory Coast. 8th Int. Fert. Congr. Moscow.

Cretenet, S. 1967 La fertilisation du cotonnier en culture de décrue dans le nord-ouest de Madagascar. Colloque sur la fertilité des sols tropicaux. Tananarive. pp. 1010-1018.

Davide, J.G. 1964 The time and methods of phosphate fertilizer applications. *In* The mineral nutrition of the rice plant. pp. 255-268. IRRI Symposium. John Hopkins Press. Baltimore.

Egoumenides, C and Pichot, J. 1975 Influence de la technique d'apport du phosphore sur l'évolution de cet élément dans un sol à fort pouvoir fixateur. Agron. Trop. 30(4): 354-357.

Engelstad, O.P. Getsinger, J.G. and Stangel, P.J. 1972 Tailoring of fertilizers for rice. TVA/AID report. TVA. Muscle Shoals, Alabama.

Evatt, N.S. 1964 The timing of nitrogenous fertilizers on rice. *In* The mineral nutrition of the rice plant. pp. 243-253. IRRI Symposium. John Hopkins Press. Baltimore.

Fox, R.H. 1972 Nitrogen fertilization in the humid tropics. Agric. Res. Seminar Trop. Soils. Ibadan.

Goswami, N.N., Bagchi, D., Gopalakrislinan, S, and Saha, J.R. 1971 Efficiency of applied phosphorus and its utilization by jute (*Corchorus olitorius* and C. *capsularis*). Int. Symp. Soil Fert. Eval. Proc. New Delhi pp.737-746.

I.A.E.A. 1970a Rice fertilization. A six year isotope study on nitrogen and phosphorus utilization. Tech. rep. ser. No.108. IAEA Vienna.

I.A.E.A. 1970b Fertilizer management practices for maize: results of experiments with isotopes. Tech. rep. ser. No.121. IAEA Vienna.

I.A.E.A. 1974 Isotope studies on wheat fertilization. Tech. rep. ser. No.157. IAEA Vienna.

I.I.T.A. Amelioration des engrais pour les pays en voie de dévelopment.
1974 Project TVA/AID. OUA-CSTR. I.I.T.A. Ibadan (Nigeria).

I.I.T.A. 1975 Annu. Rep. I.I.T.A. Ibadan, Nigeria. p.19.
1975

I.R.R.I. International Rice Research Institute Annu. Rep. 1974. Manila.
1974 pp. 12-13.

I.R.R.I. Research highlights for 1975. International Rice Research Institute.
1975 Manila. pp. 70-71.

Mahapatra, I.C. Fertilizer needs of rice. Indian Fmg. 18 (12): 21.
1969

Malavolta, E. and Neptune, A.M.L. Etude de la localisation des engrais sur
1977 des cultures tropicales. Symposium ISMA sur l'importance du phosphore en agriculture. Paris.

Massaux, F., Gestin, A.J. et Misse, C. Etude de l'absorption radiculaire du
1974 cacaoyer à l'aide d'un traceur radioactif dans les conditions écologiques du sud-Cameroun. Café, Cacao, Thé (Paris). 28 (4): 225-236.

Matsuo, H. and Dewis, J. Slowly available nitrogen fertilizers, nitrifying
1970 inhibitors and coated fertilizers. F.A.O. 12th Session of IRC Working Party on Rice Soils, Water and Fertilizer Practices. Teheran.

Murayama, N. Factors responsible for very high yields of rice. Significance
1970 of split application of nitrogen in high yielding rice culture. I.R.C. Working Party on Soils, Water, and Fertilizer Practices. Teheran.

Nicou, R. Programme de recherche coordonnée sur l'utilisation des isotopes
1974 dans l'étude de l'efficience des engrais sur les légumineuses. Compte-rendu de la deuxième réunion de coordination. Vienne, Février 1974. Agron. Trop. 29(12): 1288-1293.

Pieri, C. Utilisation des engrais dans les sols de la zone semi-aride du
1975 Sénégal. (mimeo). CNRA Bambey, Sénégal.

Poulain, J.F. Principaux résultats agronomiques obtenus par l'IRAT en Haute-
1972 Volta. Agric. Res. Seminar Trop. Soils. Ibadan.

Poulain, J.F. Amélioration de la fertilité chimique des sols agricoles du
1976 Mali. Bilan de 13 années de travaux (1962-1974). Agron. Trop. (4) 402-416.

Sadaphal, M.N. and Singh, R.S.P. Grain yield attributes, yield and nutrient
1971 uptake in sorghum as influenced by nitrogen and rates and methods of phosphorus applications. Int. Symp. Soil Fert. Eval. Proc. New Delhi. pp. 585-594.

Sanchez, P.A. and de Calderon, M. Timing of nitrogen applications for rice
1971 grown under intermittent flooding in the coast of Peru. Int. Symp. Soil Fert. Eval. Proc. New Delhi. pp. 595-602.

Sanchez,P.A. Nitrogen fertilization. *In* A review of soil research in
1972 tropical Latin America. pp. 121-145. Soil Sci. N. C. State
Univ. Raleigh. N.C.

Sanchez, P.A., Gavidia, A., Ramirez, G.E., Vergara, R and Minguillo, F.
1973 Performance of sulfur-coated urea under intermittently flooded rice
culture in Peru. Soil Sci. Soc. Amer. Proc. 37: 789-792.

Stockinger, K.R. Agronomy Report 1976. Joint Project 26. Inst. Agric.
1976 Res. Samaru, Nigeria. A.U.O. STRC.

Sewanwaong, S, and Suthdhani, S. The effect of slow release nitrogen on
1970 rice. F.A.O. 12th Session of IRC Working Party on Rice Soils,
Water and Fertilizer Practices. Teheran.

Traore, A. Influence du pH du sol sur l'efficacité des phosphates naturels
1976 d'Afrique de l'Ouest. Travail de D.E.A. d'Agronomie. IRAT et
ENSA Montpellier, France.

Velly, J. Fertilisation potassique des sols tropicaux. Agric. Res. Seminar
1972 Trop. Soils. I.I.T.A. Ibadan.

Velly, J., Celton, J. and Marquette, J. Développement agricole des Haut-
1972 Plateaux de Tananarive et du Moyen-Ouest. Essais agronomiques 1971-
1972. pp. 15-16. IRAM, Tananarive. (mimeo).

Velly, J. La résponse du riz au potassium à Madagascar. Proc. 10th
1973 Colloq. Int. Potash Inst. Abidjan pp. 453-465.

Velly, J. and Roche, P. A comparison between several phosphate fertilizers
1973 used on irrigated paddy rice and on maize in Madagascar. Agron. Trop.
946-956.

Virmani, S.M. Phosphorus fertilization of wheat. Int. Symp. Soil Fert.
1971 Eval. Proc. New Delhi. pp. 767-772.

Von Uexküll, H.R. Some notes on the timing of potash fertilization of rice
1970 (nitrogen-potash balance in rice nutrition). Proc. 9th Cong.
Int. Potash Inst. Antibes pp. 413-416.

Werts, R. and Bouyer, S. Etudes récentes sur la fertilisation des sols
1967 réalisées par l'IRAT au Dahomey. Colloque sur la fertilité des sols
tropicaux. Tananarive pp. 601-612.

Yawovi, V. Utilisation simultanée du phosphate naturel et du soufre pour la
1976 fertilisation des sols à faible acidité en milieu tropical. Travail
pour un D.E.A. d'Agronomie. IRAT et ENSA de Montpellier, France.

Paper 12

PRESENT PROBLEMS OF FERTILIZER USE

A. Tanaka

Faculty of Agriculture, Hokkaido University, Sapporo, Japan

1. INTRODUCTION

Agriculture at present faces two conflicting issues:

i. The increasing population of the world and the prevailing malnutrition of people in advancing countries demand greater production of food. As the area of potentially cultivable land is limited, it is essential that the yield of crops per unit area be increased. To achieve this more fertilizer must be used.

ii. The raw materials for fertilizer manufacture are becoming scarce and more expensive. Farmers, especially in the advancing countries, cannot use as much fertilizer as they should.

Our limited resources must therefore be used at maximum efficiency and yields kept at the highest possible level. In this context some aspects of increasing the efficiency of fertilizers while maintaining high yields of grain crops are discussed in this paper.

2. POTENTIAL PRODUCTIVITY OF CROPS AND FERTILIZER USE

The average yield of a crop in a country (the country yield) differs from one country to the other owing to differences in climate, edaphic conditions and level of crop varietal improvement and cultural practices. In Table 15 the highest country yield, the average of the top 10 country yields and the world average yield of various grain crops are given.

For example, in rice (as paddy) the highest country yield is 6.9 t/ha in Australia and the world average yield is about one-third of the yield in Australia. The recorded highest yield of rice is about 12 t/ha which was reported from experimental plots in Australia and from a yield competition among farmers in Japan. The figures suggest that there are various phases in improvement of the rice yield: (a) Improvement from high country yields (6.9 t/ha in Australia or 6.0 t/ha in Japan) to 12 t/ha, (b) improvement from an ordinary country yield (2.4 t/ha) to the average of the top 10 country yields (5.6 t/ha), (c) improvement from low country yields (for example 0.9 t/ha in the Khmer Republic) to the world average yield (2.4 t/ha) etc. Approaches to achieve improvement in each of these different phases are very different.

The potential productivity differs among crop species owing to differences in the photosynthetic rate per unit area of leaf, photorespiration, chemical composition of harvested organs, duration of growth etc. If we know the potential productivity of various crops, it is possible to estimate numerically the improvements made so far in breeding and cultural practice. In round numbers, the reported maximum yields from experiment plots are 14 t/ha for maize, 12 t/ha for rice, 10 t/ha for wheat, 6 t/ha for soyabeans, 5 t/ha for Phaseolus vulgaris etc. Thus, the potential productivity seems to be the highest in maize, less high in rice and much lower in grain legumes.

The highest country yields are in the order of maize > rice > wheat > ... > soyabeans > beans, dry > chickpeas. This order appears to conform with the order of potential productivity. The order of the world average yields among crops does not, however, coincide with that of the highest country yields. This indicates that the room for improvement is larger in some crops than others.

Table 15 HIGHEST COUNTRY YIELD, AVERAGE OF TOP 10 COUNTRY YIELDS AND WORLD AVERAGE YIELD OF VARIOUS GRAIN CROPS (kg/ha) (HIGHEST OF 1972-74) 1/

Crops 2/	Highest country yield (A)	Average of top 10 countries	World average (B)	A/B
Wheat	5733 (Netherlands)	4893	1703	3.37
Rice	6867 (Australia)	5601	2402	2.86
Barley	4593 (Belgium)	4142	1925	2.39
Maize	7333 (New Zealand)	6192	2792	2.63
Rye	4400 (Switzerland)	3711	1876	2.35
Oats	5017 (Netherlands)	3973	1694	2.96
Millet	4127 (Egypt)	2088	691	5.97
Sorghum	4651 (Thailand)	3919	1237	3.76
Beans (dry)	2771 (USSR)	2097	498	5.56
Chickpeas	1786 (Egypt)	1176	653	2.74
Soyabeans	3117 (Italy)	2080	1408	2.21

1/ Source: FAO Production Yearbook 1974.

2/ Grain crops whose cultivated area in the world exceeds 1×10^7 ha are included in this table.

In Fig.21 the country yields of rice and maize are plotted against the general level of fertilizer application in each country. In interpreting this Figure, there are the following complications: (a) the fertilizer application rates differ among crops within a country; (b) the level of fertilizer application in a country is a reflection of the overall technology, because a country which uses a large amount of fertilizers also generally uses a large amount of pesticides, fungicides etc. Nevertheless, there is a positive correlation between the level of fertilizer application and the country yield. There are, however, wide deviations from this general trend. The yield of rice is much higher in Australia and Spain, for example, than the yield expected from the level of fertilizer application. The same is true of maize; the yields in New Zealand, Israel, Italy, the U.S.A., Canada, and Saudi Arabia, are higher. Possible reasons for the high yield in these countries are better climatic conditions, especially solar radiation, in some countries and more advanced technology in others.

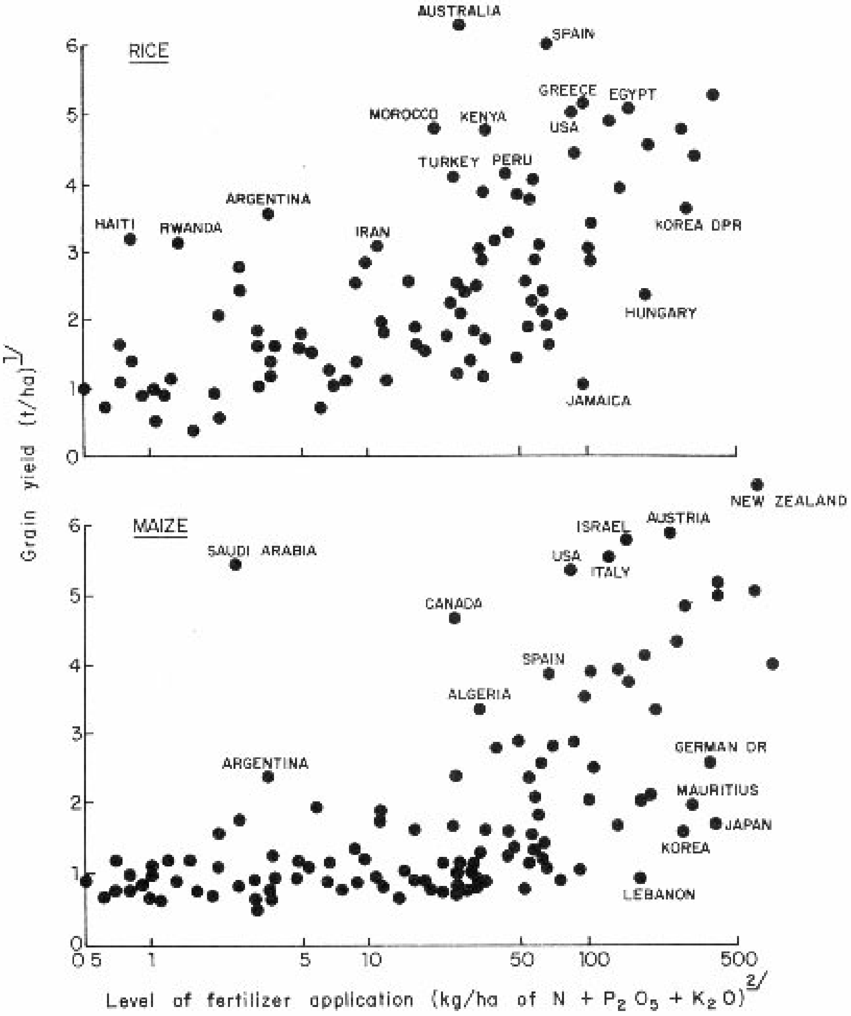


Fig. 21 Relation between level of fertilizer application and grain yield of rice (paddy) and maize

1/ Average of 1972, '73 and '74 (FAO Production Year Book '74

2/ 1972/73 (Total use of fertilizer/total arable land, countries below 0.5 kg/ha were omitted)

A very high yield can only be obtained when solar radiation is abundan because it is the only source of energy for photosynthesis. Abundance of so radiation is one of the key factors responsible for the high yields of rice i Australia and Spain (Tanaka *et al* 1973). It is generally accepted that in addition to suitable soil moisture conditions (a) a high yielding variety, (b) heavy fertilizer application and (c) high planting density are the three essential components of the technology for very high yields. The effect of fertilizers is more pronounced at closer than at wider spacings (Fig.22) (Tanaka and Yamaguchi 1972). The very high yield of maize in the U.S.A. has been accomplished by the combination of the foregoing three factors.

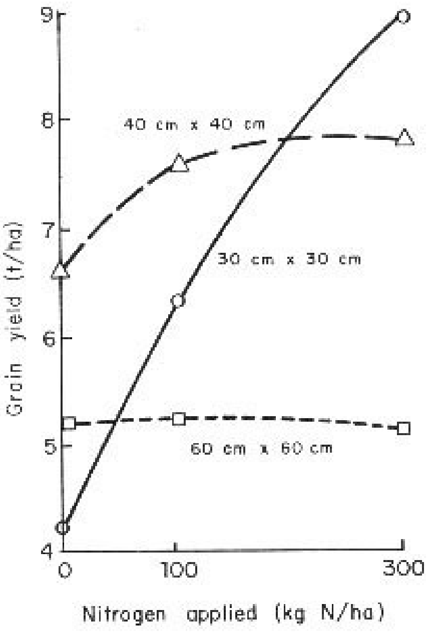


Fig. 22 Response of maize in grain yield to nitrogen application at different plant spacings

2. VARIETAL IMPROVEMENT WITH SUFFICIENT OR INSUFFICIENT FERTILIZER SUPPLY

Varieties differ in their yield response to applied fertilizer. When a heavy dressing is applied to rice the plants often tend to become tall and leafy, and lodging and mutual shading among leaves which cause an imbalance between photosynthesis and respiration may pose a problem (Tanaka *et al* 1966). Thus, varieties were bred at the International Rice Research Institute (IRRI) which retain their short stature and short erect leaves even after a heavy N application (Chandler 1972). These varieties produce a very high yield when they are grown with an ample supply of fertilizers along with other good technology. The contributions of these varieties are very large from two viewpoints: (a) farmers who can afford to use intensive technology can obtain a very high yield with these varieties, and (b) before the release of these varieties it was suspected that high rice yields which are common in the advanced countries of the temperate region are impossible in the tropics owing to adverse climatic conditions.

At present, however, it is difficult to provide all farmers in the advancing countries with sufficient fertilizer. Moreover, there is a present tendency even in the advanced countries to conserve natural resources and the environment by using less fertilizer. Under such circumstances it is necessary to decide whether different varieties are required when fertilizer rates are reduced.

Figure 23 summarizes many experiments conducted by the IRRI in which the varietal difference in response to N was tested under well controlled conditions (IRRI 1974). The maximum yield and the efficiency of applied N in increasing the yield were higher in improved than in non-improved varieties; at zero N, the yield of improved varieties was equal to that of non-improved varieties in the dry season and higher in the wet season. On such evidence the improved varieties could be recommended for both circumstances. There are, however, complications: some improved varieties are too short in stature in areas where water in the field is sometimes fairly deep, others are susceptible to certain diseases, and so on. When a heavy fertilizer application is made, the use of improved varieties is beneficial, because a very high yield is possible and intensive control of water depth, diseases, etc. is economically feasible. However, when only a limited amount of fertilizer is used, intensive management is economically impossible, and traditional varieties frequently yield more than new varieties. Thus, the merits and demerits of new varieties cannot be assessed only on Fig.23 (Tanaka 1975).

A recent experiment gave further evidence which conflicts with the tendency observed in Fig.23. Fourteen rice varieties in Hokkaido were tested with and without applied N under well controlled conditions. Using the yield data obtained (Fig.24) rice varieties can be classified into following three groups:

Group 1: Low yield at low N and low N response (Fukoku).

Group 2: Low yield at low N and high N response (Ishikari)

Group 3: High yield at low N and low N response (Eikō).

Groups 1 and 2 include old and new varieties, respectively, and if only these two groups are considered this experiment confirms the findings shown in Fig.23. However, Group 3, Eikō, which was released in Hokkaido during the second world war when fertilizer was extremely scarce, yielded more than other varieties at no applied N but did not give a high yield comparable to that of Group 2 with applied N. The ability to absorb N with no applied N was not much greater but the N absorbed by the plant was distributed more efficiently in the grain in Eikō than in the others (Table 16). This means that the efficiency of absorbed N to produce grain is higher in Eikō.

Table 16 AMOUNT AND EFFICIENCY OF ABSORBED NITROGEN RELATIVE TO GRAIN PRODUCTION OF THREE RICE VARIETIES (Hokkaido Univ. 1976)

Variety	Fukoko		Eikō		Ishikari	
N level (kg/ha)	0	100	0	100	0	100
N absorbed (kg/ha)	60	93	65	117	58	169
N in grain/N absorbed %	59	52	70	61	61	61

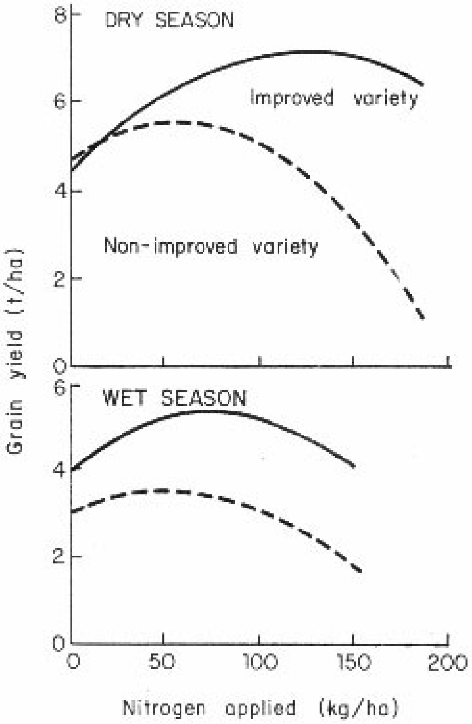


Fig. 23 Average nitrogen responses for improved and non-improved varieties based on 195 curves, by crop season, 1966-72 (IRRI 1973)

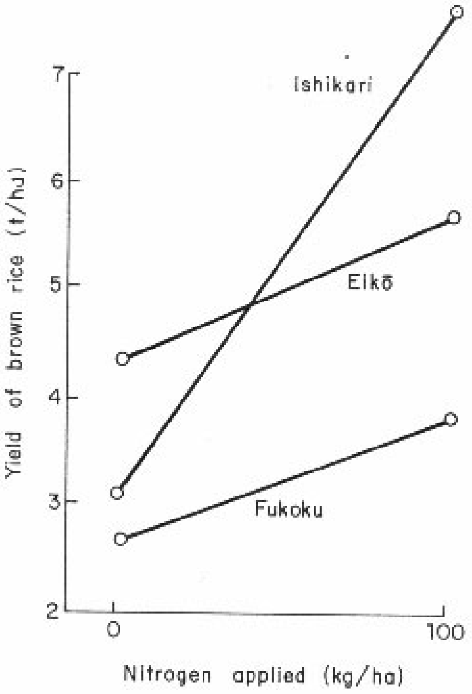


Fig. 24 Response of various rice varieties in grain yield to nitrogen application (Hokkaido University 1976)

Farmers should select Group 2 when fertilizer supply is sufficient and Group 3 when it is insufficient. If there were a Group 4, which had characteristics of high yield at low N and high N response, it would be ideal.

One other feature shown in Table 16 is that with applied N Ishikari absorbed more N than the others. The recovery percentage of broadcast fertilizer N calculated by the conventional subtraction method, was 33, 52 and 111% for Fukoku, Eikō and Ishikari, respectively. The low rates of recovery by the old varieties suggest a connection between varietal characteristics and methods of N application.

3. VALUE OF CROP RESIDUES IN RECYCLING PLANT NUTRIENTS

When a crop is grown in a field, only a portion of the crop is harvested and the residue is left in the field. Crops absorb various plant nutrients from the soil or from fertilizers, and the elements thus absorbed are distributed throughout various tissues. Tanaka and Ishizuka (1969) studied the distribution of various elements in certain organs of the maize plant at harvest. The percentage of P distributed in the grain is such that at harvest 80% of the P absorbed by the crop is removed from the field even if all the residue is returned to the soil. However, the percentage of K distributed in the grain is less than 15%. Thus, more than 85% of the K absorbed by the crop is returned to the soil when the residue is returned.

As fertilizer applications increase, the total dry matter production of the crop also increases, the grain:straw ratio decreases and the content of some elements in the straw increases. The result is an increase in the amount of plant nutrients in the residues. Thus, the need to conserve the plant nutrients in residues becomes more important under intensive conditions than it is in a more primitive agriculture.

When the yield is low owing to primitive technology, deficiencies of minor elements are generally masked. However, with an increase in yield, deficiencies of minor elements sometimes limit yields. For example, in rice, zinc deficiency has become a serious problem in some areas in India, Pakistan and the Philippines (Tanaka and Yoshida 1970). In developing countries where there is unfamiliarity with the symptoms of minor element deficiency, this causative factor of an abnormally low yield is occasionally overlooked, but once diagnosed the deficiency is quite easy to correct. The major portion of the minor elements absorbed by the plants generally remains in the straw instead of accumulating in the grain. Thus, these can be recycled by returning the crop residues, although the absolute quantity so recycled is limited by the initial quantity in the soil.

There are various methods of handling crop residues so that plant nutrients are returned to the fields. For example rice straw is utilized or disposed of in the following ways (Tanaka 1973, 1974).

i. Removal: The straw is used to make rope, bags, etc., as fuel or animal feed or to grow mushrooms. All plant nutrients in the straw are removed from the field. Labour requirements are large.

ii. Burning: By burning organic matter, N and S in the straw are lost to the air, but most of the plant nutrients remain in the ash and can be returned to the soil. Labour requirements are small.

iii. Incorporation: By incorporating the straw into the soil nothing is lost, but labour requirements are large. During the early stage of microbial decomposition of straw in a flooded soil, (a) bicarbonate, organic acids, ferrous iron, hydrogen sulphide, etc. accumulate in the soil and may reach toxic levels; (b) immobilization of N takes place, because the N content of straw is generally low, and results in N deficiency for the rice

iv. Compost: Compost is partially decomposed straw, which is produced either as such or in the form of farmyard manure. Production is highly labour intensive. The advanced stage of decomposition of the straw ensures that its use does not retard the growth of the rice plant. Provided there is no loss of slurry compost contains all of the plant nutrients present in straw plus other nutrients, especially N, added as animal excreta or fertilizers.

In East Asia great efforts have been made to utilize the straw with maximum efficiency in the form of compost. Statistics in Japan indicate that those farmers who are obtaining high rice yields are using compost intensively. Such statistics do not, however, prove that the high yield is a result of the use of compost.

Rice plants, which are grown in a soil rich in organic substances owing to compost application, absorb N continuously throughout their growth due to a gradual release of available N from the organic substances in the soil and produce a very high yield (Fig.25).

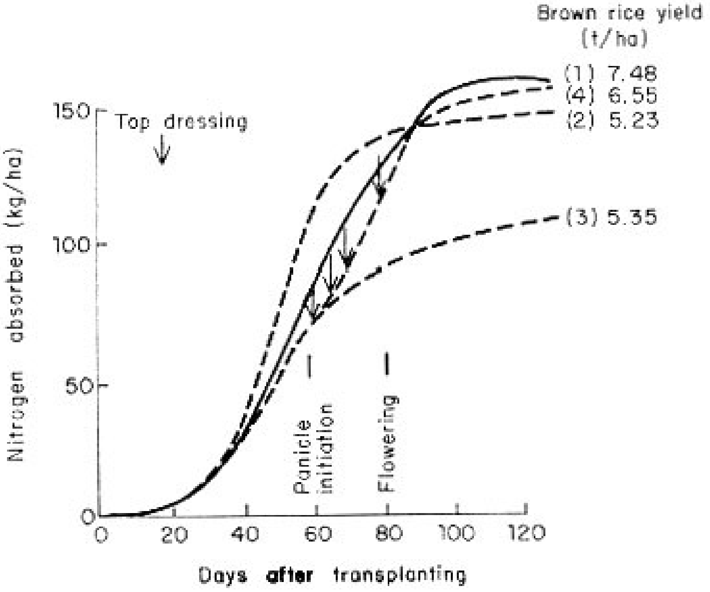


Fig. 25 Nitrogen absorption pattern during the growth of rice plants grown on different soils (Shiga *et al.* 1976).

(1) On a soil rich in organic substances.
(2) On a soil low in organic substances, basal application of 160 kg N/ha.
(3) On a soil low in organic substances, basal application of 120 kg N/ha.
(4) The same as (3) plus four top dressings at the rate of 90 kg N/ha in all.

On the other hand, when a heavy dose of N is basally applied to rice plants growing on a soil low in organic substances, the plants absorb N rapidly in the early stages of growth but extremely slowly after flowering, and produce a low yield. However, even on this soil the N absorption pattern can be made similar to that of the soil rich in organic substances and a reasonably high yield can be obtained if N is top-dressed in split doses. This means that a high yield is possible without compost if N is applied properly. However, with compost a high yield can be obtained without the grower having full knowledge of how to manipulate the growth of rice plants by N application.

NATURAL SUPPLY OF NITROGEN

By growing rice without fertilizers and removing the straw of every crop from the field, it is possible to obtain 1.5-2.0 t/ha of paddy annually for thousands of years. This yield level represents an equilibrium between the natural supply and the removal by the rice of plant nutrients, especially N.

The role of N fixed by blue-green algae in the maintenance of fertility in submerged rice soils has been known for many years. It has been claimed that about 60 kg N/ha per crop could be fixed in the flooded-planted soil, but a more recent report (Watanabe et al 1977) suggests that the rate of N fixation in the rhizosphere of rice is very low at 0.05 kg/ha per day. More quantitative data are necessary before making any definite statement.

Recently it was demonstrated that some microorganisms in the rhizosphere of Graminese, such as rice, maize, wheat, sugarcane, etc. have the ability to fix atmospheric N. This finding helps to explain the "equilibrium yield" of cereal crops. It appears, however, that the amount of fixed N in the rhizosphere of cereal crops is not very large and is decreased by N application, which in future will be the main source of increased cereal yields.

In contrast, symbiotic fixation of N by the rhizobia of grain legumes is much more important. Fig.26 shows data obtained from an experiment conducted with a set of isogenic lines of soyabeans. If it is assumed that the same amount of N accumulated by A62-2 (non-nodulating line) at no applied nitrogen was absorbed from the soil by A62-1 (nodulating line), then A62-1 accumulated 231 kg N/ha, out of which 106 kg N/ha was absorbed from the soil and 125 kg N/ha was fixed from the air. By applying N to A62-1 the amount of fixed N decreased and the absorbed N increased, and due to the balance between the two the amount of accumulated N and also the grain yield were less at moderate levels of N application than at no applied N. The yield of A62-2 with 300 kg N/ha was higher than that of A62-1 with no added N.

These data demonstrate that soyabeans are active in the symbiotic N fixation and produce a reasonably high yield without fertilizer N application. However, higher yields are possible by an application of N at a very heavy rate although it depresses N fixation. There are reports indicating that the yield of soyabeans is increased significantly by N top dressed at a heavy rate at later stages of growth.

No final conclusion can yet be drawn as to whether it is better to seek a method to accelerate the N fixation or to use an adequate method of fertilizer application to supplement (or substitute) the N fixation to obtain the maximum yield of grain legumes. In this connection it has been demonstrated that by accelerating photosynthesis, N fixation is accelerated and the grain yield is increased significantly in soyabeans (Hardy and Havelka 1975). As in cereal crops, photosynthesis is therefore the key factor for obtaining a high yield in grain legumes.

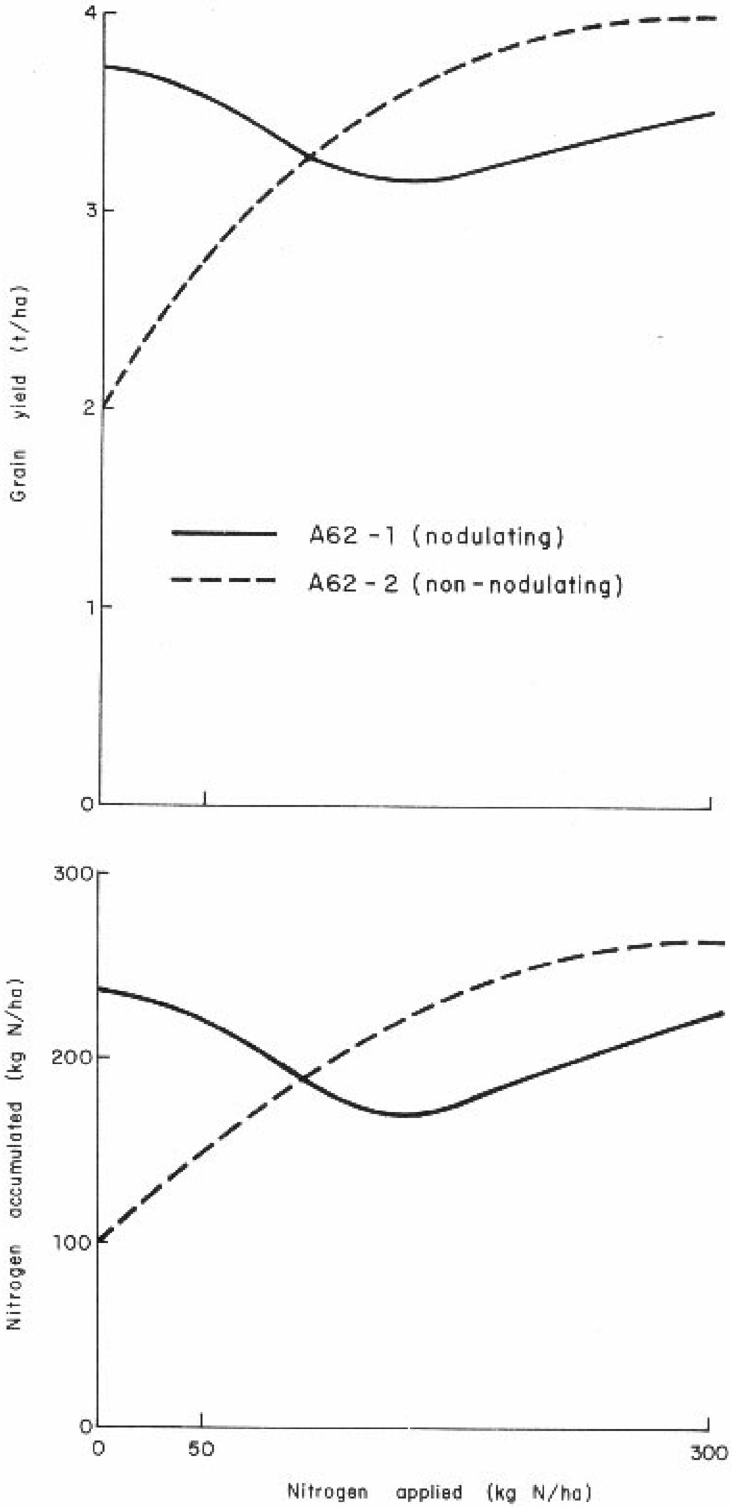


Fig. 26 Grain yield and amount of nitrogen accumulation in plants of two soyabean lines at different nitrogen levels

REFERENCES

Chandler Jr., R.F. The impact of the improved tropical plant type on rice
1972 yields in south and southeast Asia. In Rice breeding, pp.77-85.
Los Banos, Philippines, Int. Rice Res. Inst.

Hardy, R.W.F. and Havelka, U.D. Photosynthate as a major factor limiting
1975 nitrogen fixation by field-grown legumes with emphasis on soybeans.
In P.S. Nutman, ed. Symbiotic nitrogen fixation in plant, pp.421-439.
London, Cambridge University Press.

International Rice Research Institute. Annu. Rep. 1973. p.45.
1974

Tanaka, A. Methods of handling the rice straw in various countries. Int.
1973 Rice Comm. Newsl. 22(2): 1-20.

Tanaka, A. Methods of handling of cereal crop residues in Asian countries and
1974 related problems. Food & Fert. Technol. Center. Ext. Bull. No.43, 29.

Tanaka, A. Characteristics of high-yielding varieties in relation to their
1975 fertilizer requirements. Food & Fert. Technol. Center. Ext. Bull.
No. 57, 32.

Tanaka, A and Ishizuka, Y. Studies on the nutrio-physiology of the corn
1969 plant. (Part 2) Development of the growth phases and accumulation of
elements and carbohydrates associated with the development. J. Sci.
Soil and Manure, Japan. 40: 113-120. (in Japanese).

Tanaka, A, Kawano K. and Yamaguchi, J. Photosynthesis, respiration, and plant
1966 type of the tropical rice plant. Int. Rice Res. Inst. Tech. Bull.
7, 46.

Tanaka, A. and Yamaguchi, J. Dry matter production, yield components and grain
1972 yield of the maize plant. Fac. Agric. Hokkaido Univ. 51: 71-132.

Tanaka, A., Yamaguchi, J, and Kawaguchi, K. A note on the nutritional status
1973 of the rice plant in Italy, Portugal and Spain. Soil Sci. Plant.
Nutr. 19: 161-171.

Tanaka, A. and Yoshida, S. Nutritional disorders of the rice plant in Asia.
1970 Int. Rice Res. Inst. Tech. Bull. 10, 51.

Watanabe, I, et al. Biological nitrogen fixation in paddy field studied by
1977 in situ acetylene-reduction assays. Int. Rice Res. Inst. Res. Pap.
Ser. No.3.

Paper 13 THE USE OF ISOTOPES AND RADIATION IN STUDIES ON THE EFFICIENT USE OF FERTILIZERS

D.A. Nethsinghe

Joint FAO/IAEA Division of Atomic Energy in Agriculture

1. INTRODUCTION

In this paper, fertilizer use efficiency is defined as the percentage of fertilizer nutrient applied to a crop taken up by that crop.

Information on the most efficient methods, times, and sources of fertilizer application is also an essential prerequisite for the conduct of field experiments for determining the most economic rate of fertilizer application. The different rates of fertilizer tested in an experiment for evaluating the yield response curve should be applied in a manner which will ensure the highest possible fertilizer use efficiency.

Fertilizers may be rendered inefficient by any of four basic ways:

i. leaching - e.g. nitrates;

ii. surface run-off - e.g. top dressed or surface broadcast fertilizers;

iii. gaseous losses - e.g. nitrogenous fertilizers as ammonia, or as N due to denitrification;

iv. immobilization in the soil by chemical or microbiological processes - e.g. phosphates, nitrogenous fertilizers.

The extent to which these factors influence fertilizer utilization by the crop will depend on soil and climatic conditions, soil management practices, (e.g. irrigation, liming, tillage operations, soil conservation measures), method and time of fertilizer application and nature of fertilizer. Under a given set of soil and climatic conditions and soil management practices, fertilizer use efficiency can be maximized by minimizing interactions between soil and fertilizer. This can be achieved by: (a) applying the fertilizers at a place where the plant roots are most active and hence will take up the nutrient most rapidly; (b) applying the fertilizer at the time when the physiological need of the plant for the nutrient for crop production is highest; (c) applying the fertilizer in a suitable chemical form to minimize interaction with the soil while at the same time providing a high nutrient availability to the crop; (d) establishing an appropriate water regime (and other management practices).

Quantitative information of practical value on how the amount of fertilizer utilized by a crop varies with the different factors influencing fertilizer use efficiency can only be obtained through field experiments carried out under the actual conditions under which the crop is grown.

The traditional indirect "difference" methods and the modern direct isotope methods used for such studies are discussed in the next section.

2. COMPARISON OF THE DIRECT ISOTOPE METHOD AND THE INDIRECT DIFFERENCE METHOD FOR DETERMINING FERTILIZER NUTRIENT UPTAKE

Radioactive and stable isotopes[1] (e.g. P-32, N-15) provide the only means of obtaining a direct quantitative measure of the influence of various factors on fertilizer use efficiency by a crop. For instance, the amount of phosphorus taken up by a crop from a phosphate fertilizer can be directly measured in the field by labelling the fertilizer with a known quantity of the radioactive isotope P-32, applying it to the crop, and later measuring the total phosphorus and total P-32 content in the crop.

Percentage P derived from the fertilizer in the crop, % Pdff, =

$$\frac{\text{specific activity of P(ratio P-32/P-31) in crop}}{\text{specific activity of P in fertilizer}} \times 100.$$

$$\text{Total kg fertilizer P/ha in crop} = \frac{\text{total kg P/ha in crop}}{100} \times \%\ \text{Pdff}.$$

$$\text{Fertilizer use efficiency} = \frac{\text{total kg P/ha in crop}}{\text{kg fertilizer P/ha applied}} \times 100.$$

Similarly, N uptake from nitrogen fertilizers can be measured by labelling the fertilizer with the stable isotope N-15.

Isotope labelling of the nutrient element in fertilizer is a means of marking that element for subsequent identification in the plant. Without such labelling, it is not possible to determine how much of the nutrient element in the plant is derived from the fertilizer and how much from the soil. The isotopically labelled nutrient element behaves in an identical manner to the non-labelled element both chemically and physiologically, and the plant cannot distinguish the difference between them. However, the isotopically labelled element can be measured by radiation detection instruments in the case of radio active isotopes such as P, or by mass spectrographic methods in the case of stable isotopes such as N-15.

Prior to the use of isotope methods, fertilizer use efficiency studies were entirely dependent on conventional field experiments using dry matter yield responses or differences in total nutrient removed by the crop as criteria for assessing treatment differences. The effects of particular treatments (e.g. methods of fertilizer placement) are evaluated by comparison with a control plot in which no fertilizer was applied. However, such experiments can only give a measure of the impact of fertilizer application on the total uptake of soil plus fertilizer nutrient by the crop.

The difference method would be useful for the comparison of fertilizer placement methods, fertilizer sources, etc. if the experiment was carried out on a nutrient deficient soil in which marked yield responses are obtained for fertilizer application, and the level of fertilizer application is such that the magnitude of the treatment responses would still be within the steep part of the yield response curve. High levels of fertilizer application would bring the yield level of all treatments to the flat part of the yield response curve and no differences in dry matter or total nutrient yields between treatments would be observed. In practice, it is difficult to select the appropriate level of fertilizer application prior to carrying out an experiment; the

---

[1] For convenience only, isotopes are written P-32, N-15 rather than ^{32}P, ^{15}N

experiment would have to include several levels of fertilizer. Moreover, any conclusions drawn from such an experiment on the effect of a particular treatment would only be valid for crops growing under conditions where the tested nutrient is very deficient. Extrapolation of the results to normal conditions where fertilizers are applied to maintain good yields might not be justified.

The difference method may give a reliable estimate of the actual fertilizer use efficiency when the experiment is carried out on a soil of moderate nutrient deficiency and when the fertilizer applied makes no difference to the uptake of soil nutrient between fertilized and unfertilized plots. The method would underestimate the amount of fertilizer used if there was little or no yield response to fertilizer application. On the other hand, on a soil highly deficient in the plant nutrient under test and where plant growth is limited due to the nutrient deficiency, the difference method would overestimate the amount of fertilizer nutrient absorbed by the crop unless the fertilizer was well mixed in the entire root zone of the crop. Fertilizer application would produce a healthier plant which would exploit more soil nutrient than the plant in the non-fertilized plot. Also, if the applied fertilizer caused a change in the available soil nutrient pool, as for instance by the mineralization of organic nitrogen in the soil, the difference method would overestimate the amount of fertilizer nutrient absorbed by the crop. As Westerman and Kurtz (1974) pointed out, "The difference method assumes mineralization, immobilization and other N transformations are the same for both fertilized and unfertilized soils. Obviously this is an erroneous assumption and can account for gross differences between recoveries calculated by non-isotopic and isotopic techniques."

It may be concluded therefore that while the indirect difference method may sometimes serve to make quantitative comparisons of different fertilizer sources or placement methods, it will rarely give a reliable quantitative measure of fertilizer use efficiency. For the latter, it is essential to use the direct isotope method.

Westerman and Kurtz (1974) compared the uptake of fertilizer N from urea and oxamide (both labelled with N-15) by Sudan grass in a field experiment. Fertilizer use efficiency was calculated by the difference method and N-15 isotope method.

Table 17 shows the average recovery of applied N for the 3 rates of N application for each harvest and the total for 1966 and 1967. The difference method overestimated the fertilizer N use efficiency of urea and oxamide by 35% and 31%, respectively in 1966, and by 23% and 35% in 1967, when compared with the direct N-15 isotope method. Only in the third harvest in 1966 and 1967 did the percentage fertilizer N recovery calculated by the difference method coincide with that calculated by the isotope method. At the fourth harvest in 1966 when fertilizer N recovery as indicated by the N-15 isotope method was very low, the difference method showed a negative fertilizer N recovery, underestimating fertilizer use efficiency as expected under conditions of low fertilizer response. At all other harvests fertilizer use efficiency was grossly overestimated by the difference method. The exaggerated values for fertilizer N recovery by the difference method show that plants grown on the N fertilizer plots absorbed more soil N than plants grown on the unfertilized plots.

Table 17 PERCENTAGE RECOVERY OF FERTILIZER N IN SUDAN GRASS AS ESTIMATED BY THE DIFFERENCE AND N-15 ISOTOPE METHODS

Year and harvest date	N source	Difference method	N-15 Isotope method
1966			
June 30	Urea	43.9	29.4
	Oxamide	27.4	11.9
July 20	Urea	43.6	17.0
	Oxamide	47.8	23.7
August 30	Urea	2.5	2.4
	Oxamide	9.8	10.3
October 20	Urea	-4.9	1.3
	Oxamide	-3.3	4.7
Total	Urea	85.1	50.1
	Oxamide	81.7	50.5
1967			
July 30	Urea	57.5	63.4
	Oxamide	44.3	38.2
August 14	Urea	55.7	25.8
	Oxamide	79.0	50.4
September 14	Urea	2.3	3.5
	Oxamide	10.4	10.2
Total	Urea	115.5	92.6
	Oxamide	133.7	98.9

Source: Westerman and Kurtz (1974)

Numerous examples of how erroneous conclusions could be drawn from experiments using the difference method can be taken from FAO/IAEA coordinated research programme reports on rice (IAEA 1970a), maize (IAEA 1970b) and wheat (IAEA 1974).

One such (IAEA 1970a) concerned field experiments on phosphate fertilizer placement on flooded rice carried out in a number of countries. In the Philippines and Burma (Gyogon) where levels of soil P were high and there was no yield response to applied phosphate, the difference method gave negative uptakes of fertilizer P for nearly all the six placement methods tested. The P-32 isotope method, however, showed small but positive uptakes for all treatments and was able to identify two distinctly superior treatments. Underestimates of P uptake from fertilizer were also obtained by the difference method in Burma (Mandalay) and Egypt where there were moderate levels of soil P and there was some response to applied P. Low levels of soil P and high responses to fertilizer P at two centres in Thailand resulted in overestimates by the difference method, although both methods agreed on the superiority of the same two treatments (surface broadcast and hoeing). The advantage of the isotope method over the difference method is shown very clearly in Table 18 where it points to the superiority of surface broadcasting and hoeing in all countries, whereas the same conclusion can be reached by the difference method only in the two Thailand experiments.

Table 18 PLACEMENT OF PHOSPHORUS - RELATIVE EFFECTS ON THE PERCENTAGE OF P IN PLANTS DERIVED FROM FERTILIZER (d.f.f.) AND FROM YIELD (DM) BY DIFFERENCE METHOD

Location		Surface	Hoeing	Hill 10 cm depth	Hill 20 cm depth	Row 10 cm depth	Row 20 cm depth
Philippines	% P d.f.f.	100	101	35	25	25	20
	Yield	100	133	98	114	114	125
Burma (G)	% P d.f.f.	100	152	58	32	39	28
	Yield	100	102	112	94	101	102
Burma (M)	% P d.f.f.	100	100	24	25	24	17
	Yield	100	102	103	95	98	108
Egypt	% P d.f.f.	100	93	58	59	59	57
	Yield	100	92	98	92	90	93
Thailand(S)	% P d.f.f.	100	108	83	55	94	84
	Yield	100	108	96	81	88	84
Thailand(B)	% P d.f.f.	100	100	74	50	75	53
	Yield	100	90	54	24	49	29

Source: IAEA (1970a)

3. APPLICATION OF RESULTS FROM FERTILIZER USE EFFICIENCY STUDIES

For the development of sound fertilizer management practices it is necessar to express differences in fertilizer use efficiency in a quantitative way. Thus, the findings from an experiment on the placement of different rates of fertilizer might state that 45 kg P/ha applied broadcast on the surface gives the same P uptake as 77.5 kg/ha applied to hills at a depth of 10 cm.

In practice, the method of fertilizer application which leads to highest crop utilization need not necessarily be the most economic. For instance, placement of nitrogen fertilizer at 10 cm depth in lowland rice may result in more efficient fertilizer utilization than surface application, but the labour costs incurred in deep placement may be greater than the costs of extra fertilizer required for the less efficient method of surface application. The quantitative information obtained on fertilizer use efficiency should be considered in conjunction with information on labour costs, costs per unit nutrient, etc. before drawing any conclusions on the most economic fertilizer management practices.

4. EXAMPLES OF SOME FERTILIZER USE EFFICIENCY STUDIES USING ISOTOPES

The coordinated research programmes of the joint FAO/IAEA Division have included experiments on a wide range of annual and perennial crops, some of which will be discussed to illustrate how isotope methods can be used to study various kinds of problems relating to fertilizer use efficiency.

4.1 Experiment on Different Methods and Times of N Application to Maize

In this field experiment ammonium sulphate labelled with N-15 at one percent atom excess was applied at 80 kg N/ha in 6 different ways: (i) plough down at planting, (ii) banding at planting, (iii) side dressing when the maize was 50 cm high, (iv) 15 days before tasselling, (v) at tasselling, and, (vi) 10 days after tasselling. The results given in Table 19 (means of data from experiments in Argentina, Brazil, Colombia, Peru, and Egypt) show that fertilizer N uptake was about 50 percent higher when side dressed from 50 cm height to tasselling stages than band application at seeding or side dressing 10 days after tasselling. The plough down treatment was the least efficient - - about half as efficient as sidedressing up to tasselling stage. In this instance, the results show the same pattern irrespective of the criterion used for assessing fertilizer N uptake (percentage N derived from fertilizer in plant, actual fertilizer N uptake using N-15, and fertilizer N uptake by difference method). Calculation of the percentage Ndff values are independent of dry matter yields. They provide a sensitive means for comparing the efficiency of specific fertilizer practices avoiding the errors involved when yield dependent criteria are used for such comparisons. Table 20 shows the individual country data for fertilizer use efficiency for the band placement at seeding. It is seen that for the comparison of treatments in different locations the percentage Ndff data present a different picture to the yield dependent criterion percentage uptake of applied fertilizer N using the N-15 method. This is because the degree of dilution of the N-15 labelled fertilizer is no longer dependent on a single variable (different methods of fertilizer application) but also depends on other factors which varied widely in the different locations and influenced dry matter production. Hence, the percentage Ndff data cannot be used to compare the efficiency by a particular method of application in different locations where factors other than the variable under test may influence the extent to which the N-15 fertilizer is diluted. In such situations the yield dependent criterion (percentage fertilizer N utilized by the crop) based on the isotope method must be used. Table 20 also gives the percentage uptake of applied fertilizer N calculated by the conventional difference method, again illustrating the unreliability of the method for such studies.

Table 19 EFFECT OF TIME OF APPLICATION OF N TO MAIZE ON FERTILIZER N UPTAKE MEASURED BY TWO METHODS[1]

Fertilizer management practice (rate of N = 80 kg/ha)	% Nd.f.f.[2] (grain)	Uptake of Fert. N (grain) kg N/ha	
		N-15 data	Difference method[3]
Plough-down	22	11.6	7.5
Band	26	14.6	11.2
Sidedressed at 50 cm	34	21.2	17.3
Tasselling - 15 days	38	23.6	17.2
Tasselling	36	21.8	15.5
Tasselling + 10 days	26	13.4	6.6
L S D (P = 0.05)	7	6.5	8.2

Source: Joint FAO/IAEA programme, 1965

[1] Data are means from country projects in Argentina, Brazil, Colombia, Peru and Egypt.

[2] % Nd.f.f. denotes percentage of total N in the grain derived from fertilizer

[3] Total N for fertilized treatment minus total N for control.

Table 20 PERCENTAGE UPTAKE OF N FROM FERTILIZER APPLIED TO MAIZE IN A BAND AT SEEDING, MEASURED BY TWO METHODS

Country	Yield of grain (kg/ha)	% Nd.f.f.[1] (grain)	Percentage uptake of applied fertilizer N (grain)	
			N-15 data	Difference Method
Argentina	3 800	23	19.0	- 4.1
Brazil	4 450	28	18.9	11.0
Colombia	2 650	25	10.4	10.4
Peru	5 750	38	37.8	17.8
Egypt	3 650	18	8.2	- 6.5

Source: Joint FAO/IAEA programme, 1965.

[1] % Nd.f.f. denotes percentage of total N in grain derived from fertilizer.

4.2 Efficiency of Different Sources and Times of N Application to Wheat

In this experiment on wheat carried out in six countries, the efficiency of a total of 120 kg N/ha applied as ammonium sulphate and sodium nitrate was tested when applied in three split applications of 40 kg N/ha each at planting, tillering, and boot stage. For each time of application, N-15 labelled fertilizer was applied to a separate plot - - the three times of application requiring three N-15 plots. When N-15 labelled fertilizer was not added for any given time of application, unlabelled fertilizer was used. This enabled the measurement of fertilizer use efficiency of the 40 kg N/ha for each time of application separately and also for the whole 120 kg N/ha applied thrice split without confounding the effects of nitrogen supply on plant growth and nutrient uptake. This is a technique unique to the isotope method and it illustrates an important feature of the method. The results of the experiment show that when applied in split dressings sodium nitrate is more efficiently used than ammonium sulphate in all the countries - - the average fertilizer use efficiency being 46% for $NaNO_3$ and 32% for $(NH_4)_2 SO_4$. Nitrogen application at the boot stage resulted in poorer N uptake by the crop than application at tillering or planting time.

4.3 Evaluation of Efficiency of Natural Rock Phosphates

Chemically processed fertilizer materials can be isotopically labelled at the time of their manufacture for use in fertilizer efficiency studies of the type already discussed. Relatively insoluble natural fertilizer materials, such as rock phosphates (in which there is considerable interest today in developing countries) cannot be isotopically labelled. For comparing the efficiency of such fertilizers (Fried 1954) developed an indirect method based on the "A" value concept (Fried and Dean 1952). In this method the available soil phosphorus ("A" value for soil P) is measured by using P-32 labelled superphosphate. Rock phosphate is added to the soil, and the available phosphorus in the soil treated with the rock phosphate ("A" value for soil P plus rock phosphate P) is again measured using P-32 labelled superphosphate. The difference between the two "A" values gives a measure of the efficiency of the rock phosphate relative to the superphosphate.

The "A" value concept is based on the assumption that when a plant is confronted with two sources of a given nutrient in the soil, the amount of nutrient it absorbs from each source is proportional to the amounts of the nutrient available in each source. If the amount of available soil P is A (unknown) and a known amount (F) of P-32 labelled superphosphate is applied, then the "A" value for soil P can be measured from the relationship

$\frac{A}{F} = \frac{1-y}{y}$, where y is the fraction of P in the plant derived from the P-32 labelled superphosphate (100y = %Pdff). The "A" value for soil P plus rock phosphate is similarly determined. Table 21, which gives the results of a pot experiment by Fried (1954) shows the relative availabilities of rock phosphate compared to monocalcium phosphate for ryegrass on different soils. In this Table, A_1 refers to the available soil P, and A_2 to the available P in the rock phosphate fertilizers in terms of the P-32 labelled standard monocalcium phosphate used in the experiment. The results show that 4 tons of rock phosphate supplied as much P to ryegrass over a period of a month as 67 lb P_2O_5 in the form of calcium monophosphate on the Eavesboro soil, as 76 in the Davidson soil and 167 in the Brookston soil. The higher availability of rock phosphate in the Brookston soil is probably due to its low pH and high organic matter content (Fried 1954).

Table 21 RELATIVE AVAILABILITY OF ROCK PHOSPHATE (33% PHOSPHORUS PENTOXIDE) AND MONOCALCIUM PHOSPHATE AS SOURCES OF P FOR RYEGRASS DURING THE FIRST MONTH OF GROWTH

Soil	"A" value, lb P_2O_5 per acre equivalent to monocalcium phosphate		
	Soil (A_1)	Soil + 4 tons rock phosphate (A_1 + A_2)	4 tons of rock phosphate by difference (A_2)
Evesboro	58	125	67
Davidson	119	195	76
Brookston	91	258	167

Source: Fried (1954)

Table 22 COMPARISON OF VARIOUS NATURAL PHOSPHATE SOURCES FOR RICE WITH SUPERPHOSPHATE AS A LABELLED STANDARD

Fertilizer	Soil			
	Thailand (pH 4.5)	Brazil (pH 6.2)	Hungary (pH 6.6)	Pakistan (pH 8.2) 1/
Olinda	160	1 000	1 400	10 000
Araxa	220	910	3 300	10 000
Araxa Thermo	100	60	80	80
Tunis rock	110	150	1 100	1 200
Florida rock	120	240	3 300	10 000
Basic slag	120	80	140	140
Bone meal	120	140	420	600

1/ pH of soil-water suspension, 1:2.5.

Data from IAEA (1970a) show the units in grammes of fertilizer P equivalent to 100 g P in superphosphate.

Table 22 shows the results of a pot experiment carried out under the Joint FAO/IAEA Division's first Coordinated Research Programme on Rice Fertilization. Using the technique discussed above, the efficiency of seven forms of insoluble natural phosphates was measured in relation to superphosphate on soils from Brazil, Thailand, Hungary, and Pakistan. Depending on soil pH, striking differences were observed in the availability of the various phosphate fertilizers tested. On the acid soils the availability was in general high, but on the alkaline soils only the alkaline phosphates such as Araxa Thermo and basic slag had an availability similar to that of superphosphate.

4.4 Root Activity Studies on Tree Crops

The isotope method for the quantitative measurement of fertilizer use efficiency cannot be applied to perennial tree crops as it is not practical to harvest and sample whole trees. A different approach was therefore adopted in the Joint Division's coordinated research programme for obtaining information on efficient tree crop fertilization (IAEA 1975). Since placement of fertilizer in close proximity to the zone of highest root activity and at a time when roots are most active would help to maximize fertilizer uptake, a method was developed to study the root activity patterns of tree crops. The technique involves the injection of P-32 labelled phosphate solution into the soil at the various distances and depths to be tested for root activity. A few weeks after injection, leaf samples of similar age are taken from well-defined morphological positions on the tree and analysed for P-32. The P-32 contents in the leaf samples reflect the levels of root activity at the different positions tested.

REFERENCES

Fried, M. and Dean, L.A. A concept concerning the measurement of available
1952 soil nutrients. Soil Sci. 73: 263-272.

Fried, M. Quantitative evaluation of processed and natural phosphates.
1954 Agric. Food Chem. 2: 241-244.

IAEA Rice fertilization. Tech. Rep. Ser. No.108.
1970a

IAEA Fertilizer Management practices for maize. Tech. Rep. Ser. No.121.
1970b

IAEA Isotope studies on wheat fertilization. Tech. Rep. Ser. No.157.
1974

IAEA Root activity patterns of some tree crops. Tech. Rep. Ser. No.170.
1975

Westerman, R.L. and Kurtz, L.T. Isotopic and non-isotopic estimations of
1974 fertilizer nitrogen uptake by Sudan grass. Soil Sci. Soc. Amer.
Proc. 38: 107-109.

Paper 14 NEW ASPECTS OF FERTILIZER TECHNOLOGY IN BETTER EXPLOITATION OF PLANT NUTRIENTS

R.C. Horn

IFDC, Muscle Shoals, Alabama

1. INTRODUCTION

The purpose of this paper is to identify some of the newer fertilizer materials and examine current methods of fertilizer production and use as they apply to fertilizer efficiency, particularly in the developing countries.

For many people, hunger and malnutrition are a way of life. Yields per hectare and per farm worker are often extremely low, and are conducive to world food shortage and poverty of many of the world's farmers.

There are two main ways of obtaining the necessary increases in food production: (i) by the expansion of farming to land not now cultivated and (ii) by intensification of production on land already being cultivated.

Large parts of Africa and Latin America and sizeable portions of Asia, particularly in Indonesia and the Philippines, are not yet cultivated. The fact that climatic factors favour long or continuous growing seasons amplifies the potential for agriculture in those areas.

Higher yields are required to justify the increasing cost of bringing new land into production. Continuous development of new land is imperative but, for the short term, increasing crop yields per unit area of cultivated land must be the major source of any increase in food and fibre. Yields need to be at least doubled by the end of the century and to do so will require major improvements in plant nutrition.

Most fertilizers currently available have been developed for use on soils and crops in temperate zones. For most areas in the tropics and subtropics - where climate, crops, and soils differ markedly from those of the developed countries - present day technology and fertilizer materials are either agronomically inadequate or economically impractical.

Technology which uses indigenous resources to the fullest extent must be developed but need not be highly sophisticated. Some techniques, already discarded by the developed countries in favour of more economic processes or more highly concentrated products, might be entirely adequate in a developing country. Single superphosphate is an example of such a case. A phosphate rock or potash source coupled with such technology could help to insulate a developing country or area from the vagaries of the world fertilizer market for those nutrients.

Fertilizer materials and methods of application which increase the efficiency of use of all fertilizers, especially nitrogen, are urgently needed to increase food production and conserve natural resources. As long as ammonia production is mainly tied to petroleum based hydrocarbons, its price can only continue to rise.

2. PRIMARY PLANT NUTRIENTS

The concept of increased fertilizer efficiency through the slow or controlled release of nutrient is not new. Theoretically, any of the solid, water soluble fertilizer materials could be coated to slow or control the release of plant nutrients. In practice, nitrogenous materials have received the most attention, chiefly because they have been the most expensive of the primary nutrients and because they are subject to substantial nutrient losses through three different mechanisms - leaching, denitrification and ammonia volatilization.

2.1 Nitrogen

While there is an abundance of N in the atmosphere there is, paradoxically, an almost universal and persistent deficiency of N in the soil. Atmospheric N is so inert that it is useless to most organisms. Agricultural crops can directly utilize only those forms of N which have been combined ("fixed") with other elements such as hydrogen or oxygen.

Molecular nitrogen is nearly inert because the triple bond which joins the two N atoms is exceptionally strong and stable. Large quantities of energy in the form of electricity or fossil fuels must be supplied to break this bond in industrial fixation processes.

The bulk of all fixed N is of biological origin. Only a few bacteria and simple algae have the ability to fix atmospheric N as ammonia. Brill (1977) estimated bacterial fixation alone at 150 million tonnes per year. About 40 million tonnes or one-fourth of the N fixed by all systems is ammonia made by the Haber process.

Recent discoveries about the chemistry of N fixation indicate that molecular nitrogen may be much less inert than was formerly supposed, and if the N fixing activities of bacteria could be fully understood they might also be improved and ultimately used to supply N to other plant species. The outcome would be decreased dependence on synthetic N fertilizers for plant nutrition and a higher worldwide standard of living.

The major sources of N currently available in the developing world include anhydrous ammonia, aqua ammonia, ammonium chloride, ammonium sulphate, ammonium phosphates, ammonium nitrate, mixed ammonium sulphate-nitrate, calcium ammonium nitrate and urea.

Urea is the major source of N for rice and cereal production. Production of urea in Asia is expected to increase from 7.5 million tonnes of N in 1975 to over 20 million tonnes by 1980 and indicates that urea will be the major N source for food production in developing countries for the remainder of this century. Therefore, any technology which leads to improved N utilization efficiency in urea is of prime interest. Such technology will involve controlling the rate of nutrient release. The two most common ways of controlling the dissolution of fertilizers are development of compounds with limited water solubility, and coating soluble materials to retard their release to the soil solution.

Probably the most widely known coated fertilizer is sulphur-coated urea (SCU) developed by the Tennessee Valley Authority (TVA). Of the many substances tested, sulphur was chosen as having the best combination of suitable properties and economic potential for use as a coating agent. As work progressed, the coating of sulphur was decreased in weight and a wax was added to seal imperfections in it, while finally a conditioning agent was added to reduce stickiness.

The dissolution rate of SCU granules is controlled by the amount of sulphur and sealant applied, being inversely proportional to coating weight. Soil temperature and moisture content have less effect on dissolution rate. Suitable controlled release properties were obtained with a sulphur coating of 14%, sealed with 2% wax and treated with 2% conditioner. Pilot scale production of several hundred tonnes of SCU has allowed field tests to be made on several crops in 39 states of the U.S.A. and 26 other countries.

Field tests on rice indicate that SCU increases the effectiveness of applied nitrogen (Engelstad et al 1972). Rather consistent yield increases have been obtained with SCU as a basal dressing compared with uncoated urea, and economic calculations show that SCU can often compete favourably.

Among other coating materials tested for controlling the release of soluble nutrients have been such diverse materials as asphalt, coal tar resins, magnesium ammonium phosphate and organic polymers. Coatings from organic polymers and copolymers have shown promise in encapsulating both liquid and solid NPK fertilizers. "Osmocote" (Sierra Chemical Co.) is an example of a polymer-coated fertilizer; "Gold N" (Imperial Chemical Industries Ltd.) is a sulphur-coated prilled urea. Both materials are produced commercially, but are the only examples of such coated fertilizers known to be widely available.

A number of slightly soluble organic nitrogen compounds have been studied in the laboratory and glasshouse. Among those showing promise were oxamide, glycouril, cyanuric acid, ammeline and ammelide, melamine, and methylene ureas of various molecular weights. Because no practical or economic process has been devised, most of these materials have not been produced commercially for use as a fertilizer.

Recently a new process for synthesis of oxamide was reported by Hoechst in Germany (Riemenscheider 1976) which may bring this excellent fertilizer material closer to production. The process produces oxamide directly from hydrocyanic acid (HCN) and oxygen. The reaction is homogeneously catalysed by copper nitrate in aqueous acetic acid and proceeds at atmospheric pressure at 50–80°C. Oxamide of 99% purity is obtained by centrifuging and washing; the catalyst solution is recycled to the reactor. The only apparent problem with the process is that it is dependent on HCN as a raw material; however, where byproduct HCN is available from the production of plastics, conversion to oxamide might prove to be economically attractive.

Oxamide contains about 32% N and has been proved to be an excellent slow release fertilizer. As with some other low solubility fertilizers, the release rate is controlled by the particle size.

Aldehyde-urea adducts such as urea-formaldehyde products, isobutylidenediurea (IBDU), and crotonylidenediurea (CDU), represent another series of materials of low solubility which have also been proved agronomically. These materials as a group contain about 32–38% N and apparently do not hinder germination of seeds or growth of seedlings even at high application rates. Most of the materials in this group have a residual effect at least on the second crop. Commercially available materials include IBDU, CDU, and "Mag Amp", which is a mixture of magnesium ammonium phosphate ($Mg\ NH_4\ PO_4$) and magnesium potassium phosphate ($Mg\ K\ PO_4$). SCU prills are also commercially available under the name "Gold N."

Research is currently being done on systems which use mixed aldehydes with urea and thiourea to produce desirable release characteristics, while the reaction of urea with spent sulphate pulp liquors produces a slow release nitrogen fertilizer. A German patent has disclosed the preparation of catenated ammonium polyphosphates for slow release; availability of the nutrients is controlled by the temperature at which the material is prepared.

Magnesium ammonium phosphate is another example of the low solubility plant nutrient sources. It has been widely accepted for glasshouse and nursery applications and for use in critical soil areas where it is difficult to establish vegetation.

In spite of the advantages of these materials, when compared with urea, they all have the disadvantages of lower analysis and higher prices.

2.2 Phosphorus

Man is dependent for phosphate on the mineral apatite which contains calcium, phosphorus, and fluorine together with various elements substituting for calcium and fluorine in minor amounts. This mineral occurs in many igneous and sedimentary deposits scattered throughout the world, but rarely are the deposits concentrated enough to permit their development and use.

Pure fluorapatite contains about 18% P (42% P_2O_5). The term "phosphate rock" is applied to those ores in which the apatite content is high enough for the material to be used directly in a manufacturing process. For those rocks which are too low in P to be used directly, physical processes have been devised which produce concentrates by rejecting undesirable materials.

Mining, concentration, and extraction methods now in use are extremely wasteful and recovery in deposits is sometimes 60% or less of the total P originally present. As present deposits are depleted, producers are forced to mine materials of lower grade and quality. This trend increases the importance of improved processes to make the best technical and economic use of indigenous materials, especially in areas where costly imports are difficult to finance.

In terms of enhancing the efficiency of use of phosphate fertilizer, changes in management practices and modification of fertilizers to increase the availability of nutrients can be effective. Among the materials that might be classified as controlled release fertilizers are ground phosphate rock, defluorinated phosphate rock, basic slag, Rhenania phosphate, fused calcium magnesium phosphate, calcined aluminium phosphate ore, dicalcium phosphate, bone meal, magnesium ammonium phosphate, and calcium and potassium metaphosphates.

The use of ground phosphate rock is potentially more economic than chemically processed phosphate fertilizers, especially when an indigenous rock of suitable quality and reactivity is available, on the grounds of reduced processing and transportation costs.

The effectiveness of direct applications of ground phosphate rock depends upon the chemical composition and reactivity of the rock and the degree of fineness to which it is ground. Extremely fine ground rock is very dusty and troublesome to apply in the field, but although it can readily be granulated to the normal size of fertilizer particles this technique defeats the purpose of fine grinding.

The International Fertilizer Development Centre (IFDC) is studying very small granules termed "minigranules" which can be prepared by compacting the finely ground rock with certain types of equipment. These small particles, 0.4-0.07 mm in size, (48 - 200 mesh) can be applied without the dust problem associated with very finely ground rock and at a more even distribution than the larger granules.

Also under study by the IFDC is the incorporation of a suspending agent into the rock while it is being ground. On adding water to the product, which can be transported dry, a stable suspension is formed containing about 70% solids. Such a suspension can be applied in the field with very simple equipment.

Of the other phosphatic materials mentioned, none is new. Their efficiencies are largely dependent on soil pH, and most of them can be produced without the benefit of high technology. Processes could be adapted to use even small deposits of phosphate rock to serve a local area. In addition, some of these materials are good sources of secondary and trace elements.

Most research work on phosphates appears to be directed toward highly concentrated materials the production of which requires a rather high degree of technology. Research support for the developing countries should be directed toward location of indigenous materials and development of processes for the production of useful fertilizer materials, regardless of how such products might fit into conventional roles.

2.3 Potash

Controlled release potash sources have not received a great deal of attention in comparison with nitrogen and phosphate. However, tests with potassium polyphosphates and calcium potassium polyphosphates as slow release sources have been conducted by TVA. Agronomic evaluation of the materials was reported by Engelstad (1968).

Sulphur coated potassium chloride for agronomic tests has also been prepared by TVA. Yields were sometimes increased in comparison with uncoated potassium chloride, but more information is needed for agronomic and economic evaluation. Controlled release N-K fertilizers also show some promise and are under study (Hignett 1975).

3. SECONDARY NUTRIENTS

Many soils in the tropics and subtropics are inherently deficient in sulphur and these deficiencies become more serious when heavy rates of nitrogen and other primary nutrients are applied. Sulphur deficiencies have been reported in 48 countries (Beaton and Fox 1971).

A decline in the use of less concentrated fertilizers such as single superphosphate and ammonium sulphate has tended to aggravate sulphur deficiency. In some of the developing countries especially, a return to the use of single superphosphate may be the most economic and effective method for providing the needed sulphur, as well as other secondary and trace nutrients.

Elemental sulphur can sometimes be incorporated in granular fertilizer by spraying it as molten sulphur in the granulator, but it is less available than the soluble forms although recoverable over an extended period.

4. MICRONUTRIENTS

With traditional systems of cultivation, characterized by relatively low yields, micronutrient deficiencies may not be a limiting factor in crop production on tropical soils although deficiencies of Zn, Mo and B have been noted. Their correction has sometimes led to increased yields. However, as production is increased, micronutrient deficiency problems will require attention.

A systematic study of the role of micronutrients in crop production on tropical soils would be most helpful in predicting where deficiencies are likely to be a limiting factor. Where specific deficiencies can be identified, indigenous materials for correcting them should be sought. Small mineral deposits, too small to be considered a viable mining operation, might be a source of micronutrient materials. Pyrite (FeS_2) and pyrrhotite (Fe_5S_6) could be sources for iron and sulphur; chalcopyrite ($CuFeS_2$) and bornite (Cu_5FeS_4) as sources of copper iron and sulphur; sphalerite (ZnS) as a source of zinc and sulphur. Jarosites, either naturally occurring or as a byproduct from hydrometallurgical processing of copper-iron mineral concentrates, might be useful sources for iron and sulphur on highly acid soils of the tropics. Most of these materials are insoluble enough to be considered as slow release sources and would be available over extended periods of time.

5. MISCELLANEOUS METHODS FOR INCREASING EFFICIENCY

5.1 Placement Techniques

Research at the International Rice Research Institute led to the experimental use of mud balls containing urea or ammonium sulphate as a means of placing nitrogen fertilizers in the reduced zone of a flooded soil. The method, though effective in raising yields, was impractical on a large scale but prompted the preparation by IFDC of fertilizer in the form of supergranules weighing 1-3 g each or briquettes which are now available for experimental purposes. Plans for coating these large granules to slow the release of plant nutrients are under consideration. Slow release of such materials as urea and ammonium sulphate would lessen the danger of possible root damage caused by high concentrations of plant nutrients in a zone surrounding such a large granule and, in the case of urea, decrease the problem of high pH caused by rapid hydrolysis.

A new placement technique is that in which the fertilizer is applied in a band about 8 cm wide on the surface of the ground so that subsequent ploughing buries and mixes it with 8-10% of the soil. Planting in or near the band ensures high recovery of the nutrient. P and K so placed increased maize yields by 8% for five consecutive years (Barber 1977), while elsewhere N and P applied similarly raised wheat and sorghum grain yields by 20%. Liquid fertilizers are particularly well suited to this method of application. While the strip application technique was developed for use with mechanical equipment, the potential for increasing yields in developing countries should not be overlooked.

The efficiency of foliar application of certain nutrients on some crops is well known. Its potential should be investigated with special emphasis on crops which respond best to such treatment and on methods and equipment which can be employed by the small farmer.

5.2 Combination of Fertilizers and Pesticides

In the past, IFDC has been asked to prepare large granules of fertilizer containing pesticides for experimental purposes, but these requests could not be granted because of toxicity problems and lack of suitable equipment. Recent research by pesticide manufacturers has led to the development of controlled release products which may reduce toxicity hazards to the point where production of fertilizer-pesticide combinations might become feasible.

5.3 Nitrification Inhibitors

Ammonia from applied fertilizers or from bacterial action or organic matter is subject to oxidation to the nitrate (NO_3) form through the activities of a specialized group of bacteria. The nitrate form of N may be directly utilized by plants but is also subject to reduction by a second group of bacteria, thereby returning N to the atmosphere from which it came and completing the N cycle. As a result of the activities of the denitrifying bacteria and the removal of N with the harvested portion of crops, the reservoir of fixed N in the soil must be continually replenished.

Agents that reduce or eliminate the bacterial oxidation of the ammonium form of N to the nitrate form are termed nitrification inhibitors and can be helpful in increasing the effectiveness of nitrogenous fertilizers.

Several useful nitrification inhibitors have been patented: "N-Serve" (2-chloro-6-trichloromethyl pyridine) and "AM" (2-amino-4-chloro-6-methyl pyrimidine) are examples. Other such compounds are being studied to determine their effectiveness.

Recent work with urea treated with neem seed meal and extracts of neem seed indicate significant activity in inhibiting nitrification (Manickam et al 1976). Research in this area might produce other examples of indigenous materials which are effective in suppressing nitrification.

5.4 Urease Inhibitors

Under some conditions where urea is used for topdressing, substantial losses of nitrogen as ammonia can result from the action of the enzyme urease present in the soil and plant residues. Urease hydrolyses urea to the unstable salt ammonium carbonate which decomposes to ammonia and carbon dioxide. Urease inhibitors can be incorporated in the urea to slow the activity of the enzyme until the urea has penetrated the soil deep enough to lessen or prevent the loss of ammonia after hydrolysis.

Compounds which have shown promise as urease inhibitors include hydroxamic acid, acetohydroxamate and thiocarbamates. Alkyl and cycloalkyl derivatives of rhodanine-5-acetic acid and their heavy metal salts are also known to inhibit urease.

The use of urease inhibitors should be further investigated for applications where urea is not incorporated in the soil immediately after distribution.

REFERENCES

Barber, S.A. Placement of phosphate and potassium for increased efficiency.
1977. Fertilizer Solutions 21.

Beaton, J.D. and Fox, R.L. Fertilizer technology and use. 2nd ed, Chapter XI,
1971 Olsen, R.A. Ed. American Society of Agronomy, Madison, Wisc.

Brill, W.J. Biological nitrogen fixation. Scient. Amer. 236(3): 68-81.
1977

Engelstad, O.P. The role of potassium in agriculture, pp.63-77. Kilmer, V.J.,
1968 Younts, S.E., Brade, N.C., eds. American Society of Agronomy, Madison, Wisconsin.

Engelstad, O.P., Getsinger, J.G. and Stangel, P.J. Tailoring of fertilizers for
1972 rice. Bulletin Y-52, TVA, Miscle Shoals, Alabama.

Hignett, T.P. Developments in fertilizer technology and economics. Latin
1975 American Seminar on Fertilizers.

Manickam, T.S., Selvasseelan, D.A. and Krishnamoorthy, K.K. Nitrification of
1976 urea treated with nitrification inhibitors, coated fertilizers and slow-acting fertilizers in soil. Fert. News 21 (9).

Riemenschneider, W. Cyanogen or oxamide from HCN in one step. ChemTech, October
1976 1976.

Paper 15

RECENT DEVELOPMENTS IN FERTILIZER TECHNOLOGY ON NITROGEN

K. Isermann

Landwirtschaftliche Versuchsstation, D-6703 Limburgerhof, Federal Republic of Germany

1. FORMS OF NITROGEN FOR PLANTS

Nitrogen applied to crop plants is usually in the form of salts of nitrate nitrogen, ammonium nitrogen and cyanamide nitrogen. These N forms undergo microbial and chemical conversion in the soil and become available to the plant at different rates although on the whole relatively rapidly. A preference for the NO_3 form, and, to some extent also for the NH_4 form, is shown by the plant roots for the uptake of N. The rates of N fertilizer required for producing high yields, however, can result in damage to the soil due to excess salt and in losses due to leaching in areas with heavy rainfall when quick acting N forms are used. These undesirable effects can be reduced by matching the quantity and timing of N applications more closely to the needs of the plants, or slow release nitrogen fertilizers can be used which release and make the N components available more gradually. In function, they resemble a humus-rich arable soil in which the organically bound N is gradually mineralized by microbes and thus made available to the plant.

2. REQUIREMENTS AND NATURE OF SLOW RELEASE N FERTILIZERS

Ideally, the rate of supply of available N from the fertilizer should meet the changing needs of the plant in relation to the most efficient use of the N in increasing the marketable yield of the plant. In this way a slow release fertilizer could also reduce labour requirements.

The solubility in water of a slow release fertilizer should be low so as to minimize leaching, denitrification and damage from excessive salt concentration. Such a fertilizer should be comparable to common N fertilizers in handling and storage qualities and unit cost of N.

The slow release N fertilizers fall into two main groups - the natural organic materials and the synthetic substances. The former includes farmyard manure, green manure, horn meal and sewage sludge.

The synthetic substances rely upon physical and chemical methods of controlling release rate. The physical methods are typified by the coatings of sulphur, plastics, waxes etc. applied to common fertilizers, and in the case of compound fertilizers their action may also extend to K. Chemical methods include N compounds having a slight solubility in water. These compounds may be inorganic (e.g. metal ammonium phosphates) or organic such as oxamide, pyrolysis products of urea, or urea-aldehyde condensates like urea-formaldehyde crotonylidenediurea (CDU), isobutylidenediurea (IBDU). Other chemical methods are the use of nitrification inhibitors (e.g. N-Serve) used in combination with common NH_4 fertilizers, and ion exchangers such as coal, silicate or vermiculite in conjunction with common N fertilizers.

3. BEHAVIOUR OF SLOW RELEASE N FERTILIZERS IN THE SOIL

The gradual release of available N from slow release N fertilizers is due to several reasons. In the case of the slightly soluble mineral fertilizers it is the result of their relatively good chemical stability, while with coated mineral salts it is dependent on the rate of penetration of water into the granules. The release of N from organic substances is related to the intensity of microbial activity which is the effect of interactions between weather, nutrient supply in the soil and soil structure. For synthetic organic N fertilizers, temperature and soil moisture are decisive, without which large quantities of organic N cannot be converted into forms (NH_4-N and NO_3N) available to the plant.

While the rate of release is considerably slower than that for common forms of mineral N fertilizers, it is nonetheless more related to soil properties and conditions than to the specific needs of the plant. The slower release is also reflected in reduced leaching of N. Work has shown that over a period of 16 weeks cumulative leaching losses of N from ammonium nitrate could reach their peak in 4 weeks, while losses from IBDU and CDU were at a relatively steady rate over the whole period and amounted to no more than two-thirds of those from ammonium nitrate.

4. PRACTICAL APPLICATIONS OF SLOW RELEASE FERTILIZERS

The use of slow release N fertilizers is at present confined to horticultural crops such as fruit, vegetables and ornamental plants and to lawn grasses. They are well suited to such purposes as they have a good crop compatibility and produce the same crop yields as standard fertilizers, but with better use made of applied N and smaller losses from leaching and denitrification. Their application to agriculture has not yet proved to be a practical measure since this type of artificial fertilizer is expensive. An added drawback is that a peak demand for N by the plant at a certain time cannot be met, as for example occurs with cereals when flowering approaches.

Paper 16

NEW PHOSPHATIC FERTILIZERS

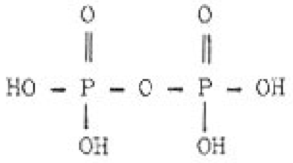
J.R. Ansiaux

Faculty of Agronomy, State University of Gembloux, Belgium

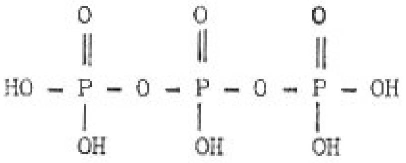
New phosphatic fertilizers can be classified into two groups: new products or processes of some commercial importance, and products still in the experimental stage. The first noticeable trend in the last 20-30 years in the manufacture of phosphatic fertilizers has been towards higher P concentrations in straight and compound fertilizers; single superphosphate has 7-8% P (16-18% P_2O_5)and triple superphosphate has 20% P (45% P_2O_5); the second tendency has been toward higher water solubility: diammonium phosphate (DAP) 18.22.0 (18.50.0) dicalcium phosphate (DCP) 0.17.0 (0.39.0) or phosphates produced by thermal methods, and thirdly, there has been the development of fluid fertilizers either in solution (all the elements in soluble form) or suspension (slurry).

To meet these three tendencies, industry has had to find new water soluble products and ones with a higher P content because it was impossible to exceed 20-22% P (45-50% P_2O_5) with monocalcium phosphate (MCP) or DAP. This has now been achieved through the development of polyphosphates (Carpentier 1969).

The polyphosphates result from the linking of two (or more) orthophosphoric acid molecules with elimination of one H_2O molecule. The first term of the series is pyrophosphoric acid, the second is tripolyphosphoric acid containing 36% P (82% P_2O_5) and so on. There are also cyclic forms (with 3 or 4 P atoms).



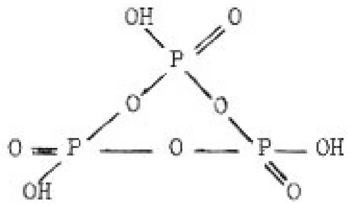
$$HO-\overset{\overset{\displaystyle O}{\|}}{\underset{\underset{\displaystyle OH}{|}}{P}}-O-\overset{\overset{\displaystyle O}{\|}}{\underset{\underset{\displaystyle OH}{|}}{P}}-OH$$



$$HO-\overset{\overset{\displaystyle O}{\|}}{\underset{\underset{\displaystyle OH}{|}}{P}}-O-\overset{\overset{\displaystyle O}{\|}}{\underset{\underset{\displaystyle OH}{|}}{P}}-O-\overset{\overset{\displaystyle O}{\|}}{\underset{\underset{\displaystyle OH}{|}}{P}}-OH$$

Pyrophosphoric acid

Tripolyphosphoric acid



Cyclic form

Superphosphoric acid (which has no connection at all with superphosphates) contains a mixture of 20 to 80% orthophosphoric acid and 80 to 20% polyphosphoric acids. Its P content is about 35% (80% P_2O_5) compared with 24% (54% P_2O_5) in orthophosphoric acid.

The polyphosphates are particularly interesting because:

i. freight charges are relatively less because of their higher P content;

ii. they are water soluble even in the presence of Ca;

iii. they do not precipitate as Fe or Al phosphate in the soil, they are not fixed and remain mobile until they are hydrolysed, fairly slowly, as orthophosphates. In some respects they behave as slow release fertilizers because P is only absorbed by plants as orthophosphoric ion.

Other kinds of polyphosphates (Davis 1975) are: Ca metaphosphate, 0.28.0 (0.63.0 on P_2O_5 basis), containing 21% Ca (29% CaO), and K metaphosphate, 0.26.30 (0.58.36 on oxide basis). They are both water insoluble but hydrolyse quite rapidly in the soil.

Products in the second group are those that are still in the experimental stage, and the hope is that some will be found with a high content of P (and N, or other elements), that do not react with the soil, that are not adsorbed, not fixed and that remain water soluble and have great mobility. In this way, it might be possible to increase the efficiency of use of P fertilizers.

More than 50 compounds (Matzel 1976) have been tried and most of them contain a covalent P-N link, e.g. amidophosphate ester

$(C_2H_5O)_2PONH_2$ or $[PN(NH_2)_2]_3$ a derivative of P nitride.

These types of compounds must meet conflicting conditions. If they are to remain mobile, they must not hydrolyse in the soil, but if they are to be absorbed or metabolized, then they must be hydrolysed.

When P - N compounds are submitted to elution in soil columns (40 cm), the depth of penetration decreases with low soil pH, because in acid soil they are hydrolysed and the products of the hydrolysis are adsorbed or precitipated with iron.

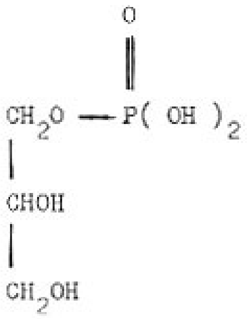
	Percentage adsorbed	
	Fine silt pH 3.8	Loess p.H 7.6
KH_2PO_4	100	60
$PO(NH_2)_3$	100	17
$(C_2H_5O)_2PONH_2$	12	8
$[(C_2H_5O)_2N]_2PONH_2$	23	5

The agronomic value, however, is no better (often lower) than that of orthophosphate.

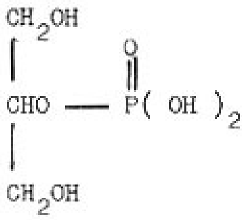
	Relative value	
	Acid soil	Neutral soil
$(NH_2)_2PO_4H$	100	100
$PO(NH_2)_3$	94	105
$(C_2H_5)_2NPO(NH_2)_2$.	112	81
$[(C_2H_5)_2N]_2PONH_2$.	35	13

None of the P - N compounds investigated so far have given a clear benefit in yield or a better P utilization than the ortho-fertilizers. Another point which must be borne in mind is their high manufacturing costs.

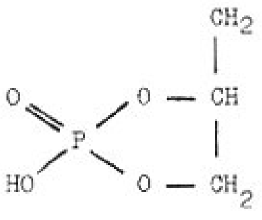
Another group of organo-phosphoric compounds, the glycerophosphates, seems to have very promising properties as P fertilizers. They are monophosphate esters (with two isomeric forms) and diphosphate esters (with two cyclic forms) (Coffey 1976).



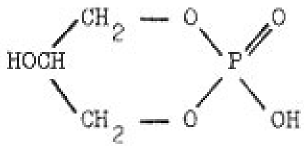
Glycerol 1-phosphate



Glycerol 2-phosphate



Cyclic 1.2 glycerophosphate



Cyclic 1.3 glycerophosphate

Glycerophosphates are relatively rich in P (18 and 20% respectively) (41 and 46% P_2O_5) ; they are water soluble, as are even their calcium salts (Lamirand and Pariselle 1941); they are not adsorbed or fixed in the soil (Rauschkolb et al 1975, Rolston et al 1974) and therefore they penetrate the soil with rain or irrigation water, but they do not descend beyond the wetting front. Moreover, they are fairly rapidly hydrolysed in the soil by phosphatases, as orthophosphates; in consequence, they are not leached to the water table. Glycerophosphates as P fertilizers should be applied as particles to the surface of the soil or with sprinkler or drip irrigation water. This gives the opportunity of correcting P deficiencies during the growth of the crop or of applying P in split dressings. It seems that the present manufacturing costs per unit of P in the form of glycerophosphates are 2 or 3 times higher than those of classical P fertilizer. The quantities to be applied, however, should be smaller and costs should become lower with production on a commercial scale.

Further reseach on the use and efficiency of glycerophosphates in agriculture is needed.

REFERENCES

Carpentier, L.J. Nouvelles formes de phosphates et leur utilisation en
1969 agriculture, Bull. Assoc. fr. Et. Sol. 4: 33-39.

Coffey, S. Rodd's chemistry of carbon compounds. 2nd ed. vol.I part E.
1976 Amsterdam Elsevier.

Davis, C.H. Nouveaux dévelopements dans la technologie des engrais. Phosp.
1975 et Agric. 65: 27-33.

Lamirand, J. and Pariselle, H. Chimie organique. Paris, Masson.
1941

Matzel, W. Value of compounds containing co-valent P - N Links as phosphatic
1976 Fertilizers. Phosph. in Agric. 67: 17-25.

Rauschkolb, R.S. <u>et al</u>. Fert. Farming Food 3(4): 66-68.
1975

Rolston, D.E., Rauschkolb, R.S. and Hoffman, D.L. Glycerophosphate as a phosphate
1974 fertilizer. Calif. Agric. 28(8) : 8-10.

APPENDIX I

PROGRAMME

Monday 18 April

10.00 - 10.30 Opening

10.30 - 12.30 Introduction

1. Problem areas and possibilities of more efficient fertilizer use.
   S.A. Barber (USA)

14.30 - 17.30 Soils in Relation to the Efficiency of Fertilizer Use

2. Quantitative prediction of fertilization demand as determined by soil, climate and plant parameters - A simple practical approach.
   U. Kafkafi (Israel)

3. Gains and losses of soil nitrogen with special reference to crop production.
   G. Stanford (USA)

4. Potassium efficiency in tropical and sub-tropical conditions.
   H. Beringer (Federal Republic of Germany)

Tuesday 19 April

09.00 - 12.00 Soils in Relation to the Efficiency of Fertilizer Use (cont.)

5. Availability of secondary and micro-nutrients for crops.
   M. Sillanpää (Finland)

6. Soil management with respect to liming and other soil amendments in East Africa.
   S.O. Keya (Kenya)

7. Role of soil testing for improved nutrient efficiency.
   A. Finck (Federal Republic of Germany)

14.00 - 17.30 Plants in Relation to the Efficiency of Fertilizer Use

8. Recent research and advances in characterization of genotypic differences in ion uptake and assimilation efficiency.
   F. van Egmond (The Netherlands)

9. Cropping systems for efficient fertilizer use.
   D.J. Greenland (UK)

Wednesday 20 April	
09.00 - 12.00	Plants in Relation to the Efficiency of Fertilizer Use (cont.)
	10. Significance of the nutrient potential of soil for crop production. O. Talibudeen (UK)
	11. Methods of fertilizer application for increasing fertilizer efficiency. J. Velly (France)
14.00 - 17.30	12. Present problems of fertilizer use on grain crops. A. Tanaka (Japan)
	13. The use of isotopes and radiation in studies on the efficient use of fertilizers. D.A. Nethsinghe (IAEA/FAO)
Thursday 21 April	
09.00 - 12.00	Fertilizer Technology
	14. New aspects on fertilizer technology to better exploitation of plant nutrients. R. Horn (IFDC/USA)
	15. Recent development in fertilizer technology on nitrogen. K. Isermann (Federal Republic of Germany)
14.00 - 17.30	16. Recent development in fertilizer technology on phosphorus. J.R. Ansiaux (Belgium)
Friday 22 April	
09.00 -	Discussions and Recommendations

APPENDIX II

LIST OF PARTICIPANTS

Dr. J.R. Ansiaux	2 Rue du Ruisseau 5870 Mont Saint Guibert, Belgium
Dr. S.A. Barber	Professor of Agronomy Purdue University, Agricultural Experiment Station West Lafayette, Indiana 47907, USA
Dr. H. Beringer	Buntehof Hannover, Fed. Rep. of Germany
Dr. A. Finck	Universität Kiel Kiel, Fed. Rep. of Germany
Dr. D.J. Greenland	Department of Soil Science University of Reading Reading, United Kingdom
Dr. R.C. Horn	Fertilizer Technology Division IFDC - 402 First Federal Building Florence, Alabama 35030, USA
Dr. K. Isermann	Landwirtschaftliche Versuchsstation D-6703 Limburgerhof, Fed. Rep. of Germany
Dr. U. Kafkafi	Institute of Soil and Water The Volcani Centre Agricultural Research Organization P.O.Box 6, Bet-Dagan, Israel
Dr. S.O. Keya	University of Nairobi Nairobi, Kenya
Dr. D.A. Nethsinghe	Joint FAO/IAEA Division Kärntnerring 11 A-1010 Vienna, Austria
Dr. M. Sillanpää	Institute of Soil Science Agricultural Research Centre Vantaa 30, Finland
Dr. G. Stanford	Biological Waste Management and Soil Nitrogen Laboratory Agricultural Environmental Quality Institute ARS/USDA Beltsville, Maryland 20705, USA
Dr. O. Talibudeen	Rothamsted Agricultural Experimental Station Soils and Plant Nutrition Department Harpenden, Herts AL5 2JQ, United Kingdom
Dr. A. Tanaka	Hokkaido University Sapporo, Japan
Dr. F. van Egmond	Agricultural University Wageningen, Netherlands

Dr. J. Velly	IRAT/GERDAT Montpellier Cedex, France
D.J. Halliday	FAO/FIAC Liaison Officer c/o Land and Water Development Division

FAO

R. Dudal	Director Land and Water Development Division (AGL)
A. Bozzini	Chief Crop and Grassland Production Service Plant Production and Protection Division
F.W. Hauck	Chief Soil Resources Development and Conservation Servi (AGLS)
P. Arens	Senior Officer Soil Resources Development, AGLS
H. Braun	Technical Officer Soil Fertility, AGLS
H. Matsuo	Technical Officer Soil Fertility, Training and Research, AGLS
C.S. Ofori	Technical Officer Soil Fertility and Management, AGLS
G.M. Higgins	Coordinator Agro-ecological Zone Study, AGLS
J. Kowal	Consultant Agro-ecological Zone Study, AGLS
S. Sarraf	Consultant Agro-ecological Zone Study, AGLS
A. Kassam	Consultant Agro-ecological Zone Study, AGLS
M. Mathieu	Chief Fertilizer Programme, AGLS
J. de la Vega	Technical Officer Fertilizer Programme, AGLS
T. Chan	Technical Officer Fertilizer Programme, AGLS
N. Stalbrand	Technical Officer Fertilizer Programme, AGLS
Miss I. Calcagni	Secretary, AGLS
Miss H. Tonkin	Editor and Meetings Officer, AGL