Fertilizer use under multiple cropping systems

FAO FERTILIZER AND PLANT NUTRITION BULLETIN

5

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Fertilizer use under multiple cropping systems

Report of an Expert Consultation
held in New Delhi
3-6 February 1982

Fertilizer and Plant Nutrition Service
Land and Water Development Division

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I. INTRODUCTION

An FAO-sponsored Expert Consultation on Fertilizer Use under Multiple Cropping Systems was held at the Indian Agricultural Research Institute, New Delhi, India, 3-6 February 1982, attended by leading scientists from 9 member nations and by representatives from a number of international and intergovernmental organizations (see List of Participants in Appendix II). It immediately followed a specially arranged 2-day visit to ICRISAT, Hyderabad, on 1-2 February.

After a formal welcome by the Director of the Indian Agricultural research Institute, Dr. H.K. Jain, and a statement by the FAO Representative to India, Dr. J.G. Rumeau, the inaugural address was given by Dr. O.P. Gautam, Director-General of the Indian Council of Agricultural Research, to whom a vote of thanks was proposed by Dr. N.N. Goswami, Head of the Division of Soil Science and Agricultural Chemistry of the Indian Agricultural Research Institute. Dr. N.S. Randhawa, Deputy Director General of the Indian Council of Agricultural Research, then delivered the keynote address on 'Fertilizer use in multiple cropping systems: an appraisal of present knowledge and future needs'.

Abridged versions of the papers presented during the Technical Session are included in the present report, together with the Consultation's conclusions and recommendations. To avoid duplication of references used in each of the papers, a consolidated Bibliography is included at the end.

Speakers at the closing Plenary Session included Dr. H.K. Jain, Dr. N.N. Goswami and, on behalf of FAO, Dr. J. de la Vega.

II. CONCLUSIONS AND RECOMMENDATIONS

Increasing food production by increasing the area under cultivation is perhaps no longer possible in many countries, except marginally. The answer to achieving the projected food production target for the burgeoning population of developing countries, therefore, lies in increasing yields per unit area per unit time through the adoption of a high level of agricultural technology. It is in this context that multiple cropping (sequential cropping, relay cropping and intercropping) assumes great importance.

Among other important issues, efficient fertilizer use and maintenance of soil fertility under multiple cropping systems are of utmost importance in the developing parts of the world. Concern for efficient use of fertilizers due to their limited availability and rising prices is another compelling reason to work out optimal fertilizer schedules for various cropping systems rather than for a single crop.

Information on fertilizer use in multiple cropping systems is not only limited but is scattered in published and unpublished reports in individual countries. This Expert Consultation, therefore, served the purpose of reviewing the present state of knowledge for the purposes of bringing into focus the information which can be immediately transferred to the farmers, to provide guidelines for on-farm trials and demonstrations and identifying the gaps in knowledge for further research planning.

The Consultation made the following conclusions and recommendations:

1. <u>Technology for Immediate Transfer</u>

i. <u>Rice based cropping systems</u>

a. <u>Irrigated rice</u>

a.1 Rice - wheat sequential system:

For alluvial soils in the Indian sub-continent, N to be applied to both crops, P to be applied to wheat, and K and Zn to be applied to rice.

a.2 Rice - rice - mungbean or soybean sequential system:

N to be applied to both the rice crops, while P to be applied only to one (preferably the second, dry season) rice crop together with K, S and Zn on the basis of soil tests.

a.3 Rice - jute sequential system:

N to be applied to both crops; P, K, S and Zn, if needed, to be applied to jute.

b. Rainfed rice

b.1 Rice - chickpea, rice - lentil, rice - horsegram, rice - niger, rice - mustard, rice - linseed, rice - groundnut and rice - soybean sequential systems:

N, P and other nutrients, as required, to be applied to rice crop only, 20 kg P_2O_5/ha to be applied to the sequential legume crop if moisture conditions are favourable.

b.2 Rice + pigeonpea, rice + maize, rice + cassava, rice + *Leucaena leucocephala* and rice + kenaf intercropping systems:

N, P and K to be applied to the rice crop only, Zn and Fe to be applied to rice when needed (iron as foliar spray).

(b.1 = bunded; b2 = non bunded).

ii. Maize-based cropping systems

a. Humid tropics

a.1 Maize - cowpea sequential system:

a.2 Maize + cassava, maize + groundnut and maize + Phaseolus bean intercropping systems:

a.3 Maize + gram/cowpea alley cropping with *Leucaena leucocephala*:

b. Sub-humid tropics

b.1 Maize + pigeonpea, maize + soybean, maize + cowpea and maize + chickpea/safflower (for deep Vertisol areas with 200 mm plant-extractable water per metre (depth) intercropping systems:

N to be applied to maize only, P to be applied to maize and associated legumes, K, S and Zn to be applied to maize as and when needed.

iii. Sorghum-based cropping systems for semi-arid tropics

a. Sorghum + pigeonpea, sorghum + mungbean, sorghum + cowpea and sorghum + groundnuts intercropping systems:

b. Sorghum - yam and sorghum - chickpea/safflower sequential systems:

N, P, K, S and Zn to be applied to sorghum only.

iv. Cassava-based cropping systems for humid tropics

a. Cassava + maize/beans intercropping systems:

Fertilizers to be applied to either crop, according to its importance in the region.

v. Inclusion of leguminous green manure or forage legume prior to an irrigated rice crop can contribute 30-40 kg N/ha.

vi. Inclusion of grain legumes, such as mungbean or cowpea, in the cropping systems can contribute 20-25 kg N/ha.

vii. Inclusion of blue-green algae/Azolla in the irrigated rice crop can contribute 20-25 kg N/ha.

viii. *Leucaena* sown at 4 m spacing can contribute, from top prunings incorporated in the soil, up to 60 kg N/ha to the companion crop.

ix. Fertilizer applications should be based on local experience and on the corresponding soil tests. In formulating N rates, due consideration should be given to the contributions from associated leguminous crops grown in the system.

2. Gaps in Knowledge and Need for Further Research

There are many research gaps yet to be filled in perfecting sound multiple cropping systems both for irrigated and rainfed agriculture and the associated agronomic practices. In order to sustain the practice of multiple cropping systems efficient use of fertilizers is of utmost importance.

2.1 Fertilizer management

i. Possibilities for application of organic manures, green manures and farm crop residues in multiple cropping systems to ensure economy and efficiency in the use of mineral fertilizers need to be explored and perfected.

ii. The introduction of legumes (annual and perennial) into multiple croping systems appears to be beneficial. The extent to which legumes fix atmospheric N and its contribution to the soil N economy need to be critically evaluated by using isotopic techniques. Research is also needed to increase N fixation by developing efficient *Rhizobium* strains and inoculation methods. Since N fixation by legumes is influenced by fertilizer N, more tolerant cultures of *Rhizobia* need to be evolved for intercropping systems.

iii. The development of associated symbionts (non-Rhizobial symbiosis) for non-legumes should be accelerated.

iv. Utilization efficiency of applied N at present seldom exceeds 50 percent in upland crops and is below 30 percent in lowland rice. Information on recommended agronomic practices such as fertilizer rates in relation to soil tests and time and method of application, is inadequate. In order to maximize the use efficiency of applied nitrogenous fertilizers, these aspects need to be evolved as precisely as possible by conducting field experiments over several seasons.

v. Development of suitable delayed and slow-release N fertilizers, as well as nitrification and denitrification inhibitors, needs to be pursued (making use of available indigenous materials where possible) so as to increase the efficiency of fertilizer N in cropping sequences and to minimize losses.

vi. The efficiency of utilization of applied P is often below 20 percent, mainly due to fixation. Research efforts are needed to discover the best means of using phosphatic fertilizers in multiple cropping systems; e.g. which crops should receive P fertilizer, rates of application in relation to soil test results, methods of application and the fertilizer types to be used so as to reduce soil fixation and increase efficiency. Use of indigenous sources of P such as rock phosphate and basic slag (a by-product from iron and steel manufacture) should be exploited where possible by determining to which crop(s) in the system they are best suited.

vii. More emphasis should be placed on growing crops and cultivars in those cropping systems which can best utilize the soil P.

viii. More investigation is needed of the role of P-solubilizing micro--organisms and mycorrhiza in increasing the availability of P.

ix. Further research is needed to monitor the needs of intensive cropping systems for K, S, Mg, Ca and micronutrients such as Zn, Cu and Mo. Deficient areas need to be delineated by suitable soil and plant tests. Appropriate corrective measures (and periodicity of repetition) need to be determined.

x. Soil testing methods require improvement and should be calibrated so as to evolve correct fertilizer recommendations for complete cropping systems rather than for individual crops.

2.2 Water management in relation to fertilizer use efficiency in multiple cropping systems

i. Research efforts to devise methods for utilizing limited rainfall and conserving soil moisture so as to ensure success of multiple cropping systems in dryland areas should be intensified.

ii. Tillage requirements and land treatments for seedbed preparation suited to various soil and topographical conditions need to be evaluated in order to ensure effective *in situ* soil moisture conservation and increase fertilizer use efficiency. Likewise, research efforts are needed to devise best ways to catch runoff water and recycle it at critical water stress periods.

iii. Water requirement schedules for cropping systems need to be worked out. Clear guidelines for the most efficient use of fertilizers in relation to proper use of irrigation water need to be established.

2.3 Soil erosion control

Since soil erosion is a serious problem in considerable areas of the world, specific cropping patterns and water management practices should be designed to minimize the loss of soil and applied nutrients in erosion-affected areas.

2.4 Adverse soil conditions

Further research is needed to identify crops suitable for adverse soil conditions, such as salinity, sodicity, acidity and Al toxicity. Appropriate fertilizer recommendations for suitable cropping systems should be developed for these problem soils.

2.5 Development of simple tools and farming implements

More applied research is needed to devise simple tools and implements for use by small farmers for simultaneous seeding and fertilizer application. These implements should be easily manufacturable at low cost using locally available materials and expertise.

2.6 Economic implications

Research efforts addressed to solving problems in all these areas should always take into account the economic aspect of the solutions proposed, as well as the social implications, which might influence their large-scale adoption by farmers.

3. Guidelines for Action Programme: Field Trials and Demonstrations

For upland intercropping systems, P fertilizers should be band placed, as far as possible, to all the crops in the system. K fertilizers are better broadcast over the entire area before planting and incorporated into the soil. Nitrogenous fertilizers should be topdressed adjacent to the non-legume crop rows.

The following trial and demonstration designs on farmers' fields are suggested. The rates of fertilizers should be determined according to the local conditions.

Cropping Systems	Crops/Treatments				Remarks
3.1 Rice-based systems (lowlands) i. 2-crop sequential systems:	Rice	Other cereals	Legumes		
	000 N00 NPO NPK	000 NPO NPO POK			Other cereals include wheat, maize or sorghum. In areas of soils high in K, this nutrient can be omitted.
	000 N00 NPO NPK		000 OPO 000 OPK		Legumes can be either grain legumes (mung, soybean, cowpea, groundnut) or forage legumes. As for K, see above remarks.
ii. 3-crop sequential systems:	Other cereals	Rice	Legumes		
	000 N00 NPO NPK	000 N00 N00 N00	000 OPO 000 OPK		Other cereals include rice, maize, sorghum or wheat. Legumes are grain or forage legumes. K application may be omitted if soil is high in K.
	Legumes	Rice	Other cereals		
	000 OPO 000 OPK	000 N00 N00 N00	000 N00 NPO NPK		Similar remarks as for previous case.
	Legumes	Rice	Legumes		
	000 OPO 000 OPK	000 N00 N00 N00	000 000 OPO OPO		Same remarks as for above.
3.2 Uplands crops-based systems	Cereals	Legumes	Wheat	Maize/sorghum	
i. 2-crop sequential	000 NPO N00 NPK NPK+Zn	000 OPO N00 000 000			Small quantity of N (20-30 kg/ha) applied to the legumes in the third plot.
			000 NPO N00 NPK NPK	000 NPO NPO NPO NPO+Zn	
ii. 3-crop sequential system:	000 NPO N00 NPK	000 000 N00 000		000 N00 NPO NPO	Cereals mainly wheat. Small quantity of N (20-30 kg/ha) to the legumes in the third plot.

4. General recommendations

i. The terminology used in multiple cropping systems is interpreted in various ways by researchers in different countries. The need for unification and standardization of terminology is strongly felt at all levels. It is suggested that FAO should further review and standardize the terminology in use in multiple and related cropping systems. A special committee might be set up for this purpose.

ii. The group felt that there is an urgent need for another Expert Consultation exclusively to discuss results on fertilizer management for efficient use in multiple cropping systems, especially mixed cropping systems for rainfed upland conditions.

iii. Rates of fertilizer application needed for optimum crop productivity are highly variable. No single uniform recommendation is possible for any system.

iv. Banding of fertilizers is preferable to broadcast application. Where practicable, fertilizers should be placed beside and below the seed. Relatively less soluble fertilizers and sandy soils are exceptions.

v. Micro- and secondary nutrients may present problems under some soil and environmental conditions. Crop susceptibility may be an important consideration when deciding the micro- and secondary nutrient needs and rates of application.

vi. Adverse soil conditions (acidity or alkalinity) affecting crop performance need to be ameliorated if successful multiple cropping patterns are to be developed.

vii. Inoculation of legumes with efficient strains of *Rhizobia* will aid better growth of the legumes.

viii. Soil testing facilities should be augmented in member countries. FAO should help in creating these facilities.

ix. An efficient fertilizer distribution network for multiple cropping systems requires very specific data in terms of the type, pattern, quantity and time of consumption of fertilizers. Special emphasis, therefore, needs to be laid on the most realistic comsumption estimates from the grassroots level upwards.

x. Credit requirements need to be assessed for the total crop sequence. This assessment should normally be valid for 2-3 years. Mid-term adjustments could easily be made if any change were to occur in the sequence.

xi. Training of fertilizer distribution personnel at all levels, to face the challenge of efficiently meeting the requirements of multiple cropping systems, should be a continuous exercise.

III. WORKING PAPERS

Paper 1 FERTILIZER USE UNDER MULTIPLE CROPPING SYSTEMS - AN OVERVIEW

R.N. Roy and H. Braun[1]

1. INTRODUCTION

The bulk of food consumed in most tropical countries is produced in small farming systems characterized by landholdings of a few hectares, limited mechanization, and a wide variety of multicropping systems in which several crops, often grown simultaneously in the same field, are harvested in a year. Therefore providing technical and economical support for the development and improvement of this system practised by the small and poor farmers in the developing countries is of great concern to FAO.

Any system of intensive cropping drains the soil heavily of available plant nutrients. Increased use of mineral fertilizers, therefore, is a key factor. With limited availability and the rising price of fertilizers, increasing the efficiency of their use and finding alternative sources of plant nutrients have therefore assumed great importance. Until recently, research efforts have been directed to finding an optimum fertilizer schedule based on the single crop system. It is now increasingly recognized that use efficiency of fertilizers could be further increased if an optimum fertilizer schedule could be prescribed for a cropping system taking into account components such as the residual effects of the previous crop and its fertilizer treatment on the requirements of the succeeding crop; the contribution of N to the system by legumes; the best crop season and time for application of different types of fertilizers; the level of soil-water-crop management; the cumulative effect of organic manures in supplementing mineral fertilizers, etc.

During the last decade considerable research has been done on fertilizer use in multiple cropping systems. The purpose of this review is to assess the state of present knowledge and identify main gaps existing from a practical point of view.

2. BASIC TERMINOLOGY

Although multiple cropping has been practised by farmers from time immemorial, only recently has it been dealt with by scientists. As a result, there is still some lack of uniformity, and indeed confusion, in terminology. One may cite as examples terms such as, on the one hand, monoculture, single crop, sole crop (Wit *et al.* 1966; Sadanandan *et al.* 1974, 1976; Rao *et al.* 1976; Mahapatra 1974; etc), and, on the other hand, polyculture, multiple cropping, parallel

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[1] Technical Officer and Chief, respectively, Fertilizer and Plant Nutrition Service, Land and Water Development Division, Food and Agriculture Organization of the United Nations, Rome.

multiple cropping, companion cropping, multi-storey cropping (Wichman and Trenkel 1977; Donald 1978), as well as sequential cropping, intercropping, row cropping, etc.

Based on the existing terminology in various countries, a successful attempt to propose a uniform terminology has been made by Andrews and Kassam (1977), who have suggested definitions of the main multiple cropping patterns together with other related terms currently in use. Multiple cropping, which is the highest category, is subdivided into two subcategories: sequential cropping and intercropping. The former is based on the principle of time sequence and the latter on space dimension. The principles just mentioned are very well reflected in the subdivisions of the two main multiple cropping systems, as can be seen in Tables 1 and 2.

Table 1 DEFINITIONS OF THE PRINCIPAL MULTIPLE CROPPING PATTERNS

MULTIPLE CROPPING		The intensification of cropping in time and space dimensions. Growing two or more crops on the same field in a year.
1.	Sequential Cropping - Growing two or more crops in sequence on the same field per year[1]. The succeeding crop is planted after the preceding crop has been harvested. Crop intensification is only in the time dimension. There is no intercrop competition. Farmers manage only one crop at a time in the same field.	
1.1	Double cropping	Growing two crops a year in sequence.
1.2	Triple cropping	Growing three crops a year in sequence.
1.3	Quadruple cropping	Growing four crops a year in sequence.
1.4	Ratoon cropping	The cultivation of crop regrowth after harvest, although not necessarily for grain.
2.	Intercropping - Growing two or more crops simultaneously on the same field. Crop intensification is in both time and space dimensions. There is inter-crop competition during all or part of crop growth. Farmers manage more than one crop at a time in the same field.	
2.1	Mixed intercropping	Growing two or more crops simultaneously with no distinct row arrangement.
2.2	Row intercropping	Growing two or more crops simultaneously where one or more crops are planted in rows.
2.3	Strip intercropping	Growing two or more crops simultaneously in different strips wide enough to permit independent cultivation but narrow enough for the crops to interact agronomically.
2.4	Relay intercropping	Growing two or more crops simultaneously during part of the life cycle of each. A second crop is planted after the first crop has reached its reproductive stage of growth but before it is ready for harvest.

[1] The farming year is 12 months except in some arid areas where only one crop can be grown every 2 years due to moisture limitations. In these areas sequential cropping involves growing two or more crops every 2 years.

Table 2 RELATED TERMINOLOGY USED IN MULTIPLE CROPPING SYSTEM

Sole cropping	:	One crop variety grown alone in pure stands at normal density. Synonymous with solid planting; opposite of intercropping.
Monoculture	:	The repetitive growing of the same sole crop on the same land.
Rotation	:	The repetitive cultivation of an ordered succession of crops (or crops and fallow) on the same land. One cycle often takes several years to complete.
Cropping pattern	:	The yearly sequence and spatial arrangement of crops or of crops and fallow on a given area.
Cropping system	:	The cropping patterns used on a farm and their interaction with farm resources, other farm enterprises, and available technology which determine their make up.
Mixed farming	:	Cropping systems which involve the raising of crops, animals, and/or trees.
Cropping index	:	The number of crops grown per annum on a given area of land x 100.
Land Equivalent Ratio (LER)	:	The ratio of the area needed under sole cropping to one of intercropping at the same management level to give an equal amount of yield. LER is the sum of the fractions of the yields of the intercrops relative to their sole crop yields.
Income Equivalent Ratio (IER)	:	The ratio of the area needed under sole cropping to produce the same gross income as one hectare of intercropping at the same management level. IER is the conversion of LER into economic terms.

Andrews and Kassam's attempt to give more precise scientific definitions of the principal multiple cropping patterns is a good basis for agronomic interpretations. However, very often one has to deal with intermediate systems, which have been developed in regard to both time and space, called "relay cropping", which is neither pure sequential cropping nor pure intercropping. It would seem reasonable that "relay cropping" should appear as a second subdivision of "multiple cropping" which would then have the following subdivisions:

Multiple cropping:
1. Sequential cropping
2. Relay cropping
3. Intercropping

Further improvement can be made by introducing in the subcategory of intercropping the system of multi-storey (or multi-tiered) cropping: "an intercropping system involving crops of significantly different height".

The above classification can by no means be considered complete. It is given only as an example for further discussion.

3. FERTILIZER MANAGEMENT IN MULTIPLE CROPPING SYSTEMS

Multiple cropping is an intensive farming system with several advantages: (i) more profit potential from two or more crops grown on the same area in one year; (ii) more production from the same area; (iii) more efficient use of nutrients, moisture, sunlight, equipment, labour and other production inputs; (iv) crop price and crop failure risks are spread over two or more crops; (v) wind and water erosion is reduced by better vegetation cover for a greater proportion of the time; and (vi) intensive use of the farmers' most expensive resource - land.

Among the several factors which are important for successful multiple cropping, soil fertility management has not received due attention primarily owing to the complexity of the problem. This Expert Consultation reviews the present state of knowledge on the subject in order to transfer the practical results to the farmers and draw up future lines of work.

A few generalized principles which have so far emerged from the mass of data are given in this paper along with suggestions for further work.

3.1 Sequential Cropping

Though in many countries sequential cropping has been practised for a long time, fertilizer recommendations have so far been single crop oriented.

While sequential cropping systems in irrigated conditions are based on the availability of short duration and photo- and thermo-insensitive high-yielding varieties, cropping systems under rainfed conditions have been developed depending on availability of cultivars with a short growing period, that escape drought periods, or are drought resistant. Under both systems, increased productivity is ensured through the use of fertilizers. What is more important to their judicious use are recommendations for fertilizer application related to the crops in sequence so that the optimum requirement of each crop is met taking advantage of residual effects and the contribution of any legume crop in the system. The residual effects may be different from what is known about traditional crop rotations because of the shorter time span involved.

Many generalized principles have been developed for efficient fertilizer use and are relevant to sequential cropping systems:

i. In a low fertility soil with crops requiring a heavy amount of plant nutrients it would be necessary to apply recommended rates to all the crops grown in sequence.

ii. The question of N in cropping systems is of major practical importance because of the large quantities of N removed by the harvest in intensive cropping systems. Further, in the absence of any appreciable residual effect, each crop should receive the optimum rate of fertilizer N, particularly in rotations which do not include a legume. However, there are some findings suggesting a carryover, especially when nitrification inhibitors and slow-release nitrogenous materials have been used in the preceding crop. Further experimentation would be necessary before coming to a meaningful conclusion.

iii. If properly inoculated and adequately fertilized with P, a legume crop not only requires little nitrogen for its own growth (a starter dressing of 20 kg N/ha has been found optimum) but leaves about 20-50 kg N/ha for the succeeding crop, depending on whether it is grown for grain or fodder.

iv. For optimum nitrogen economy, organic manures should be applied to the *Kharif* (wet season) crop rather than the *Rabi* (dry season) crop as their decomposition and assimilation are better during *Kharif*.

v. Capacities of various crops to utilize native as well as applied nutrients vary considerably, which ultimately influences the residual effect of applied nutrients. Proper phasing of fertilizer application appears essential for maximum efficiency on the succeeding crop. It is well established that, in the case of potato-based cropping systems, application of P and K to the potato crop gives a better result. Similarly, in a legume-based system, P is better applied to the legume and benefit from the carryover effect accrues to the succeeding crop.

vi. It is accepted that, in general, in medium fertility soil, phosphorus use should be preferred in *Rabi* crops so that the benefit of residual P accrues to the following *Kharif* crop. Similarly, K and Zn application in crops has been found more profitable.

As a starting point, it is suggested that fertilizer schedules for efficient and widely practised sequential cropping systems in various agro-ecological zones should be worked out, superimposing some of the above quantifiable effects on the fertilizer recommendations for individual crops. This should be followed up by a number of adaptive trials in the farmers' field to refine the schedules.

Since the current approach to optimizing fertilizer recommendations in a cropping system has been developed primarily from agronomic experiments, it needs a greater scientific footing for combining response functions, fertility carryover equations, etc. into a dynamic economic model based on long-term soil fertility experiments and supported by proper soil and plant analyses. Further, soil testing will also have to be improved and calibrated to evolve proper fertilizer recommendations suited to the cropping systems rather than to the component crops of the system.

It is generally accepted that N should preferably be applied to each crop in the sequence and P and K be applied once a year to the most responsive crop. This would probably call for reorientating the fertilizer distribution and supply strategy.

3.2 Intercropping

The bulk of food consumed in most tropical countries is produced in small farming systems characterized by landholdings of a few hectares, limited mechanization, and a wide variety of multicropping systems in which several crops, often grown simultaneously in the same field, are harvested in a year. Therefore providing technical and economical support for the development and improvement of this system practised by the small and poor farmers in the developing countries is of great concern to FAO.

Intercropping has been practised for centuries in many parts of the world, but the scientific community's interest in such a system as a means of increasing food production per unit of land and time is more recent in origin.

Reasons for the popularity of intercropping among farmers of smallholdings have been listed as follows:

i. Flexibility: sowing and planting dates are arranged to optimize labour requirements.

ii. Profit maximization: higher outputs are obtained per unit area.

iii. Resource maximization: land area use, light interception, water, nutrients, labour, etc.

iv. Risk minimization: offers a more dependable return.

v. Soil conservation: resulting from longer periods with ground cover.

vi. Soil fertility maintenance: intercropping may be regarded as a type of crop rotation practised each season on the same land.

vii. Weed control: crop competition is the cheapest method.

viii. Nutritional reason: a single plot of land can provide a better nutritional balance.

ix. Additional income: some companion crops require little additional input.

One can readily comprehend all these items except: ii. profit maximization, iii. resources maximization, and vi. Soil fertility maintenance, in each of which many factors interact to produce the desired result.

Data now available show that the advantages of intercropping apply not only at subsistence level but also at higher levels of productivity. As to the possibility of intercropping maintaining and increasing soil fertility, available information is scarce mainly due to the complexity of the problem.

The farmers' objectives influence, to a large extent, the amount of fertilizer to be used in intercropping systems:

- When two or more crops are grown together in subsistence farming as an insurance against total crop failure, the level of fertilizer use is generally low as available supplies of fertilizer are often limited. Under these conditions, additional application of fertilizers in balanced nutrient ratios will be beneficial.

- When intercropping is practised to enhance the utilization of limited agronomical inputs such as irrigation water, no extra fertilizer is added to the intercrop.

- The same holds true if an intercrop is grown not so much for its extra yield but for its weed-suppressing effect or as a green manure. Small amounts of nitrogen may be given in such cases in order to avoid any decrease in yield of the main crop as a result of competition for nitrogen between the main crop and the intercrop.

- If, however, the objective is to maximize plant production per unit of area and time, then the economic optimum quantity of nutrients must be applied to all crops in the combination in order to optimize total production.

Fertilizer requirements for intercropping systems (mixed, row and relay) may often differ considerably from the mere addition of fertilizer requirements of the individual crops, because growing two crops in association may result either in better exploitation of soil resources (uptake of nutrients from different soil depth due to different root distribution systems, and by change in the cycling of plant nutrients) or in competition between the crops for nutrients and other growth factors.

The root distribution of annual crops most often grown in mixture is given in Table 3.

Table 3 ROOT DISTRIBUTION IN SOME IMPORTANT CROPS GROWN IN INTERCROPPING SYSTEMS

Group of crops	Depth of root distribution (cm)	Crops
with shallow roots	0-30	sugarcane
with medium depth of roots	0-50	groundnut, beans, sorghum, rice, soybean, cowpea, millet
with deep roots	0-70	maize, cotton
with very deep roots	0->70	cassava, pigeonpea (perennial)

It is obvious that any combination between the crops from the different groups can contribute to better soil exploitation through utilization of different soil layers by the crop components. However, it has to be emphasized that the root distribution system is not only a characteristic of each species, but also it may be strongly influenced by some soil properties (hard-pan, clay-pan, ground-water level, toxic substances, etc.). This has to be taken into consideration when evaluating a particular crop mixture from this point of view. The distribution of the root system is variety-specific.

It is also recognized that morphological features such as the number of roots, the degree of subdivision of the root system, and the rate of growth and extension of the root system, may also regulate ion uptake by determining the amount of active surface exposed to the soil solution during root growth. The possibility of modifying the distribution of the root systems in varieties of a certain species by selection and breeding is essential for better crop combinations in mixed intercropping in relation to the increase of efficiency in the use of soil nitrogen, phosphorus and potassium.

In this regard one must emphasize the importance of the favourable effect a mixed cropping system may have in changing the cycle of plant nutrients. This improvement of the nutrient cycle by mixed cropping can be explained by involvement of nutrients primarily in the so-called "biological cycling", i.e. soil-plants, instead of "geological cycling": plants-soil-atmosphere or ocean. Such a change in the nutrient cycle is caused by:

a. increased plant density, therefore increased nutrient uptake;

b. different periods of maximum nutrient uptake by the plants involved in the crop mixture during the vegetation period.

Amongst the crop combinations in mixed cropping, intercropped legumes are considered very important in inducing favourable change in plant nutrient cycling and in the recovery of soil fertility. This pattern is attractive since legumes do not compete for sunlight (because of their short stature) or for soil nutrients (because of their ability to fix nitrogen).

i. Basic crops in intercropping

Summarizing the existing rather voluminous information in the literature, the following is a list of those plants most widely grown in intercropping systems and crop combinations:

Perennial trees including fruit trees: coconut, oil palm, rubber trees, mango, banana, coffee.

Leguminous crops: pigeonpea, beans, soybean, cowpea, groundnut (peanut).

Cereals: rice, maize (corn), millet, sorghum.

Fibres: cotton.

Roots and tubers: cassava.

Different crops: leaf vegetables, sugarcane.

The most widespread combinations are:

Rice with maize or cassava.

Maize with pigeonpea, beans, rice, soybean, vegetables.

Sorghum with cowpea, millet, groundnut, pigeonpea, cotton.

Cotton with cowpea, pigeonpea, groundnut, onion.

Groundnut with millet, sorghum, pigeonpea, maize.

Cassava with beans, cowpea, maize, rice.

Pigeonpea with beans, cowpea, groundnut, maize, millet, sorghum.

Coconut with cassava, groundnut, maize, rice, soybean, banana.

Oil palm with cassava, groundnut, maize, rice, banana.

Rubber trees with cassava, groundnut, maize, soybean.

Mango with rice, maize, cassava.

Banana with cowpea, groundnut, maize, millet, beans, vegetables.

Coffee with yam.

Sugarcane with maize, soybean, beans.

ii. Nutrient aspects

From a plant nutrition point of view, the success of any of these combinations in intercropping systems depends primarily on the nutritional requirements of the individual crops and on any possible interaction in their uptake of plant nutrients from the soil. There is plenty of information on nutritional requirements in the literature; therefore only a short summary will be given here with emphasis on problems related to intercropping systems. Unfortunately, the information available for many crops is only qualitative (high, medium or low requirements) and so of relatively little value for multiple cropping. In order to extrapolate and apply data on single crops to intercropping systems, at least the following information must be available:

a. total nutrient uptake by individual crops at different yields, which will give the basis for future predictions;

b. dynamics of nutrient uptake, which is essential for prediction of the competition for nutrients in the different intercropping systems and with various crop combinations;

c. length of the vegetation period of individual crops in intercropping; this information is also relevant to the dynamics of nutrient uptake;

d. root distribution of individual crops grown in multiple cropping systems, which will provide the basis for a more precise estimation of the possible sources for plant nutrients and for predicting competition for plant nutrients.

Data on these four points for the crops most often grown in intercropping are given in Table 4. Nutrient removal is taken mainly from Sanchez (1976). The final column of the table gives some qualitative characteristics of the dynamics of nutrient uptake. Limited quantitative data on the same subject are available for some individual crops grown in multiple cropping systems and should be used for formulating fertilizer recommendations.

Table 4 PRINCIPAL CROP CHARACTERISTICS IN RELATION TO NUTRIENT UPTAKE BY PLANTS

Crop	Yield t/ha	Nutrient removal kg/ha			Vegetation period in days			Depth of root distribution (cm)	Critical periods of nutrient requirement
		N	P	K	1	2	3		
Coconut	1.2	60.0	7.2	40.0		Perennial		0-90	
Banana	10.1	39.0	3.3	76.0		Perennial		0-20	
	30.0	85.0	10.0	226.0		-		-	
Oil palm	15.0	90.0	8.8	112.0		Perennial			
Rubber tree	3.0	7.0	1.2	4.0		Perennial			
Coffee	1.0	25.0	1.7	16.0		Perennial		0-30	
Rice (dryland)	1.5	42.0	8.0	2.80	110-130	130-150	150-160	0-40	tillering stage and panicle primordium stage
Maize	1.0	40.0	9.0	33.0	90-110	110-130	130-180	0-60	elongation of stalk to silking
	4.0	110.0	18.0	68.0	-	-	-	-	
	7.0	200.0	34.0	130.0	-	-	-	-	
Millet	1.1	17.0	5.0	59.0	60-70	70-120	120-180	0-40	
Sorghum	1.0	26.0	1.3	6.0	75-110	110-130	130-180	0-50	two weeks before, to the end of flowering
	8.0	200.0	14.0	40.0	-	-	-	-	
Pigeonpea	1.8	32.0	10.0	11.0		90 - 250		100	between flowering and seed set
Beans	1.0	31.0	3.5	6.6	60-80	80-100	-	0-30	
Soybean	1.0	49.0	7.2	21.0	80-90	90-110	110-180	0-30	flower buds to full bloom
Cowpea	1.5	85.0	6.6	24.9	60-90	90-130	130-200	0-40	
Groundnut	1.0	49.0	5.2	27.0	90-105	105-120	120-145	0-40	
Cassava	8.0	30.0	10.0	50.0		150 - 360		0-80	8-10 months after planting for varieties with 14 mths vegetation period
	16.0	64.0	21.0	100.0	-	-	-	-	
	30.0	120.0	40.0	187.0	-	-	-	-	
Cotton	0.8	30.0	4.7	7.0	125-145	145-160	160-195	0-60	emergence to blossoming
Sugarcane	100.0	75.0	20.0	125.0		2 years		0-20	during the tillering stage
	200.0	149.0	29.0	316.0		-		-	
	300.0	254.0	35.0	499.0		-		-	

iii. Competition for nutrients and fertilization practice

In addition to the nutritional requirements of the individual crops, their interaction and possible competition for soil factors play an important role in nutrient uptake when plants are grown in mixed cropping systems.

The plant roots deplete the nutrient compounds of the soil and the depletion area is proportional to the mobility of the nutrients and the root system and its distribution pattern. N moves to the plant roots almost entirely by mass flow and that is the reason for its depletion zone being large enough to overlap and cause competition. P and K move mainly through diffusion.

Competition for nutrients and light in intercropping systems is often interrelated, particularly for some specific crop combinations, e.g. non-legume species. On low nitrogen soils the non-legume is often suppressed, but in high nitrogen soils the vigorous growth of the non-legume usually causes it to dominate over the legume by shading (Trenbath 1976). The effect of this combined competition for light and nutrients can sometimes be corrected by an appropriate fertilizer application. It is considered (Trenbath 1976) that the competition for nutrients in a single stand can be higher than in mixtures.

During the period of most intensive study of the competition for light in multiple cropping systems, 1970-76, it was established also that some particular crop combinations have a very high land equivalent ratio (LER), which is considered to be one of the best criteria for intensification of land use. Scientists, mainly from the international research institutes (IRRI, ICRISAT, IITA and CIAT) had performed at that time a great number of field experiments studying the crop geometry of different multiple cropping systems. Similar field experiments were conducted by several national research institutes, mainly in East Asia (India, Philippines, Thailand, etc.).

The next question was how the crops in intercropping systems would respond to a high rate of fertilizer application. The philosophy of fertilizer practice of multiple cropping is not essentially different from that in a single crop (Oelsligle *et al.* 1976). According to Bray's nutrient concept (Oelsligle *et al.* 1976; Trenbath 1976), the relatively mobile forms of nutrients like NO_3 can be extracted from the "root system sorption zone", which is much greater than the root zone; in this case the principle of mass flow is valid. Phosphorus and potassium, which are relatively immobile nutrients, are extracted from the "root surface sorption zone", which is practically the root zone. Oelsligle *et al.* (1976) suggested that based on Bray's concept, the fertilizer rate for mobile nutrients should be based on actual plant use, whereas that for immobile nutrients would be based on estimates of the relative sufficiency of soil supply.

3.2.1 Row intercropping

In this system one may expect a real plant interaction between the crop components in regard to plant nutrients. The interaction will depend on (a) crop combinations, (b) planting arrangements, and (c) distance between the rows.

i. Combinations of cereals with legumes

The combinations are maize, sorghum and millet, with groundnut, soybean, cowpea, beans or pigeonpea. These combinations are the most widespread and of great economic importance. Their crop components have different requirements for nutrients; therefore, fertilizer use is considered complicated, in particular the question of the most appropriate rate, time and application of fertilizers in order to obtain the highest economic effect without disturbing the biological function of legumes in nitrogen economy. Nitrogen fertilizers are of greatest significance: cereals (maize in particular) have high nitrogen requirements, while most legumes in the tropics possess an effective mechanism for symbiotic N fixation; further, the nitrogen fixing mechanism of *Rhizobia* is very sensitive to nitrates. Experiments (Kurtz *et al.* 1952) have shown that fertilizer N reduces competition between intercrops of pigeonpea and maize, but the optimum requirement of fertilizer nitrogen for maize would have an adverse effect on grain yield of pigeonpea, when grown together.

Most publications on fertilizer use under intercropping are devoted to nitrogen problems in row cropping systems involving cereals and legumes. The key point for the leguminous crop grown in intercropping systems is the problem of nodulation, when nitrogen fertilizer has to be used for the companion non-leguminous crop. While high N fertilizer rates in cereal/legume intercropping reduce the intensity of symbiotic N fixation, this harmful impact of N fertilizer in row intercropping may be reduced or eliminated in the following ways:

a. application of N fertilizer to the cereal crop only;

b. application of slow-release or nitrification-inhibitor fertilizers;

c. application of N fertilizer 10-20 days earlier than the beginning of symbiotic N fixation by legumes/*Rhizobia*;

d. selection of the appropriate crop combination requiring less N.

ii. Combinations of cereals with cereals

Combinations can be maize - sorghum; maize - millet; sorghum - millet, etc. They usually consist of crops with more or less similar requirements of plant nutrients as regards timing, placing and types of fertilizers. It seems that the best way to determine an appropriate rate of fertilizer application is the balance method, i.e. calculating the requirements for each component crop based on soil test fertilizer recommendations for pure stands.

iii. Combinations of perennial trees or trees and shrubs

Available scientific information on fertilizer practice for these systems is scarce. Competition for nutrients in these systems is quite possible. It seems that the best approach for fertilizer recommendation should be based on the balance method and the dynamics of nutrient uptake, but unfortunately information on the latter subject is almost non-existent.

The following generalized conclusions on fertilizer practice in row intercropping can be drawn:

a. most studies have shown that under this system the majority of crop combinations did not demonstrate acute competition for nutrients;

b. all crop combinations have shown better utilization of fertilizers than any of the component crops grown alone;

c. calculation of fertilizer requirements based on the balance method can serve as a rough guide;

d. most intercropping patterns allow localized placement of a particular nutrient depending on specific crop needs; this is important for nitrogen application in cereal-legume combinations;

e. intercropping cereals with N-fixing legumes appears to be a promising means of providing N to a subsequent cereal without investing time in growing a green manure. Improvement of soil physical properties has also been noted. Whether legume nitrogen transfer is an important consideration in the nitrogen economy of intercropping systems remains controversial;

f. from biological and economical points of view, the most suitable rate of N for cereal-cereal combinations is higher than for cereal-legume combinations;

g. a specific scientific approach to giving fertilizer recommendations for different crop combinations is virtually non-existent and needs to be speedily established from well laid out field trials in various agro-ecological zones.

3.2.2 Mixed intercropping

From a nutritional point of view, this system is considered to be the most complex (Oelsligle *et al.* 1976). The publications concerning fertilization practice of mixed intercropping are, however, very scarce, excluding the mixtures of grass-legume for forage production, which have been studied more intensively under the temperate climate.

In order to understand better the nutritional requirements of crops grown in mixed intercropping, one must distinguish two types: (a) cases in which the component crops are grown in one row and (b) those in which the component crops are grown in "randomized" spatial arrangements of plants. Theoretically, from a nutritional point of view, the former has many disadvantages. It does not permit localized placement of fertilizers as with alternate rows. The nutritional area for each component crop is less. Competition for P and K is possible as well as for

N. In addition, the inter-row space is not fully utilized as it is in pure stand row crops. All these disadvantages have been demonstrated very clearly by Dalal (1974). From a biological point of view, the combination maize-pigeonpea is considered to be highly suitable with a minimum competition for nutrients. Pigeonpea starts flowering after the maize has been harvested and its period of greatest nutrient demand occurs when the maize has already completed its growth cycle. As even this combination has shown some competition when the two crops are grown in one row, one could expect much greater competition for other biologically less suitable combinations, in which the highest rate of nutrient absorption by the component crops coincides.

Randomized spatial arrangement of plants in mixed intercropping seems logically to be one of the most suitable arrangements for utilization of plant nutrients, always providing that the crop combination is well chosen. So long as the component crops have dissimilarly-shaped nutrient-absorption curves, this system could be the most efficient in utilization of the natural resources of plant nutrients in soils. However, if these natural resources are not enough and additional nutrients must be added in fertilizers, then combinations with similarly-shaped nutrient-absorption curves and similar total nutrient requirements are considered to be ideal from the viewpoint of fertility management.

Mixtures of perennial tree crops and annual crops

Scientific publications on fertilizer application to these systems are limited. Wrong fertilizer practice can cause a long-lasting negative effect. In most cases fertilizers may be applied independently to the two crops.

3.2.3 Strip intercropping

Some scientists (Oelsligle *et al*. 1976) consider this system as not too different from sole cropping, from the viewpoint of fertility management.

3.2.4 Relay intercropping

A relay system is essentiallly a sequential cropping with an overlap of the harvest and seeding of the two respective crops. Depending on the amount of time overlap between seedings, there may be an increased efficiency in nitrogen recovery when late N applications are made on the first crop.

4. PROBLEMS OF PRIORITIES IN STUDIES OF FERTILIZER PRACTICES IN MULTIPLE CROPPING

The following aspects seem to deserve more intensive studies:

i. analysis of growth, dry matter accumulation and dynamics of nutrient uptake;

ii. improvement of the classification of multiple cropping systems in regard to fertilizer management, particularly the grouping of crop combinations with similar nutrient requirements and fertilizer management;

iii. quantification of residual effects of fertilizer application to the preceding crop (legumes and non-legumes);

iv. inter-row and intra-row competition for plant nutrients in intercropping systems;

v. quantification of N transfer, if any, from the legume crop to the non--legume crop grown in association;

vi. possibilities and approaches for transferring the results of soil testing for single crops to multiple cropping systems;

vii. nitrogen fixation by *Rhizobia* in non-leguminous/leguminous combinations as affected by fertilizer management.

Acknowledgement

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Paper 2 THE FAO/IAEA COORDINATED RESEARCH PROGRAMME ON NUCLEAR TECHNIQUES IN THE DEVELOPMENT OF FERTILIZER AND WATER MANAGEMENT PRACTICES FOR MULTIPLE CROPPING SYSTEMS

F. Zapata and J.B. Bole[1]

1. INTRODUCTION

The Joint FAO/IAEA Division of Isotope and Radiation Applications of Atomic Energy for Food and Agricultural Development was established in 1964 at the IAEA headquarters in Vienna. The programme supplements and supports priority areas of FAO and IAEA activities where radiation and isotope techniques are particularly promising. The main activities are coordination and support of research, technical assistance including training and dissemination of technical and scientific information. Currently, over 300 research institutes in Member States are cooperating in some 25 coordinated research programmes, all of which are designed to solve practical problems of immediate concern with the food supply and the economy of developing countries. The objectives of each programme are discussed and drawn up by specially convened panels of experts. Competent research institutes are then contacted and invited to take part in the programme, which can last from three up to five years. A report is normally published at the end of the programme. Summarized data are presented in a form which highlights the more significant conclusions. It is also recognized that publication by the participants of their individual data is normally the most appropriate and effective way of contribution to the benefit of agriculture in their own country.

The established system of the IAEA Research Contract Programme not only contributes to the solution of priority problems in developing countries, but also assures maximum cooperation and coordination in the execution of the projects. Apart from the problem-oriented aim of the coordinated research programmes, they are by nature educative and bear an incentive for training. This is a result of the interaction which raises and improves the level of knowledge and experience of all the participants.

2. THE PROGRAMME

An Advisory Group Meeting was organized by the Joint FAO/IAEA Division and held in Ankara, Turkey, 8-12 October 1979, to advise on and to evaluate the need for a new coordinated research programme aimed at the development of adequate fertilizer and water management practices for multiple cropping systems. The proceedings were published as Technical Document IAEA-TECDOC-235 and copies are available on request.

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On the recommendation of this Advisory Group, a Coordinated Research Programme was initiated during 1980. The Soil Fertility, Irrigation and Crop Production Section of the Joint FAO/IAEA Division has the technical responsibility for its implementation. The Head of this Section is also the Project Officer. The programme is not designed to evaluate the results of intercropping but rather to use nuclear techniques in the development of fertilizer and water management practices for the multiple cropping system known to be the most efficient in the region.

The first meeting of participants in the programme was held in Vienna 14-18 September 1981, attended by participants from 9 countries (S.U. Patwary, Bangladesh; W. Sisworo, Indonesia; S. Remison, Nigeria; R. Tejeira, Panama; J. Samki, Tanzania; A. Suwanarit, Thailand; N. Ahmad, Trinidad; P. Giordano, USA; and R. Rajoo, Zambia). R.N. Roy, representative of FAO, also participated and reported on FAO's activities in the field of multiple cropping. The initial plans were to study effective placement and timing of nitrogen fertilizer and placement of phosphorus fertilizer using ^{15}N and ^{32}P labelled fertilizers. Although at least three experiments which provided valuable information have been completed and others are in progress, local problems and late arrival or loss in transit of the isotopically labelled fertilizer has slowed the progress of the programme. Progress has not been as rapid as the group would have liked. Future plans were formulated to determine more precisely N fertilizer placement and timing for the cereal component of a legume/non-legume intercropping system and to study the effect of P placement on nutrient uptake and N fixation by the legume.

The research contract holders of the programme attended a workshop on the use of isotope techniques in soil/plant studies in the following week, 21-25 September 1981.

3. PROGRESS REPORT ON THE NITROGEN EXPERIMENT OF THE PROGRAMME

Multiple cropping is widely practised in developing countries because it can provide the advantages of higher total annual yield per unit area, yield stability through more efficient utilization of water and increased insect and disease tolerance, and where the crops are grown for human consumption, a more varied and nutritious diet. Multiple cropping agriculture has not changed significantly and has benefitted little from the bulk of the research conducted on monoculture. Most studies have dealt with the most suitable crop combinations, plant populations, or crop development rather than fertilizer or water requirements.

The optimum method of fertilizer application for an intercropping system becomes quite complex when the crops have widely differing fertilizer requirements. A legume can often supply a part or most of its own N by dinitrogen fixation but has a high P requirement. A non-legume generally requires less P but is dependent on soil or fertilizer N.

The initial experimental plans of this Programme were designed to determine the optimum methods of applying fertilizer N and P to an intercropping system by means of isotope techniques. An experimental guideline was prepared containing one experiment for N and another for P. Optional studies were planned to compare water use efficiencies of intercropped and sole-cropped systems. The present report refers to the nitrogen experiment which was part of the Seibersdorf Laboratory's contribution to the programme.

This experiment was carried out during 1981 in a loam alluvial soil at the experimental field of the IAEA Seibersdorf Laboratory. A row intercropping system of sorghum (*Sorghum vulgare*) cv. Duet and soybean (*Glycine max*, L., Merrill) cv. Chippewa was seeded on 20 May. Fertilizer treatments (Table 1) were selected based on what was considered most feasible under a labour-intensive agricultural system with limited mechanization; rates were below those needed for maximum yields. Ammonium sulphate was applied as N fertilizer in dry form. The labelled material used was enriched with 0.774% ^{15}N atom excess at the 80 kg N/ha rate and 1.985% ^{15}N atom excess at 40 kg N/ha. The design was a randomized complete block of 7 treatments in 6 replicates. Only isotope plots were included, consisting of 3 rows of each crop, 1.5 m long with 50 cm spacing between rows. Each metre of row contained 25 sorghum plants or 20 soybean plants. The legume seeds were inoculated with a local inoculant immediately prior to seeding. Supplemental irrigation was applied during dry periods. Soil water measurements were made with a neutron moisture meter. Side dressing to sorghum was provided at a plant height of 50 cm or about 50 days after planting.

Harvest was on 9 October (about 140 days after planting), when sorghum plants were at the beginning of ripening (stage 11) and soybean at the R6 stage. All above-ground plant material was gathered and weighed fresh. It was then separated into grain and stover; these were handled separately to obtain representative subsamples. The dried subsamples were finely ground, analysed for total N by the Kjeldahl procedure and ^{15}N content by mass-spectrometry.

3.1 Results

The data for each crop were calculated based on the entire plot area harvested (cereal plus legume), and combined to provide the total dry matter and nitrogen yield for the treatment. The results are given in Table 1. Total dry matter and nitrogen yield were similar for all treatments. This statement, however, does not apply for the sorghum crop, for which placement of 80 kg N/ha (treatments 2 and 3) in the cereal row produced a yield decrease. A possible explanation could be the high salinity generated in the rooting zone of the seedlings. This effect was more pronounced where N was broadcast and incorporated near the cereal row. Certainly moisture availability in the rooting zone throughout the growing season was another significant factor. It is evident that splitting N into two increments afforded no yield advantages when compared with the three basal applications. Note that timing was a confounded effect since yield was used as the criterion of evaluation.

Reports indicate that sorghum grown as a grain crop has a high capacity for extracting soil N and consequently less demand for fertilizer N. The use of ^{15}N permits determination of the percentage nitrogen in the plant which was derived from fertilizer, thus directly measuring the fertilizer use efficiency.

Figure 1 displays the effect of placement of 80 kg N/ha on the sorghum

Table 1 INFLUENCE OF N FERTILIZER TREATMENTS ON DRY MATTER AND NITROGEN YIELD OF SORGHUM AND SOYBEAN IN A ROW INTERCROPPING SYSTEM

N FERTILIZER TREATMENTS		DRY MATTER YIELD (kg/ha)			TOTAL NITROGEN YIELD (kg/ha)		
N rate and time of application		Sorghum	Soybean	Total	Sorghum	Soybean	Total
1. 80 kg N*/ha Broadcast and incorporated over entire plot at seeding		8189 b	3529	11718	126 b	97	222
2. 80 kg N*/ha Broadcast and incorporated near the cereal row at seeding		5284 a	4930	10214	82 a	118	200
3. 80 kg N*/ha Banded near the cereal row at seeding		5883 ab	3679	9560	86 ab	95	181
4. 40 kg N*/ha over entire plot at seeding	40 kg N/ha side-dressed when sorghum 50 cm high	7200 ab	4064	11264	108 ab	118	231
5. 40 kg N/ha over entire plot at seeding	40 kg N+/ha side-dressed	7295 ab	4070	11365	112 ab	113	225
6. 40 kg N*/ha near cereal row at seeding	40 kg N/ha side-dressed	6616 ab	4435	11058	102 ab	128	230
7. 40 kg N/ha near cereal row at seeding	40 kg N*/ha side-dressed	6794 ab	3636	10430	101 ab	103	204
Coefficients of variation (%)		15.8	19.6	9.5	17.3	18.0	12.5
F test		**	NS	NS	*	NS	NS

Numbers followed by the same letter are not significantly different at the 95% confidence level plant and grain N derived from the labelled fertilizer. Results reveal a distinct advantage from placement near the row. This comparison shows that concentrating N fertilizer in a band limited immobilization and/or losses associated with mixing of the N throughout the soil mass, as had previously been found for maize. The influence of time of application is shown in Figure 2. As expected, side-dressing N at a plant height of 50 cm resulted in maximum N in the grain derived from the fertilizer.

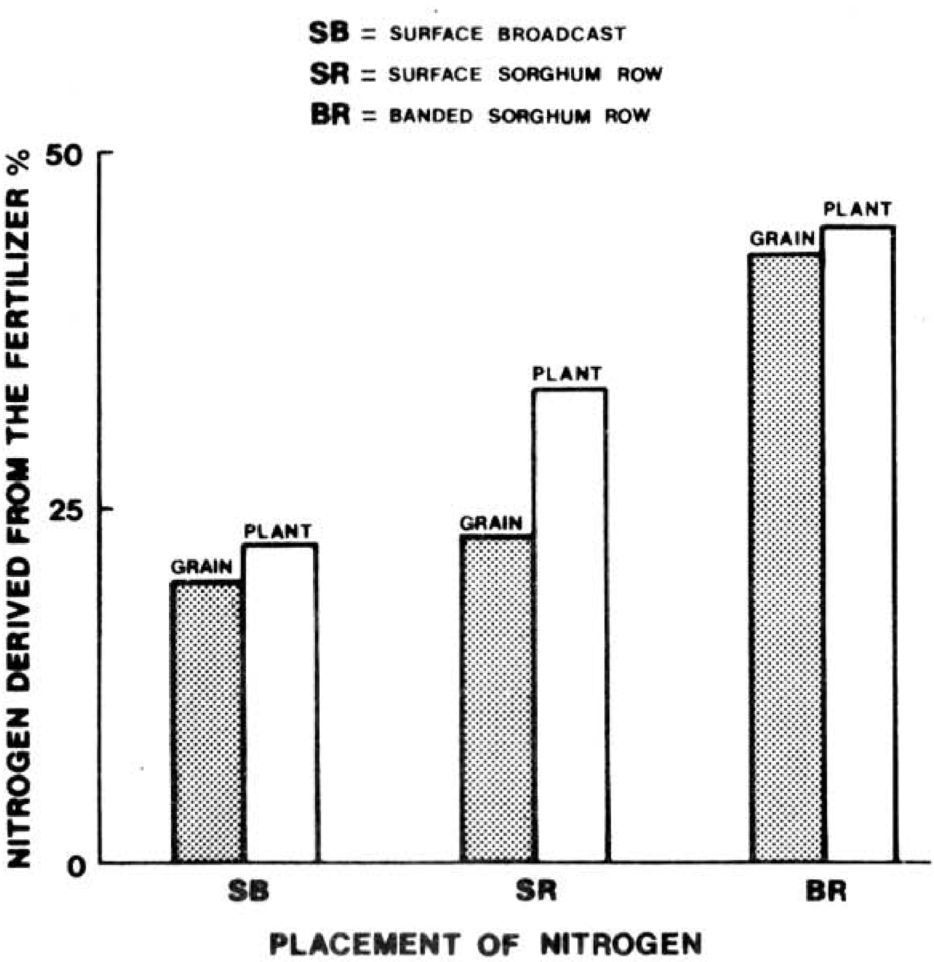

Fig. 1 Influence of placement of 80 kg N/ha on sorghum plant and grain nitrogen derived from the fertilizer

The data on nitrogen fertilizer yield and fertilizer use efficiency are reported in Table 2, in which the data from treatments 4 and 5, and 6 and 7, respectively, are combined. Again, it is evident that band treatment at seeding was superior to all other treatments. The greatest efficiency of this treatment reflects the response of sorghum to this placement of N. The yield data in Table 1 alone would have suggested that all placements studied were equally effective but the fertilizer use efficiency data indicate clearly the superiority of the band treatment.

Treatment 1 where ^{15}N-labelled fertilizer was broadcast uniformly over the

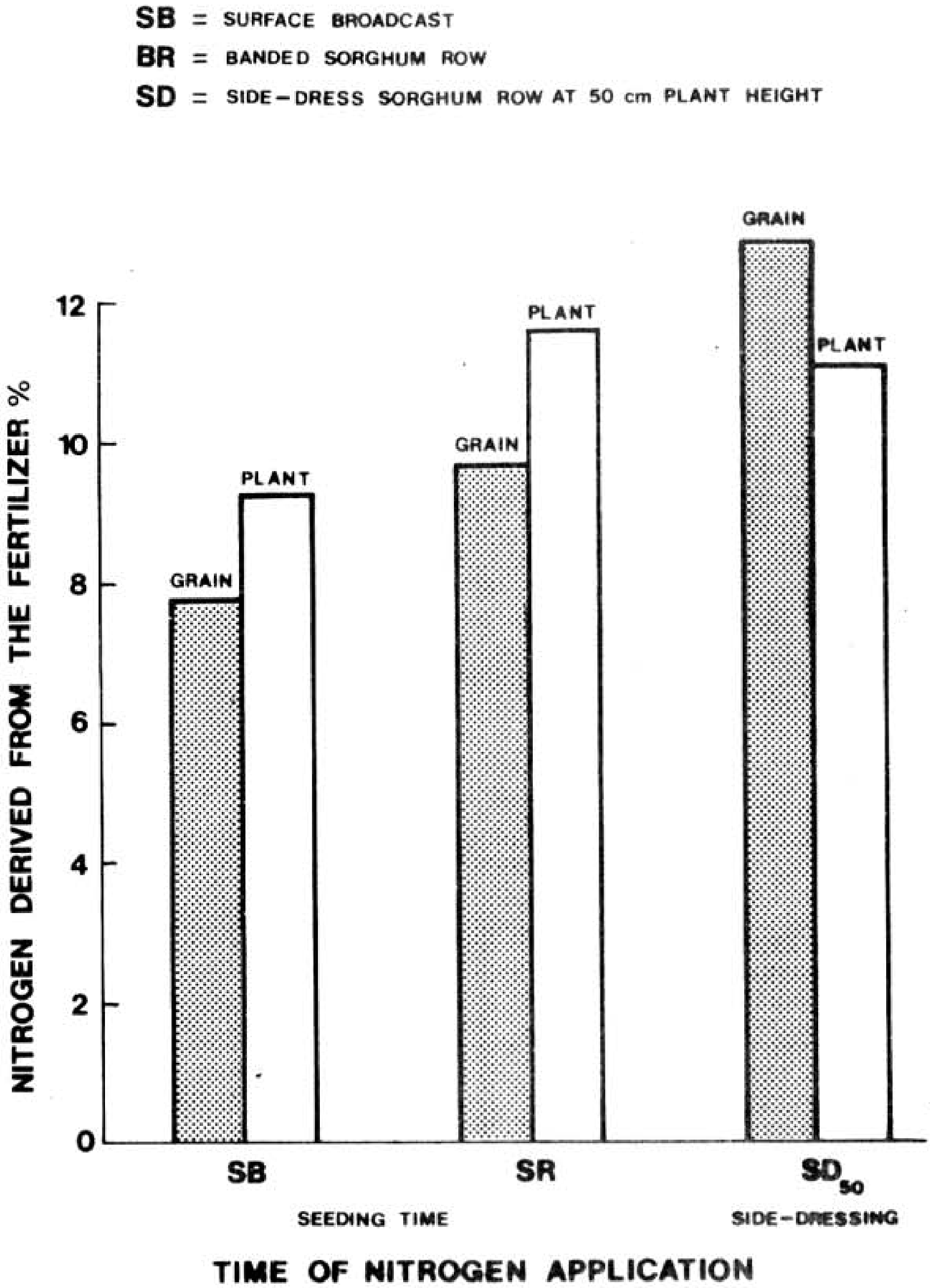

Fig. 2 Influence of time of applying 40 kg N/ha on sorghum plant and grain nitrogen derived from the fertilizer

entire plot was also found adequate to provide an estimate of the symbiotic N contribution of the legume to the system. Since the same amount of labelled fertilizer was applied to both crops, fixation was estimated by the relationship indicated by Fried and Middleboe:

$$\% \text{ N derived from fixation} = \left(1 - \frac{\% \ ^{15}\text{N atom excess legume}}{\% \ ^{15}\text{N atom excess standard}}\right) \times 100$$

The results in Table 3 indicate that soybean intercropped with sorghum fixed a significant amount of nitrogen.

Table 2 INFLUENCE OF N FERTILIZER TREATMENTS ON FERTILIZER NITROGEN YIELD AND FERTILIZER USE EFFICIENCY BY SORGHUM AND SOYBEAN IN A ROW INTERCROPPING SYSTEM

N-Fertilizer Treatments	Fertilizer Nitrogen Yield (kg/ha)			Fertilizer Use Efficiency %		
	Sorghum	Soybean	Total	Sorghum	Soybean	Total
Single (1) 80 kg N*/ha	28.1 a	8.5	36.6 b	35.0 a	10.5	45.5 b
Single (2) 80 kg N*/ha	26.7 a	4.6	31.2 ab	33.5 a	5.8	39.3 ab
Split (4 5) 40 + 40 kg N*/ha	22.0 a	7.0	29.0 a	27.5 a	8.8	36.3 a
Split (6 7) 40 + 40 kg N*/ha	22.3 a	5.3	27.6 a	27.8 a	6.5	34.3 a
Coefficient of variation (%)	10.5	28.4	7.3	10.5	27.2	7.4
F test	**	-	**	**	-	**

Numbers followed by the same letter are not significantly different at the 95% confidence level.

Table 3 ESTIMATE OF SYMBIOTIC NITROGEN FIXATION BY SOYBEAN GROWN INTERCROPPED WITH SORGHUM

Crop	Plant part	Dry matter yield kg/ha	% N	Total nitrogen yield kg/ha	N derived from fixation %	Fert. nitrogen yield kg/ha	N derived from fixation %	Fixed N kg/ha
SORGHUM	Straw	4 635	1.51	71	27.4	17.18		
(Standard	Grain	2 135	1.89	41	19.8	7.81		
non-	Chaff	1 420	1.01	15	21.5	3.12		
fixing								
crop)	TOTAL	8 190		127	22.5*	28.10		
SOYBEAN	Straw	1 939	1.00	19	15.8	2.99		
(Legume	Seed	986	6.39	63	7.2	4.46		
fixing	Husk	605	2.17	14	7.9	0.98		
crop)								
	TOTAL	3 530		96	8.8*	8.43	60	59

* Weighted average values for the whole plant

Paper 3 FERTILIZER USE UNDER MULTIPLE CROPPING SYSTEMS IN SOUTH EAST ASIA

Rajat De[1]

1. INTRODUCTION

Cropping systems in the humid tropics of the South East Asia region have a remarkable similarity. There is almost a set pattern of devoting low wetland, poorly drained soils to rice cultivation. Upland soils, up to moderate elevations which are comparatively well drained, are put under crops such as upland rice, maize, groundnuts, cassava, *kenaf*, cotton, mungbeans, soybeans and tropical vegetables; or perennial crops such as rubber, cotton, oil palm, fruit trees or coffee. At still higher elevation where temperatures are milder, temperate vegetables, field crops and fruit trees are grown. Fields are mostly monocropped but, if supplemental irrigation is available or the rainy period extends beyond the duration of a crop, double cropping is practised.

Although rice is the dominant crop in the region, its yields are low compared to Japan or South Korea. The main reasons are continuance of traditional cultivars and lack of improved management practices. To meet the growing food needs of the burgeoning population standards of cultivation must change. Improved varieties and management practices including balanced fertilizer use will be needed. High costs of fertilizers and their relative unavailability when needed, as well as lack of technical information on the management of rice under different water regimes, are constraints to yield increases. There is, however, a considerable possibility of increasing rice yields through proper fertilizer management under actual farmers' conditions as has been shown in INSFFER reports describing IFDC-IRRI sponsored experiments on cultivators' fields.

2. GREEN MANURING AND CROPPING SEQUENCES

Before the advent of chemical fertilizers, green manuring with legumes like *Crotolaria* or *Sesbania* was a common practice in the rice-growing tracts of the Indian sub-continent. This practice declined as farmers felt they could substitute fertilizers instead of green manuring and instead grow a crop of economic value, but the prevailing high cost of fertilizers has again aroused interest.

Beri and Meelu (1979) have shown that green manuring alone can give more yield or rice than obtained with 60 kg N/ha (Table 1) and that burying the green manure one day before transplanting enables the rice to be harvested 15 to 20 days sooner and so facilitates timely sowing of the following wheat crop.

Green-manured rice top-dressed with 40 kg fertilizer N/ha yielded as much as a crop fertilized with 120 kg N/ha by the recommended practice (Tiwari *et al.*

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Table 1 EFFECT OF GREEN MANURING ON RICE YIELD (t/ha)

Preceding crop	N fertilizer applied to rice (kg N/ha)		
	0	60	120
Fallow	2.55	4.86	5.93
Green manure crop buried 10 days before transplanting	4.17		
Green manure crop buried 1 day before transplanting	5.96		

Source: Beri and Meelu (1979)

1980). In a jute-rice cropping system in Eastern India stripping of jute leaves in the field and incorporating them in the submerged soil before transplanting rice has been reported to give benefit equivalent to 30 kg fertilizer N/ha.

Where irrigation facilities are available or where rains are expected after the rice harvest, fodder or grain legumes are grown in the rice fallows. Some of these can benefit the subsequent rice crop substantially. Meelu and Rekhi (1981) showed that the effect on rice of green manuring with mung foliage after harvesting the pods was equivalent to 60 kg N/ha (Table 2).

Table 2 RICE YIELD (t/ha) AS AFFECTED BY GREEN MANURING WITH PREVIOUS MUNG CROP

Management of mung	N fertilizer applied to rice (kg N/ha)	
	60	120
Mung residues removed	5.01	7.08
Mung incorporated as green manure after removing mature pods	7.18	8.65

Source: Meelu and Rekhi (1981)

A similar experiment on a Peninsular clayey soil at Hyderabad tested several grain and fodder legumes. A preceding crop of grain cowpea or mung benefitted rice to the extent of 50-70 kg N/ha. The grain yield from mung or cowpea would moreover be a valuable source of protein in the diet of a rice-eating population. Another advantage was a better utilization of fertilizer nitrogen by the rice crop. The practice of green manuring or growing previous crops of suitable grain or fodder legumes appears to act in the soil as a source of slow-release N, thus giving a higher response to top-dressed fertilizer. Short season fodder legumes of 55 to 60 days duration have a similar role (Giri and De 1981).

All legumes are not equally effective in improving soil productivity and their potential will need to be evaluated under various soil and climatic conditions. The choice between them should be such as to benefit crops of economic importance.

3. NITROGEN FERTILIZER USE IN CROPPING SYSTEMS

INSFFER analysis (de Datta and Gomez 1980) shows that, due to insufficient use or inefficient management of fertilizers, the gap between farmers' actual and potential rice yields is of the order of 1 t/ha or more. To correct this situation better management of fertilizer nitrogen by use of slow-release materials, large-granule urea and split dressings of fertilizer N have been recommended. The INSFFER trials have shown that, during the wet season and in poorly drained soils, sulphur-coated urea and urea super-granules gave no significant gain in rice yield over prilled urea. However, Reddy and Prasad (1977) and Soundararajan and Mahapatra (1979) have reported from trials in India that use of sulphur-coated urea or neem (*Melia azadirachta*) cake coated urea proved better than prilled urea not only for rice but also for wheat grown subsequently. Rice yield was increased almost 40 percent by the use of the modified urea material and the benefit to the subsequent wheat was equivalent to about 40 kg N/ha.

Since fertilizer N in general has little residual value, each cereal crop grown in rotation has to be given enough fertilizer nitrogen to obtain optimum yield, but where modified materials are used some residual benefit may accrue. There is thus a need to evaluate the modified materials in cropping systems.

4. FERTILIZER PRACTICES IN INTERCROPPING SYSTEMS

In countries like India and Indonesia mixed cropping practices are common. In Indonesia mixing of several crops is a common practice, not only to meet the dietary needs of the farmers but also as an insurance against crop failure. A point which is often missed is the high land utilization efficiency of mixed cropping. Some legumes when grown as intercrops have the capacity to increase the productivity of the non-legumes grown in association. For example, Das and Mathur (1980) found that the yield of maize intercropped with black gram (*Vigna mungo*) was 3.69 t/ha compared to 3.13 t/ha from maize grown alone. This increase was equivalent to about 40 kg N/ha applied to the maize. Benefit from maize-black gram intercropping was also noted in the subsequent wheat crop. There is thus a need to evaluate the effect of legumes in inter and sequential cropping systems in the countries of the South East Asia region where mixed cropping practices are common and farmers are acquainted with such cropping systems.

5. USE OF BULKY ORGANIC MANURES IN CROPPING SYSTEMS

Formoli *et al.* (1977) reported from a 3 year trial (1972-1975) that there was no difference in rice yield whether farmyard manure was applied to the rice or the preceding wheat, but the wheat definitely benefitted from farmyard manure applied to the preceding rice.

6. NUTRIENTS OTHER THAN NITROGEN

The needs of rice grown as a subsistence crop in the traditional agriculture of the South East Asia region have generally been met from the soil reserves. Earlier trials with P and K showed no response to these nutrients. Recent experiments with high-yielding varieties in the INSFFER programme 1977-79 (IRRI Report 1980) have, however, shown a significant yield reponse to phosphorus up to 20 kg P_2O_5/ha in most of the experiments conducted in Bangladesh, India, Indonesia, Nepal, Philippines, Sri Lanka and Thailand.

The response to P depends not only on the soil P status but also on parameters such as the nature of the crop and climatic conditions. In experiments in India on the apportionment of phosphorus fertilizer to different crops grown in sequence, it has been found more remunerative to apply P to a winter season crop like wheat; the residual P in the soil is then able to meet the needs of the following hot season crop such as maize (Raheja *et al.* 1975, Goswami and Singh 1976; Meelu and Rekhi 1981). Similar results were reported by Srivastava and Pathak (1976), who found that total response to P in a chickpea-rice rotation was higher when the P was applied to the chickpea crop.

Formoli *et al.* (1977) and Chatterjee *et al.* (1978) reported that the effect of P given to rice in superphosphate-treated farmyard manure persisted even up to the third subsequent crop (rice after potato and maize or wheat).

Goswami *et al.* (1976), reviewing the results of more than 1000 experiments on cultivators' fields in India 1968-74, concluded that in a rice-wheat cropping sequence the rice benefitted more than wheat from applied K. Since K removal by rice is 37 percent more than that of N (Roy and Kanwar 1979), it is advisable to apply potassium to rice in a cropping sequence, the amount being based on soil K content; 75 ppm available K is the critical limit below which K fertilization of rice is indicated (Subba Rao *et al.* 1976).

Among the various micronutrients, zinc deficiency has been reported to be widespread in India (Takkar and Randhawa 1978). A significant response to zinc sulphate application up to 20 kg $ZnSO_4$/ha has been reported on a recently reclaimed saline soil (Tiwari and Pathak 1976). Rice responded to zinc application when the available zinc in the soil was equal to or less than 0.85 ppm, but wheat did not respond even when the available zinc was below 0.58 ppm. In zinc responsive soils, therefore, it is recommended to apply this micronutrient to the rice in a rice-wheat cropping sequence.

7. CONCLUSIONS

Crop productivity is low in most countries of the South East Asia region. Fertilizers can play a significant role in increasing their productivity. However, their cost and relative unavailability when needed act as deterents to their use by peasant farmers. Fertilizer use efficiency is also low and research efforts to increase efficiency need to be strengthened. The fertilizer needs of cropping sequences need to be evaluated rather than those of a particular crop. The need is all the more important in South East Asia where farming standards have yet to reach optimum levels. Green manuring practices or preceding grain/fodder legumes can provide a crop with initial nitrogen; top-dressing a small quantity of nitrogen can meet subsequent needs. Similarly, legumes in intercropping or mixed cropping systems can not only give advantage to the non-legumes growing in association but also prevent soil erosion losses in young coconut, rubber or oil palm plantations in the equatorial regions of South East Asia. Additionally, the legumes can give monetary returns to small farmers until the plantation crops come of age.

Increased cropping intensity would obviously need a balancing of fertilizer nutrients and put greater demand on phosphorus and potassium as well as on secondary and micronutrients. There is a need to evaluate the phases of cropping systems which will make the best use of these other nutrients. Identification of the crops in a given cropping sequence which most need fertilization with P, K or micronutrients would help the peasant farmer to reduce his input costs.

In order to evaluate the fertilizer use needs of cropping systems, it is recommended that a "Network" concept of testing fertilizers in cropping systems be developed in the South East Asia region. The emphasis should be on conducting trials on farmers' fields, keeping local needs in view as also the nature of soil and climatic conditions.

Paper 4 FERTILIZER USE IN MULTIPLE CROPPING SYSTEMS IN NIGERIA, TANZANIA AND SENEGAL

B.T. Kang[1]

1. INTRODUCTION

Multiple cropping, defined as the growing of two or more crops on the same field in a year (Andrews and Kassam 1976), includes intercropping (growing two or more crops simultaneously) and sequential cropping (growing two or more crops in sequence). Multiple cropping is an old widespread practice of tropical subsistence farming, especially under rainfed upland conditions. Even so, it is only during the last two decades that serious research efforts have been made to evaluate better the merits of multiple cropping, particularly intercropping, in tropical Africa (Okigbo and Greenland 1976). Many studies have shown numerous advantages of intercropping systems including: higher combined yields, higher yield stability from season to season, better spread of production over the growth period, improved quality of products, reduced adverse effects of pests, higher returns, and better soil protection against erosion (Andrews 1972; Baker 1979; Norman 1972; Okigbo 1979; Willey and Osiru 1972). Emphasis has been placed on evaluating geometric and time arrangements and varietal suitability in intercropping systems (Okigbo and Greenland 1976).

Multiple cropping in tropical Africa is widely practised on land managed under the traditional fallow-crop production rotation system. Soil fertility is regenerated during the fallow period and is relatively "high" immediately after land clearance but declines during the cultivation period. Farmers tend to adapt by planting the most demanding crops (mainly cereals) during the early part of the cropping cycle and following them with less nutrient-demanding root and tuber and leguminous crops (e.g. cassava and cowpeas). The less nutrient-demanding species are frequently also relay intercropped into the high nutrient--demanding species.

Multiple cropping in the humid and sub-humid regions of tropical Africa is also exercised widely on the low activity clay soils, consisting mainly of Alfisols, Ultisols and to a limited extent also Oxisols. These soils, which are characterized by low CEC, are relatively infertile; the Ultisols and Oxisols also have acidity and Al-toxicity problems. In a recent review, Kang and Juo (1981) reported that N and P (and, with continuous cropping, also K) are commonly deficient, while S and Zn are frequently deficient in the sub-humid region.

Although the same basic principles apply as for sole cropping, fertilization practices to ensure adequate nutrient supply are perhaps more rigorous with mixed cropping (Oelsligle *et al.* 1976). The problem of fertilization becomes more important when shorter fallow cycles and longer cropping periods are introduced into traditional systems. Several approaches have been used. Del

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Valle (Oelsligle *et al.* 1976) found that "critical" soil P and K levels established for sole crops of maize and *Phaseolus* bean also applied when these were intercropped. Others (Bradfield 1970; IRRI 1972) determined recommended fertilizer rates by summing the estimated requirements for each crop; though technically sound, this may not be the most efficient method. It is important, particularly when developing fertilizer practices for multiple cropping systems for marginal farmers, that the economics of such practices also be considered simultaneously with their biological potential (Oelsligle *et al.* 1976).

Despite its importance for sustained crop production in tropical Africa, only limited information is available on fertilizer use in multiple cropping systems in the region, as is illustrated below with research results from Nigeria, Tanzania and Senegal.

2. FERTILIZER USE IN MULTIPLE CROPPING: NIGERIA

2.1 Intercropping

Mixed intercropping (growing two or more crops simultaneously with no distinct row arrangement) and relay intercropping (growing two or more crops simultaneously during part of the life cycle of each) as defined by Andrews and Kassam (1976) are the most popular mixed cropping systems in Nigeria. Though a large number of species may be encountered, there are usually two or three major crops that are dominant components (Agboola 1979): in the sub-humid northern region, sorghum, millet, groundnuts and cotton; in the southern perhumid and humid region, root and tuber crops (cassava, yam, cocoyam), plantain and rice, with speciality tree crops scatter-planted in the field; in the middle belt, which is often designated as the mixed grain (millet and sorghum) belt, root crops and maize (Agboola 1979; Norman 1976; Okigbo and Greenland 1976). However, only a limited number of fertilizer trials have been carried out.

2.1.1 Cereal-legume cropping

Palmer (1971) reviewed the results of mixed cropping trials in northern Nigeria, 1924-71, and observed that:

i. Results of maize-groundnut mixed cropping at Mokwa, without and with N applied to maize only showed that groundnut yield was reduced by intercropping. There was no evidence that maize in the absence of N application benefitted from intercropping with groundnuts.

ii. In a mixed cropping trial with sorghum and groundnuts in the proportion 1:3, application of N and P increased only the sorghum grain yield, with no effect on groundnut yield. With higher proportionate sorghum population, the increase in sorghum yield due to fertilizer was accompanied by a decrease in groundnut yield, probably as a result of increased shading.

iii. Another sorghum-groundnut mixed cropping trial showed that N applied to sorghum increased the grain yield of intercropped sorghum, with no measurable effect on groundnut yield.

In mixed cropping trials of maize with *Calopogonium* cowpea and green gram for four growing seasons, Agboola and Fayemi (1971) observed that: (i) maize interplanted with legumes did not respond to application of 56 kg N/ha; (ii) maize yield was high in both fertilized and unfertilized plots interplanted with legumes; (iii) yields were lower from plots with neither legume nor fertilizer; and (iv) intercropping with maize reduced legume yield. Agboola and Fayemi (1972) also reported that cowpea and *Calopogonium* interplanted with maize did not benefit early-season maize (Table 1) but as a green manure they were an important N source for late-season maize (Table 2). On the other hand, green gram interplanted with maize increased the yield of early-season maize, but contributed little to late-season maize.

Table 1 YIELD OF EARLY SEASON MAIZE AS AFFECTED BY INTERPLANTED LEGUMES AND FOUR LEVELS OF N (Agboola and Fayemi 1972)

Fertilizer kg N/ha	Maize yield (shelled corn, kg/ha) Interplanted legume			
	None	Cowpea	Green gram	Calopo
None	1 790c[1]	1 850bc	3 080a	1 850bc
45	3 080a	2 750ab	3 070a	3 050a
90	3 420a	2 750ab	2 750ab	3 070a
135	2 580b	2 920ab	1 960bc	2 920ab

[1] Numbers followed by the same letter are not significantly different (P = 0.5)

Table 2 YIELD OF LATE-SEASON MAIZE AS AFFECTED BY LEGUMES INTERPLANTED WITH EARLY-SEASON MAIZE RECEIVING FOUR LEVELS OF N (Agboola and Fayemi 1972)

Fertilizer N applied to early-season crop kg N/ha	Maize yield (shelled corn, kg/ha) Legume interplanted with early crop			
	None	Cowpea	Green gram	Calopo
None	1 210c[1]	1 970bc	1 510c	2 120bc
45	2 720ab	2 880ab	2 570ab	2 720ab
90	2 880ab	2 990ab	2 880ab	2 480a
135	2 570ab	2 420bc	2 720ab	2 990ab

[1] Numbers followed by the same letter are not significantly different (P = .05)

Results of a maize-cowpea mixed cropping trial on N-deficient Entisol (Kang, unpublished) showed significant N responses of sole crops of maize and semi-erect cowpea (Figure 1); row intercropping only slightly affected maize grain yield but cowpea seed yields were significantly decreased, particularly at high N rates. There was however an increase in LER with intercropping.

Adetiloye (1980) studied the effect of plant population, varieties, N rates and planting season on performance of intercropped maize and cowpeas. Yields of both semi-erect (cv. VITA 1) and semi-prostrate (cv. VITA 5) cowpea cultivars were reduced by associated maize, possibly due to increased shading with increasing maize population and N application during the late season. However, during the early season, the effect depended on variety and location. In the early cropping with adequate rainfall cowpea cv. VITA 1 was able to escape maize dominance by changing from semi-erect to climbing type and compete well with the maize crop; this also resulted in lower maize yield when intercropped with cv. VITA 1 than CV. VITA 5 (Figure 2). Grain yield of intercrop maize was significantly reduced in the absence of applied N. Higher cash returns were obtained at the highest maize plant population in both late- and early-season crops.

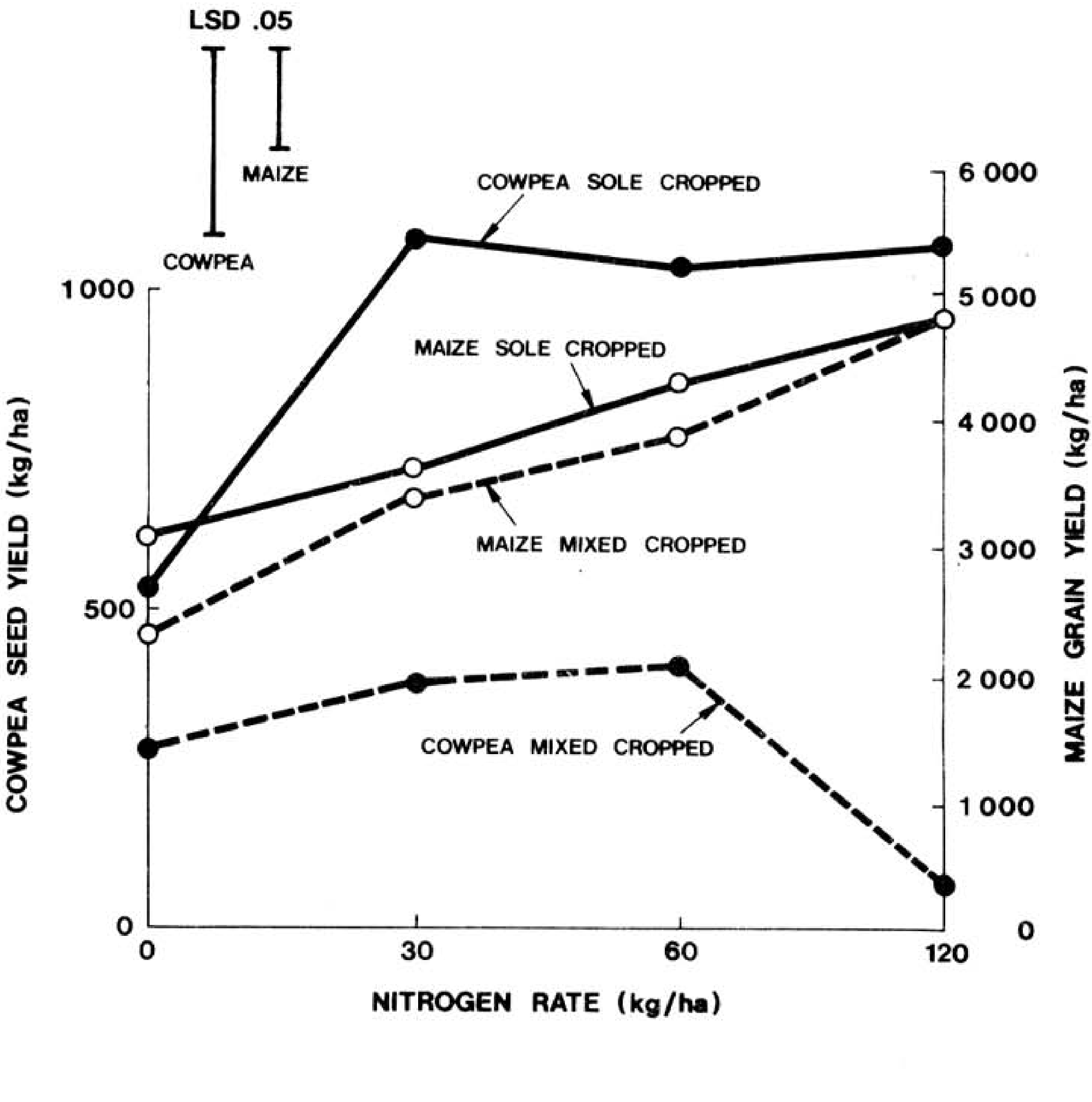

Fig. 1 Effect of N rates on seed yields of sole and intercropped maize and cowpeas grown on N-deficient Entisol (Kang, unpublished)

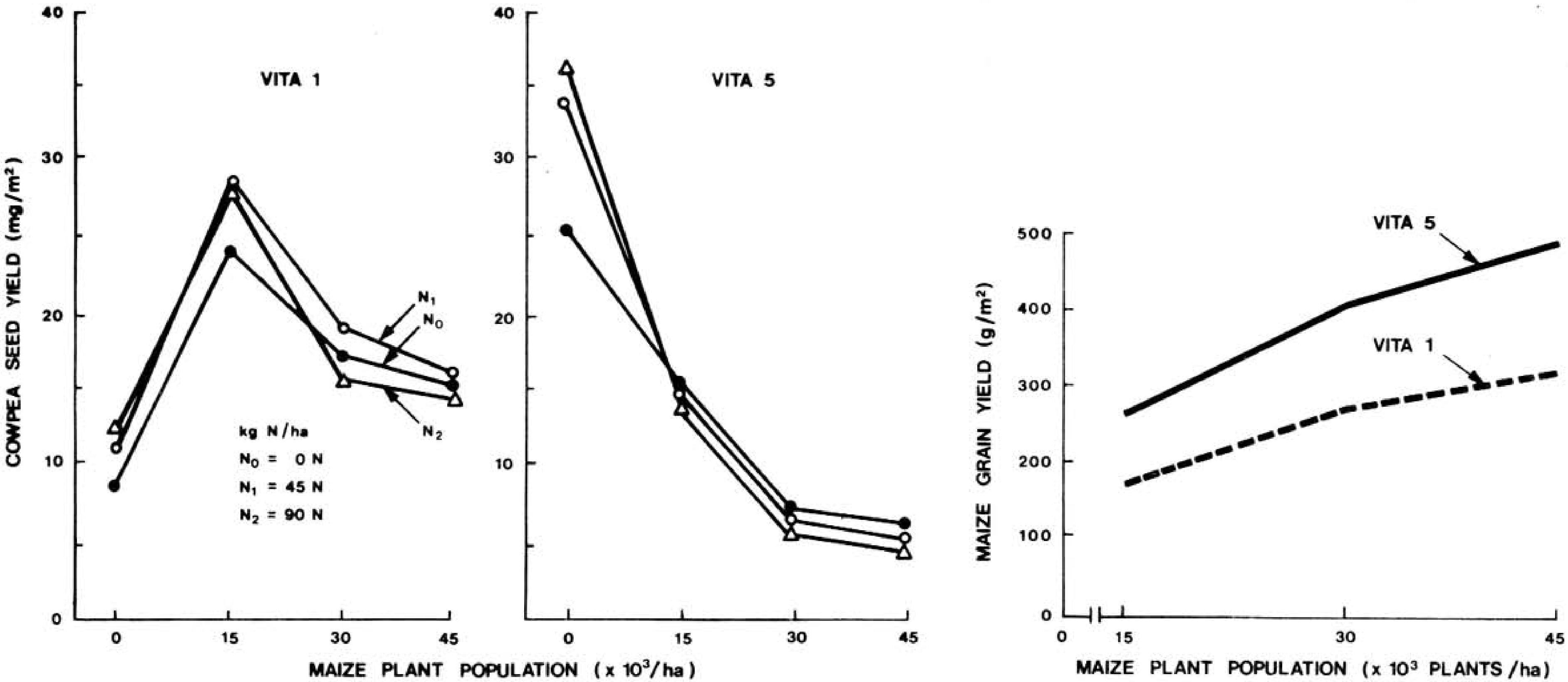

Fig. 2 Effect of N rates and maize plant population on yields of intercropped cowpea cultivars VITA 1 and VITA 5 and maize grown in the first season at Ikenne (Adetiloye 1980)

Remison (1978) studied the interactions of maize and cowpea at various levels of N and P. The competitive relationship between maize and cowpea in the proportion 1:1 was unchanged by N or P application. Cowpea grown alone or in association was unaffected by fertilizer application; maize responded to N and P when grown alone, but responded to P alone when grown with cowpea. The high yield of maize grown in association with cowpea was interesting.

In N-uptake studies of intercropped maize and cowpeas, Eaglesham *et al.* (1981) observed that at low N level, the N content of intercropped maize was higher than that of sole maize, indicating some transfer of fixed N from cowpea to maize (Table 3).

Table 3 NITROGEN ACCUMULATED BY SOLE-CROPPED AND INTERCROP COWPEAS AND MAIZE (Eaglesham et al. 1981)

Treatment		N-content (mg N/plant) Cowpea	Maize
0 N	Sole crop	1 535	469
	Intercrop	1 195^{NS}	915*
25 N	Sole crop	1 346	426
	Intercrop	1 223^{NS}	782*
100 N	Sole crop	1 095^{NS}	810
	Intercrop	924	989^{NS}

NS = not significant * = P (0.05)

When maize is intercropped with leguminous cover crops, legumes such as *Psophocarpus palustris*, *Centrosema pubescens* and wild groundnut (*Arachis repens*) have been shown to contribute significantly to N nutrition of the maize crop. Intercropped maize responded to fertilizer N only up to 60 kg N/ha while sole maize responded up to 120 kg N/ha (Akobundu 1980).

Kang *et al.* (1981) studied the effect of intercropping maize in established rows of *Leucaena leucocephala* in alley cropping. In this system *Leucaena* prunings provide a substantial amount of N which benefits the intercrop. The N fertilizer requirement is reduced, and the system provides an alternative method for obtaining sustained yield with low inputs.

2.1.2 Cereal-cereal intercropping

Intercropping millet with other cereals is widely practised in traditional farming. Pearl millet is highly competitive and can readily dominate other crops grown in association. Kassam and Stockinger (1973) measured N uptake in a millet-sorghum mixture and found that the millet utilized 80 percent of the total N removed, leaving only 20 percent for the sorghum. Sorghum in mixture is also more efficient in utilizing available N; it produced 34 kg grain/kg N taken up in mixed cropping compared with 20 kg grain/kg N in sole cropping, while millet produced 14 kg grain/kg N. The mixed crop removed a total of 152 kg n/ha, more than the 132 kg N/ha applied at sowing, indicating the high foraging efficiency of this mixture for N.

2.1.3 Cereal-root crop intercropping

Intercropping of cereals with root crops is common in the middle and southern regions. A maize-cassava mixture is widely used and is highly adaptable and compatible (Wilson and Agboola 1979). On N-deficient soil, maize which has a higher N requirement responded more to applied N than associated cassava. On highly fertile soil, N application did not affect maize yield but lowered cassava tuber yield (Kang and Wilson 1980).

2.1.4 Traditional mixed cropping

The effect of fertilizer use in traditional mixed cropping was studied in the Funtua agricultural development project, 1976-80 (Daplyn 1981). Only maize, sorghum and groundnuts gave low but positive fertilizer reponses. Maize, which is a newly introduced crop in the area, showed a distinct yield increase with fertilizer application after 1978/79, which coincides with an upsurge in interest in improved varieties and monocropping.

2.2 Sequential Cropping

Under rainfed upland conditions, sequential cropping is only feasible in the southern region, where it has been found that a higher maize yield can be realized with a maize-cowpea than a maize-soybean system, particularly without N application. The maize-maize system gave the lowest yield (Table 4).

Table 4 EFFECT OF N-RATES AND ROTATION ON GRAIN YIELD OF MAIZE VARIETY TZPB GROWN ON EGBEDA SOIL (OXIC PALEUSTALF) (Kang, unpublished)

Treatment N-rate kg N/ha	Maize-Maize FS*	SS**	Total	Maize-Soybean FS	SS	Total	Maize-Cowpea FS	SS	Total
					kg/ha				
0	812	826	1 638	1 045	1 222	2 267	1 732	1 046	2 778
45	2 556	1 947	4 503	3 015	2 710	5 725	3 044	2 127	5 171
90	3 289	2 648	5 937	3 427	2 448	5 875	3 351	2 318	5 669
Mean	2 219	1 807		2 496	2 126		2 709	1 830	
LSD .05	Between rotation means: FS = 348; SS = 280 Between fertilizer means within rotation: FS = 489; SS = 385 Between fertilizer means between rotation: FS = 528; SS = 421								

* FS = First season maize grain yield following previous year second season maize, soybean or cowpea crops

** SS = Second season maize grain yield following first season maize, soybean or cowpea crops

3. FERTILIZER USE IN MULTIPLE CROPPING: TANZANIA

Multiple cropping is also widely practised in Tanzania with tree crops, cereal, leguminous, root and tuber crops and bananas (Okigbo and Greenland 1976). Several fertilizer trials have been conducted at Morogoro, to test the effect of N and P applications in maize-grain legume intercroppings. Finlay (1975) found that, in maize-soybean intercropping, the maize grain yield increased with N and P applications while the yield of soybeans did not (Figure 3). Maize grain yield was also increased by soybean inoculation. Intercropping depressed soybean yield. Mongi *et. al.*(1976) observed that P application increased yield of sole and intercropped maize in maize-cowpea mixed cropping, but depressed that of intercropped cowpeas (Table 5). Maize yield was highest and that of cowpeas lowest with relay intercropping. Alternate row intercropping gave the highest monetary return of 44 percent over that of sole cropped maize. Mongi *et al.* (1980) later showed that the N level, but not P or K, of maize ear leaves was significantly increased by intercropping in the same hole with cowpea.

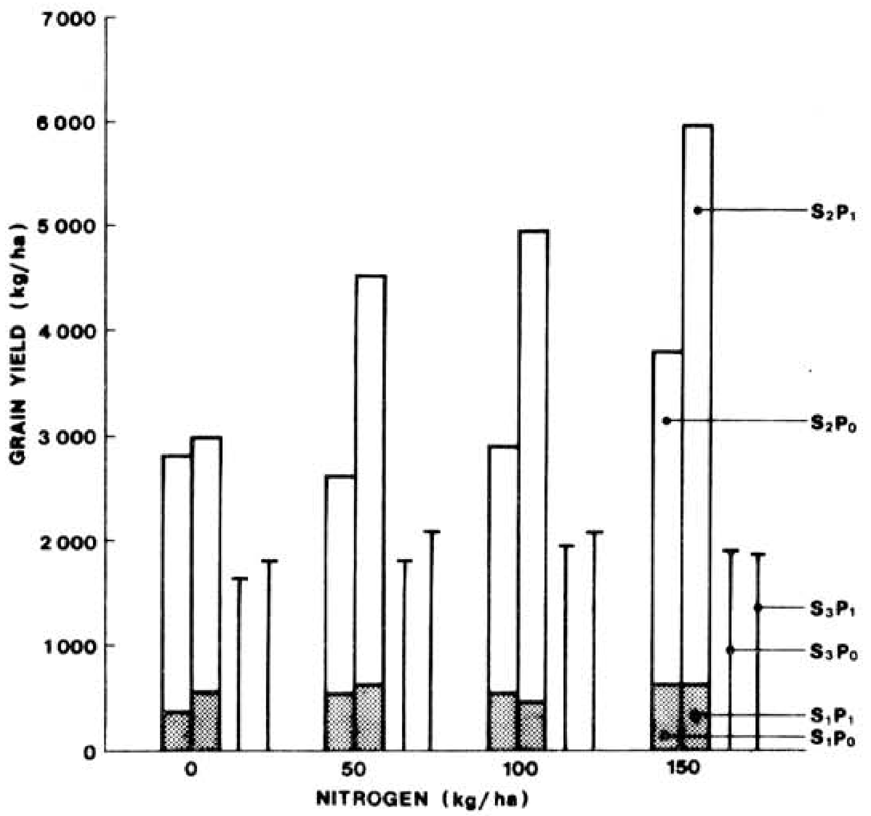

Fig. 3 Mean grain yield of soybean intercrop (S_1), soybean + maize intercrop (S_2) and soybean monoculture (S_3) without phosphate (P) and with phosphate added (P_1) at four levels of nitrogen (Finlay 1975)

4. FERTILIZER USE IN MULTIPLE CROPPING: SENEGAL

Because of limited moisture availability (N'Diaye 1980; Leroux 1980), multiple cropping is not commonly practised. Groundnuts and cotton are the dominant cash

Table 5 EFFECT OF INTERCROPPING METHODS AND P-RATES ON SEED YIELDS OF MAIZE AND COWPEA (Mongi et al. 1976)

	P-rate (kg/ha) 0		30		60	
	Maize	Cowpea	Maize	Cowpea	Maize	Cowpea
			yield (kg/ha)			
Monocrop maize	3 390	-	4 025	-	4 275	-
Alternate row intercrop	3 762	217	4 015	186	4 200	175
Relay intercrop	3 755	15	4 132	15	4 545	20
Same hill intercrop	3 807	182	3 832	171	4 112	136
LSD .05 for P-rates	Maize 487; Cowpea					

crops. The principal cereals (millet, sorghum, rice and maize) are mainly grown in sole cropping following a distinct rotation pattern depending on the region (Pelisseur 1980). Mixed cropping of millet, sorghum, maize, Casava and groundnuts, however, is practised in the southern higher rainfall region of the Casamance, particularly around compounds (Toure and Pocktier, personal communications). Cowpea is virtually the only crop, grown in mixed, particularly relay, cropping with millet in the north and west central regions; it is relay-cropped 1:1½ months before harvesting (*souna*) millet (Dancette 1981; Pelisseur 1980). Investigations at Louga and Bambey showed that relay cropping millet and cowpea gave higher combined yields and returns (Dancette 1981; Galiba 1980; Miandje 1979).

Fertilizers are mainly used on cash crops (Pieri 1972), but none are currently used on traditional food crops such as millet and cowpea. At Louga, Dancette (1981) showed that N application increased grain and straw yields of sole and mixed crop millet, but had no effect on cowpea yield (Table 6).

Table 6 EFFECT OF NITROGEN APPLICATION ON SEED AND STRAW YIELD OF SOLE AND MIXED CROPPED MILLET AND COWPEA AT LOUGA, SENEGAL 1978-1980 (Dancette 1981)

Treatment	Seed yield[1] (kg/ha)	Straw yield[1]
Sole millet ON	1 280	6 526[2]
Sole millet +N	1 633	9 633[2]
Sole cowpea ON	1 645	2 171
Mixed cropped millet ON	916	2 926[2]
Mixed cropped millet +N	1 222	4 726[2]
Mixed cropped cowpea ON	657	1 065
Mixed cropped cowpea +N	572	1 033

[1] Total yield for three years

[2] Total yield for 1979 and 1980

5. CONCLUSIONS

Despite the great interest and significant progress made in research in recent years, most fertilizer use trials in multiple cropping systems have been carried out for one season cropping and little information is available for continuous cropping systems which will probably benefit more from fertilizer use. Moreover, available information on fertilizer use in mixed cropping systems in the region concerns only N and P despite the fact that on low-activity materials in the sub-humid regions, K, S, B and Zn are frequently deficient (Kang and Juo 1981).

Available information on fertilizer use in mixed and relay croppings of cereals and grain legumes shows that N and P applications benefit the intercrop cereals more than the associated grain legumes. At high N and P rates, there is a greater trend for depression in yield of the associated legumes. In maize-cassava intercropping, N application also benefitted the intercropped maize more than the cassava.

Maize benefitted from intercropping with *Calopogonium*, *Phaseolus aureus*, *Psophocarpus palustris*, *Centrosema pubescens* and *Arachis repens* from alley cropping with *Leucaena leucocephala*, but some controversy exists as to the direct benefit obtained from intercropping with cowpeas.

Because the efficiency of fertilizer use in traditional multiple cropping is low, improvement in cultural practices (better plant stand, etc.) and use of better varieties should receive higher priority than fertilizer use.

Paper 5 FERTILIZER MANAGEMENT IN MULTIPLE CROPPING SYSTEMS WITH PARTICULAR REFERENCE TO ICRISAT'S EXPERIENCE

M.S. Reddy, T.J. Rego, J.R. Burford and R.W. Willey [1]

1. INTRODUCTION

In the semi-arid tropics[2], moisture has been usually regarded as the most limiting resource for crop production. The farmers' cropping systems have been developed to minimize the risks caused by drought. However, traditional cropping systems have a low productivity and usually a low efficiency of soil moisture use. By introducing improved cultivars, the aim is to develop improved systems that would make better use of soil water, partly by extending cropping as much as possible and thus resulting in high as well as stable yields. Because even the traditional varieties, with their lower yield potential, are often grown under conditions of marginal nutrient sufficiency (e.g. in India, for N, P and Zn), the introduction of improved cultivars usually results in a considerably increased requirement for fertilizer. However, the characterization of fertilizer requirements of various crop-soil combinations is still not complete for monoculture in dryland SAT India. Much less is known about fertilizer requirements of the improved cropping systems that are currently being developed. The present paper is based on research at ICRISAT Centre, Patancheru (25 km northeast of Hyderabad), particularly on systems for deep Vertisols and Alfisols under a relatively assured rainfall in the rainy season.

2. SOIL MOISTURE

The main types of cropping systems can be simply related to the length of growing season, varying in the dryland agriculture of SAT India, from as short as 9 ± 3 weeks on a relatively shallow and light-textured soil under low rainfall (e.g. Alfisol at Anantapur, A.P.) to as long as 24 ± 3 weeks for deep heavy-textured soils under an assured rainfall (e.g. deep Vertisol at Indore, M.P.). For the shortest growing season, cropping is limited mainly to a single season crop, with intercropping available to extend the cropping season in the event of late rains. With a longer growing season, one may consider the use of longer duration cultivars, or perhaps the use of very short duration crops to allow two sequential crops. With the longest growing season, one may expect to grow two sequential crops; but, where soil moisture restricts the choices for the second crop, the chances of establishment may be improved by relay planting the second crop 2-3 weeks before the first crop is harvested; or, if sorghum is the first crop, one may attempt to rely on its ratooning to provide one component of the second crop.

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[2] Abbreviated henceforth to SAT.

The difference between the water holding capacity of deep Vertisols (WHC up to 250 mm) and Alfisols (110-150 mm) at ICRISAT is the main factor responsible for the large difference in the length of growing season (12-24 weeks). Additionally, crops on the Vertisols will be less prone to mid-season moisture stress.

The reliability of rainfall in the rainy season is another important determinant. Thus, the deep Vertisols can be divided agroclimatically into two separate zones: the zone in which the rainfall is insufficiently reliable to attempt a rainy season crop, and the zone in which a rainy season crop is feasible.

3. CROPPING SYSTEMS FOR DEEP VERTISOLS

Farmers who use the traditional system on the deep Vertisols in India bare-fallow the land during the rainy season; a crop is then grown during the post-rainy season on the residual soil moisture. This is a logical development for areas of undependable rainfall. In the more dependable rainfall areas, the reason for bare-fallowing during the rainy season is not lack of moisture *per se*; it is that crop management can be particularly difficult at that time. These heavy soils are poorly drained and likely to be waterlogged; they are extremely sticky when wet, so cultivation, sowing and weed control may be difficult. In these latter areas, growing only a post-rainy season crop represents an under-utilization of the potential cropping period; moreover, bare-fallow during the rainy season leaves the land subject to runoff and soil erosion (Kampen 1979). Cultural techniques to facilitate double cropping have been developed; major elements are the use of a graded bed and furrow system to create good drainage and improved soil workability, and the seeding of crops in a dry seedbed just before the arrival of rains (Krantz *et al.* 1978).

4. DOUBLE CROPPING OF DEEP VERTISOLS

At ICRISAT initial studies showed that a productive rainy season crop of sorghum or maize could be easily grown. Pigeonpea and sorghum grown as post-rainy season crops benefitted from early planting; to achieve this, relay planting was necessary when a crop was grown in the rainy season. However, relay planting is difficult on a field scale, particularly after sorghum or maize. Nevertheless sequential instead of relay planting reduced yields by 22 percent for pigeonpea and 9 percent for sorghum. In contrast, the delay in planting was beneficial for chickpea and safflower, these crops preferring cooler temperatures.

Use of maize as the rainy season crop caused no reduction in the subsequent relay sorghum crop, and only small reductions in relay pigeonpea or sequential chickpea, when compared to fallow in experiments performed over 3 years. For these particular systems, maize therefore provides an additional crop with little or no yield loss of the traditional post-rainy season crop. In practice, however, it may not be feasible to grow sorghum and pigeonpea as relay crops, despite the potential yield advantage.

Use of sorghum as the rainy season crop, instead of fallow, caused quite marked average yield reductions for the same three-year period: 31 percent for relay sorghum (40 percent for sequential), 28 percent for pigeonpea (46 percent for sequential), or 36 percent for sequential chickpea. These were mainly due to the large reduction in the 1977-78 season; in this year of below-normal rainfall, all crops following sorghum showed marked suppression of growth from establishment onwards and were easily distinguishable from those following maize or fallow. This depression in yield after sorghum is obviously the phytotoxic effect of the kind that has been widely reported in India and elsewhere (Nambiar 1942; Guenzi *et al.* 1967). No such effect was visually apparent in the two subsequent "normal rainfall" years, although yields of post-rainy season crops were slightly lower after sorghum than after maize. The lower yield could not be ascribed to any single cause; release of growth-inhibitors during decomposition of sorghum roots is suggested as one cause but depletion of moisture and nutrients, and locking up of nitrogen during the microbial decomposition of the high C:N stubbles probably also contribute.

In small plot experiments to evaluate the most remunerative cropping systems for these soils, systems that involved crops in both the rainy and post-rainy seasons gave much higher returns than the traditional single season cropping. Sequential and relay systems containing maize or sorghum compared favourably with the respective cereal/pigeonpea intercropping in a normal year (1979); but the average of two years' returns from double-cropping systems were lower than those from intercropping because the post-rainy season crops could not be established in the subsequent dry year (1980). Of the two intercrop systems (cereal/pigeonpea), that based on sorghum gave the higher returns because of a better price for sorghum grain.

Planting of chickpea after maize in a maize/pigeonpea intercrop gave an additional pulse yield of 528 kg/ha (36 percent of sole crop) without causing any yield reduction in pigeonpea. This 3-component cropping system gave the highest returns of all the systems explored in 1979. Chickpea failed to establish in 1980 because of early cessation of the rains, so the returns were lower than those of maize/pigeonpea due to the additional costs incurred on chickpea seed and planting. The possibility for a third crop in the space vacated by the early maturing intercrop should be considered only in good years for full use of the moisture and for extra income.

Sequential mung-sorghum did not appear to be very attractive because of the low yields of mung. However, this system does provide an option where moisture is not sufficient for two full season crops. Ratooning of rainy season sorghum gave a yield equivalent to 50 percent of the first season crop in 1979, but failed completely in 1980 because of shootfly attack and moisture stress.

To further evaluate the systems shown to be promising in small plot experiments, comparisons have been made of the maize/pigeonpea intercrop and maize/chickpea sequential systems in operational scale tests. The value of improved genotypes and high inputs were also tested. Average yields over four years from the improved systems were substantially higher than from the traditional system using local cultivars and local management practices. Intercropping gave only slightly less maize than the sequential system but produced a much greater pulse yield. The gross profit from intercropping was a little higher (19 percent) than that from the sequential system, but much higher

(638 percent) than that from the traditional system. For an extra annual cost of about Rs 1200/ha the intercrop earned an additional profit of about Rs 3100/ha, which represents about 250 percent return on expenditure (Ryan and Sarin 1981).

Intercropping appears to offer more promise for double cropping than sequential crops. In intercropping, both crops are planted at the same time; this avoids the risks associated with establishing the second crop at the end of the rainy season, which may be difficult in years of early cessation of rains because the surface soil dries quickly. Additionally, the farmer at this time of the year may be generally faced with shortage of labour and time, because of the need to harvest rainy season crops.

5. CROPPING SYSTEMS FOR ALFISOLS

The number of cropping system options available for Alfisols is restricted by the length of the growing season. The much lower water holding capacity of these soils very much restricts the crop growth that can occur when the rains cease. Crops are therefore grown only during the rainy season. Sorghum, groundnut, *setaria* and *ragi* are grown as sole crops, or as mixtures with each other or with pigeonpea, pearl millet and castor. Cereals (pearl millet, sorghum) intercropped with low canopy legumes (groundnut, green gram, cowpea) are the commonest systems, the cereal for food and the legume for cash returns. Pearl millet/groundnut intercropping (1:3) illustrates the advantages in these combinations in which both crop components mature at similar times; intercrop groundnut produced 77 percent of the yield obtained from a sole crop, but millet produced a yield of 54 percent of the sole crop, which is more than double that expected (25 percent, for a 1:3 combination); in total, intercropping gave a 31 percent yield advantage over the sole crop. Sorghum/groundnut can give comparable advantages, although sorghum is more competitive and alters the yield proportion of cereal to groundnut. The choice depends both on which cereal is preferred for food, and which is better adapted to the particular environment. The scope for improving cereal yield by intercropping with another cereal (e.g. sorghum/millet) has also been explored. Although this has given an advantage as high as 40 percent in some instances, the results have varied between seasons; the average over 10 locations in two years was only 8 percent. The major advantage would appear to be in ensuring more stable food production, rather than higher yields *per se*.

On Alfisols, intercropping with long season crops such as pigeonpea or castor provides an excellent opportunity to extend cropping beyond the rainy season, and thus utilize such late rains as may occur. Studies at ICRISAT have been confined to pigeonpea as the extended crop, with sorghum, millet or groundnut as the most widely grown intercrops. Sorghum/pigeonpea intercropping produced good sorghum yields at 89 percent of sole crop yield, although pigeonpea was somewhat lower at 59 percent of sole crop yield; the 48 percent advantage thus obtained represents a genuine intercrop benefit, in as much as the farmer on these soils does not have alternative means of using the residual moisture after the sorghum harvest. In normal farming practice, groundnut is grown with pigeonpea in much more varied proportions than the cereal intercrop; quite often, many rows of groundnut are planted with only an occasional row of pigeonpea, but such a practice results in a loss of productivity. In ICRISAT studies, pigeonpea was grown in rows 135 cm apart, with five very closely spaced (22.5 cm) rows of groundnut between; at 7 locations over three years, yields of groundnut averaged 76 percent and pigeonpea 89 percent of sole crop; in total, there was an advantage of 65 percent over sole cropping.

In small plots studies on Alfisols over three years, sole crops of castor and pigeonpea gave good net financial returns in all years, although groundnut and sorghum gave much higher returns in the third year because of high grain prices. Introduction of mungbean before castor gave higher returns in one year, when castor was relay planted; but introduction of mungbean before millet (e.g. pearl millet or *Eleusine*) did not compare well with sole millet in the rainy season. The relatively poor return from sole pearl millet could be increased by adding a sequential or relay crop of horsegram; nevertheless, the overall returns were still low. Ratooning of sorghum gave poor additional yield because of shootfly; net returns were only a little more than from sole sorghum. Pigeonpea/groundnut gave the highest returns in the two years in which it was tried. Sorghum/pigeonpea gave substantially higher returns than the respective sole crops in all years, but in two years its returns did not exceed those of pigeonpea/groundnut or of castor-based systems; millet/groundnut intercropping gave substantially higher profits than sole millet in all years than sequential or relay systems of millet in two years; but the returns were only slightly better than from sole groundnut. High net returns from intercropping systems emphasize the great value particularly for Alfisols, where the moisture available may exceed that needed by a single crop but is insufficient for a sequential or relay system based on a second 'full' season crop.

6. FERTILITY REQUIREMENTS OF IMPROVED CROPPING SYSTEMS

The soils of the SAT are known to be deficient in nutrients for some crops, and to be marginal for others under current cropping intensities; increased productivity is associated with an increased uptake of nutrients. Very few generalizations can me made concerning increased need for fertilizers because experimental data are lacking. However, some of the concepts involved can be discussed.

An improved cropping system may not require additional fertilizer if only one component needs fertilizer and there is little competition between the component crops for the nutrient concerned. An example is sorghum/pigeonpea intercropping, in which nitrogen fertilizer is applied to sorghum and not to the legume (Fig. 1); response curves for intercropped and sole cropped sorghum were sensibly similar in shape in each of three years. The response in each year was slightly lower for the intercropped sorghum; not as a result of competition from the intercrop but rather due to the changed row arrangement. The effect of season on response was marked; responses to N were large in years of average or better-than-average seasonal rainfall. Although LERs decreased with increasing input of fertilizer N, the advantage of intercropping was still particularly large at 120 kg N/ha in the two years of 'normal' or above-'normal' rainfall.

Similar principles appear to apply for phosphorus. For example, in a long-term phosphorus experiment at ICRISAT, the relative responses to applied phosphorus were sorghum ≈ millet > pigeonpea (Fig. 2). Therefore, in a

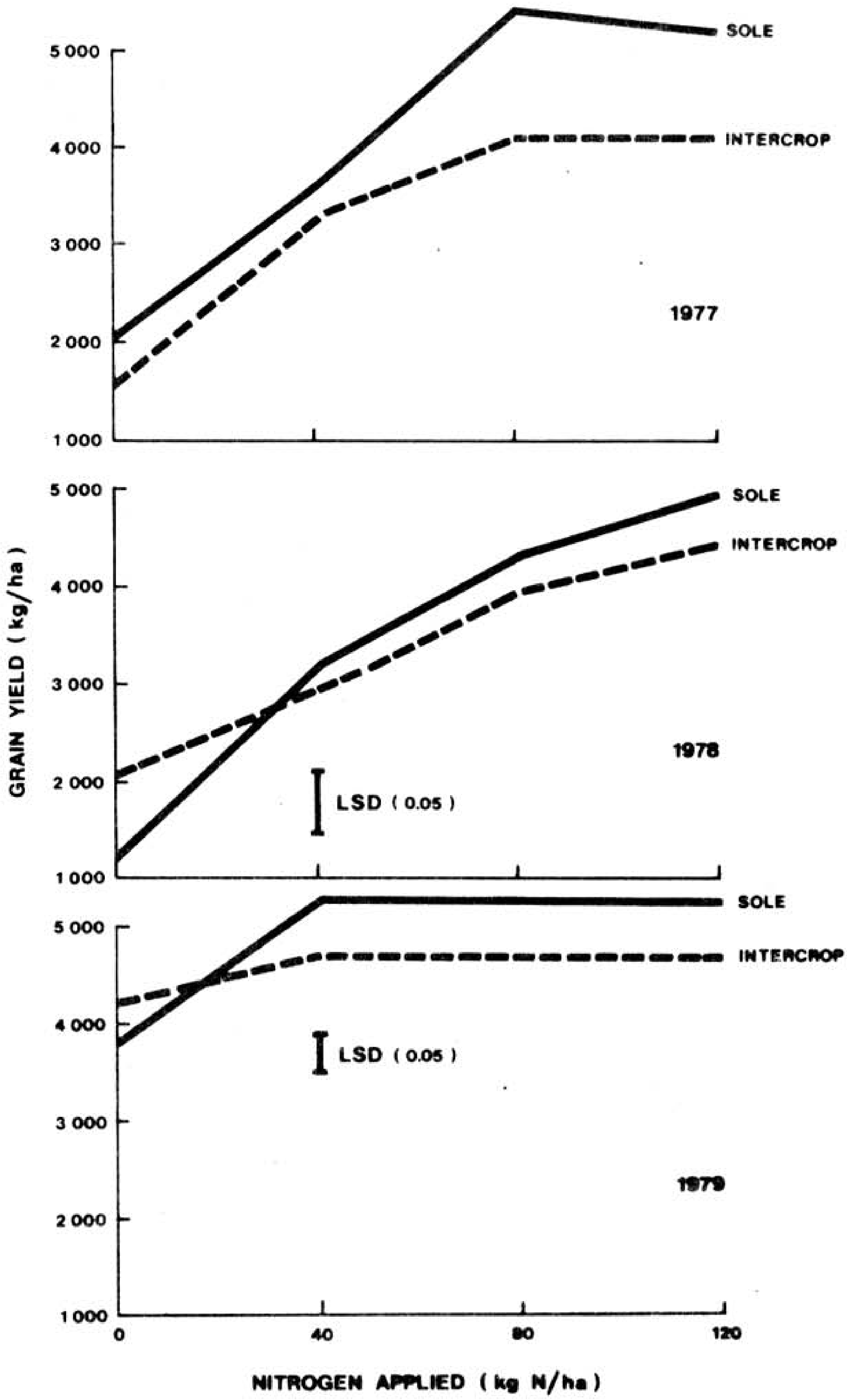

Fig. 1 Response of sole and intercropped sorghum to nitrogen - Vertisols

sequential crop of sole sorghum-sole pigeonpea, P fertilizer need be applied only to sorghum. In a cereal/pigeonpea intercrop it seems that there is a need to apply P to the millet or sorghum only. Chickpea is another crop that responds only little, if at all, to fertilizer P under dryland conditions at ICRISAT. For deep Vertisols in assured rainfall areas, replacement of the fallow post-rainy season crop of sorghum (receiving N and P) by a rainy season/post-rainy season crop sequence of sorghum or maize (receiving N and P) followed by chickpea (without fertilizer) may not result in a substantial increase in fertilizer requirement.

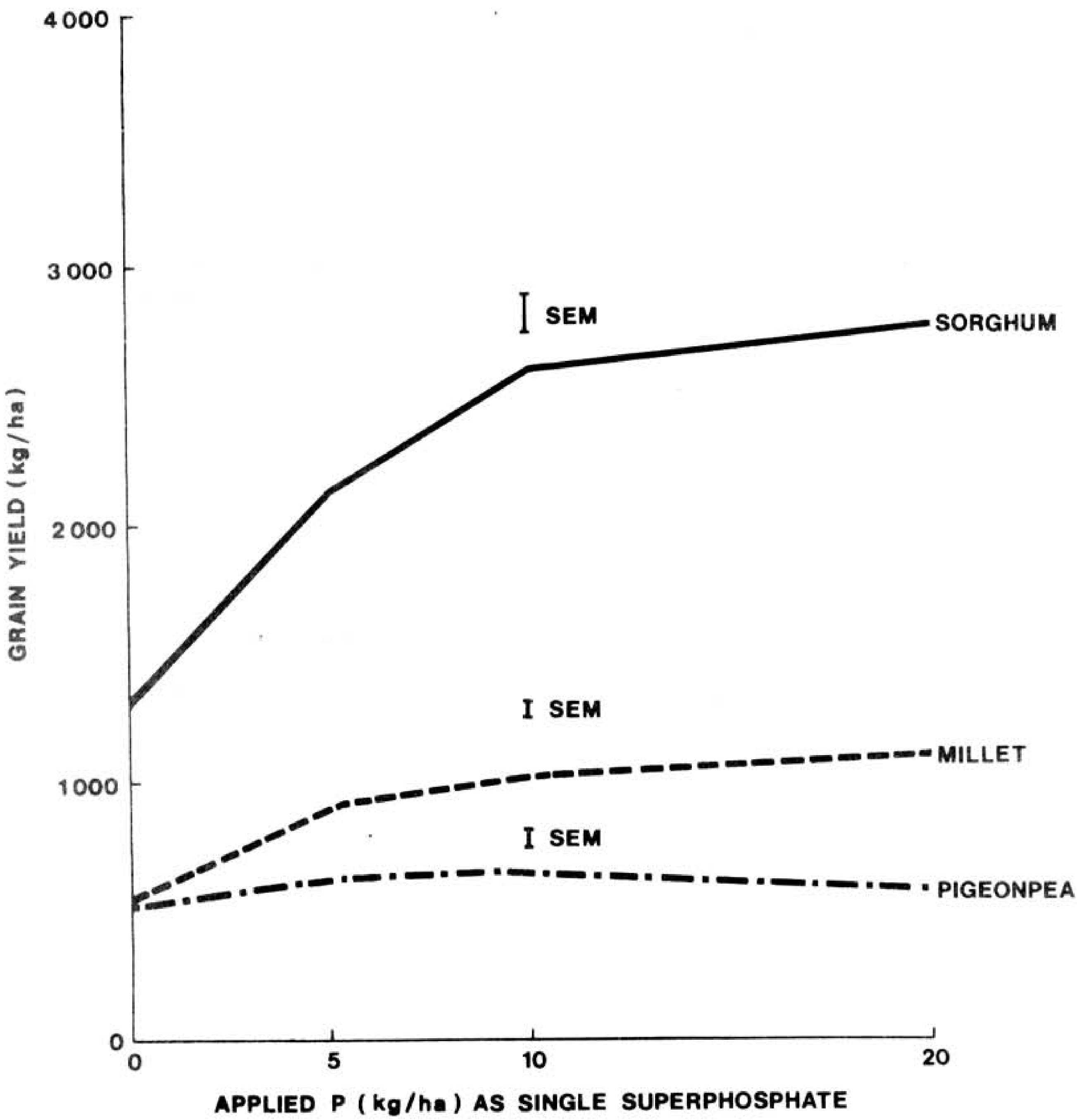

Fig. 2 Effect of applied P on the grain yield of sorghum, millet and pigeonpea (1976-79)

Where both component crops of an improved system require the same nutrient, one may expect an increased requirement for fertilizer. For example, in a cereal/legume intercrop such as millet/groundnut, the requirement for P and S may be greater than under sole cropping. Similarly, for a cereal intercrop like sorghum/millet, the N requirement may be greater. Further, if a rainy season fallow/post-rainy season cereal system is replaced by two consecutive non-legume crops, then additional nitrogen may well be required. Only preliminary data on these aspects have been obtained.

The inclusion of legumes in cropping systems offers considerable benefits because of their ability to fix nitrogen biologically. However, their contribution in SAT cropping systems is uncertain because a substantial proportion of the crop is harvested as grain; for some grain legumes, it has been suggested that there may even be a net decrease in soil nitrogen because more nitrogen may be removed as grain than is fixed by the crop.

There are two main types of mechanism postulated for the beneficial effects of legumes on other crops in a cropping system:

i. Current transfer, in which transfer of N from the legume occurs during the life of both crops.

ii. Residual effects, in which N fixed by the legume is available to an associated sequential non-legume after senescence of the legume and decomposition of its organic residues.

Although there has been only a little quantification of these effects in the dryland SAT, the residual effects of legumes are well known especially where there has not been a removal of some of the plant product (e.g. grain) and all the plant is allowed to decompose in the soil. There is very little evidence to demonstrate large contributions by direct transfer.

In experiments at ICRISAT with groundnut and cereals, there have not been any detectable increases in maize yields that could indicate direct transfer of N from groundnut to a companion maize crop. However, sole groundnut had a residual effect equivalent to a fertilizer application of 15 kg N/ha on subsequent sorghum. Residual effects on maize were detected where groundnut was grown, either sole or intercropped, but only if the maize received fertilizer. Similar experiments with a cowpea/sorghum intercrop showed that only sole cowpea produced a measurable residual effect, equivalant to 25-50 kg N/ha.

7. NUTRIENT x WATER INTERACTIONS

Nutrient x water interactions have been given little attention. In preliminary studies at ICRISAT on a millet/groundnut intercrop on an Alfisol, a combination of both N and moisture stress caused very slow initial growth of sole crops, the millet growth being poorer than that of groundnut (Fig. 3). Relieving moisture stress, but not N stress, produced a marked increase in groundnut yield but only small responses in millet. In contrast, relieving N stress, but not moisture stress, gave substantial responses in millet yield. Thus groundnut yields were limited by moisture availability, whereas millet yields were limited

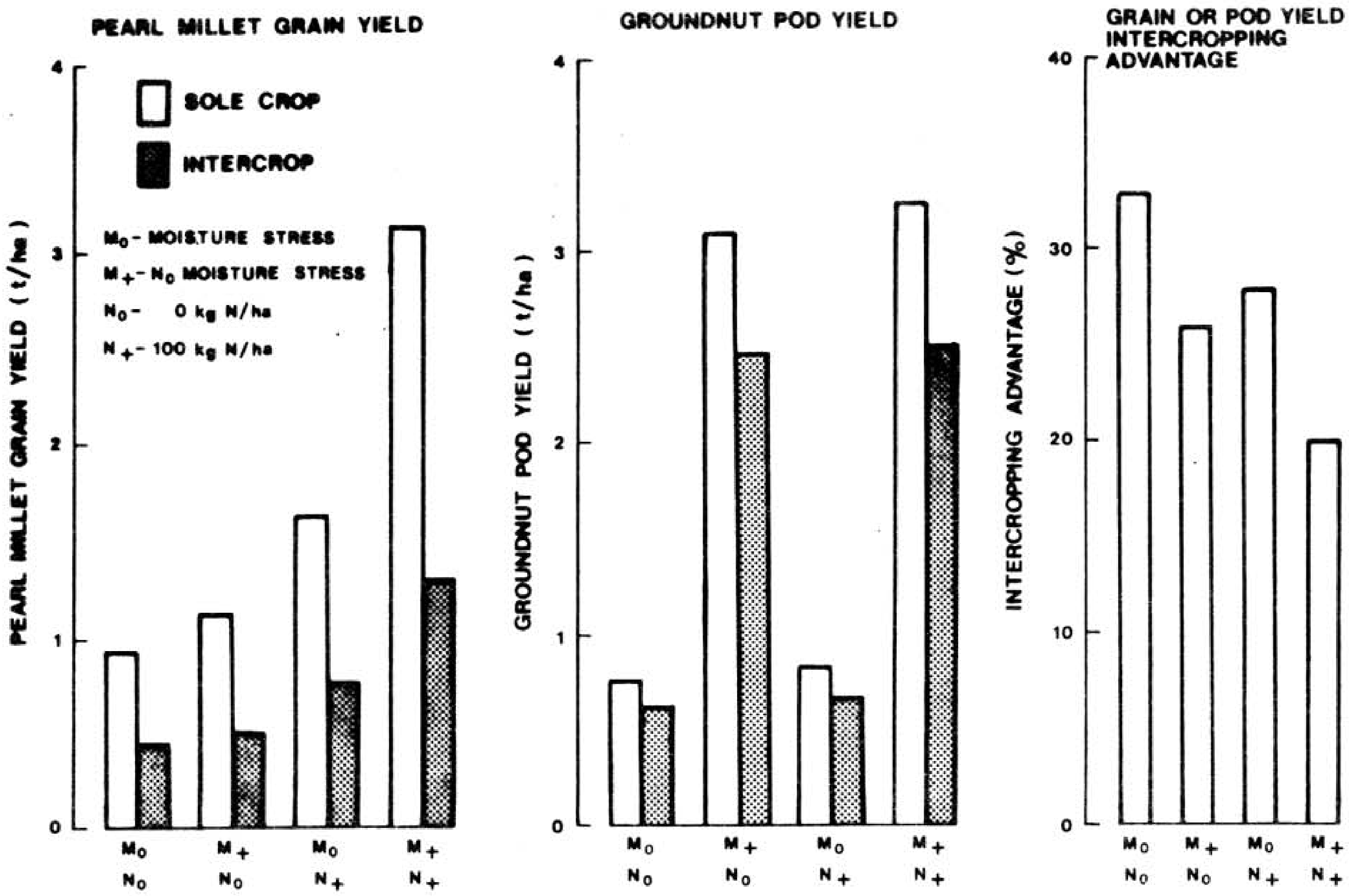

Fig. 3 Effect of moisture x nitrogen interaction on grain or pod yields and intercropping yield advantages in sole and intercrop of pearl millet/groundnut (1981 summer season)

by N availability. When both N and moisture stress were removed for the millet, there was a strong positive interaction on final yield.

Yield responses in intercrop followed a very similar pattern to the sole crops, but, rather surprisingly, the nitrogen and moisture treatments produced relatively little effect on the competitive balance between the crops. There was evidence of decreasing intercropping advantages with decrease in stress; with both N and moisture stress the advantage was maximum i.e. 33 percent, but this advantage decreased to 26 percent with only N stress, 28 percent with only moisture stress, and 20 percent with no stress for either factor.

Paper 6 DYNAMICS OF SOIL NUTRIENTS IN MULTIPLE CROPPING SYSTEMS IN RELATION TO EFFICIENT USE OF FERTILIZERS

R.E. McCollum [1]

1. INTRODUCTION

Nutrient dynamics in multicrop systems cannot be rationally approached without due consideration to growth (and yield) dynamics of the system itself. Multiple cropping usually involves several crop species with differing product forms as well as differing durations of their reproductive cycles. Furthermore, because cropping seasons range from very short (in high latitude climates) to infinitely long (low latitude environments with good rainfall distribution), cropping system durations are also likely to differ.

Multiple cropping (whether as intercrops or sequentially planted monocultures), by and large, is a long-growing-season phenomenon. In North Carolina, the season is long but determinate because of low temperatures. In other parts of the world, both tropical and subtropical, the season is "fixed" by long dry periods. In much of the tropical world, however, rainfall is sufficient to support year-round plant growth; and continuous production of food crops is not only feasible but managerially desirable.

The author's recent research falls into two categories: (i) how crops grow (plant ontogeny in field environments) and how crop plants use nutrients as they grow; and (ii) the yield potential of intercrops under mid-Atlantic environments, effects of fertilizer (principally nitrogen fertilizer) and other controllable factors on the productivity of intercrops, and the interpretation of intercrop data. A third research programme at the departmental level has been the establishment of a viable and permanent agriculture in the upper Amazon basin (Yurimaguas, Peru) as an alternative to the traditional shifting cultivation system. All three of these endeavours are drawn upon in illustrating salient considerations for managing the fertilizer regime on multiply cropped land.

2. MULTIPLE CROPPING IN INFINITE SEASON ENVIRONMENTS

Yurimaguas, Peru, is near the equator (5°S). Annual rainfall exceeds 2000 mm, reasonably well distributed (evapotranspiration may exceed precipitation for some 30-45 days during mid-year). Food grains in Yurimaguas are scarce and their importation is prohibitively expensive. Benites (1981) postulated that he could grow more of these products by a system of intercrops than in conventional monocultures of the intercrop components. To test this hypothesis he studied seven cropping systems for the greater part of one year, with four levels of fertilizer N superimposed (0, 80, 160 and 240 kg/ha on a per-crop basis to non legume components). System duration ranged from 278 days (monoculture cassava)

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to 368 days (sequentially planted monocultures of peanuts (groundnuts), rice and rice). Since the study began on 3 January 1978, the "production cycle" can be divided into 3-monthly periods which roughly coincide with calendar trimesters. Crop duration, absolute yield of each crop, and per-crop accumulation of N, P and K for 80 kg N/ha are shown in Table 1. Yields of all crops and of all systems were near maximal with 80 kg N/ha.

Table 1 PER-CROP YIELDS OF PRODUCTS AND TOTAL ACCUMULATION OF N, P AND K BY INTERCROPS AND MONOCULTURES DURING ONE PRODUCTION CYCLE (1978) AT YURIMAGUAS, PERU
(Benites 1981)

C = corn (maize); R = rice; Ca = cassava; P = peanuts (groundnuts); N = 80 kg/ha/trimester to non-legumes; blanket applications of P, K, lime and micronutrients as required to maintain "high" status

Cropping system and symbol[1]	Species and trimester	Crop duration days[3]	Prod. yield kg/ha	Total accumulation N	P (kg/ha)	K
Intercrops						
C-R/Ca-P[2]	C (1)	112	2 240	37	5	31
	R (1)	123	1 600	40	9	60
	Ca (2-3)	278	13 330	82	19	57
	P (2)	96	870	59	4	25
C-P/Ca-R	C (1)	112	2 870	50	7	49
	P (1)	107	1 090	87	6	42
	Ca (2-3)	278	11 780	92	22	49
	R (2)	129	1 150	40	6	27
Sequential Monocultures						
C→P→R	C (1)	112	3 210	64	12	63
	P (2)	97	3 020	212	14	99
	R (3)	124	4 120	93	16	146
P→R→R	P (1)	107	2 910	178	13	88
	R (2)	129	3 880	130	25	122
	R (3)	124	3 850	98	16	95
R→P→C	R (1)	123	3 750	106	19	140
	P (2)	91	2 250	214	12	61
	C (3)	108	4 260	78	23	90
C→C→C	C (1)	112	3 260	64	9	59
	C (2)	103	4 840	72	15	90
	C (3)	108	5 250	93	31	137
Ca	Ca (2-3)	278	24 080	125	25	108

[1] Monoculture population (plants/ha): C = 53 333; R = 1 280 000; P = 160 000; Ca = 16 667.
Intercrop population : each species at 66 percent of monoculture

[2] Slash symbol indicates Ca-R or Ca-P relay interplanted into first crop-pair

[3] Turn-around times of 1 to 5 days between crops are not shown, but they are included in calculations involving system duration

2.1 Yield-Equivalency Ratios

While the yields constitute the basic data for comparing land use efficiencies, valid comparisons among the several systems can be made by quantifying yield in terms of common parameters such as Land Equivalency Ratio (LER), due to Harwood and his colleagues at the International Rice Research Institute (IRA 1974) and Area-Time Equivalency Ratio (ATER), due to Hiebsch and McCollum (Hiebsch 1978).

The summation of relative yields over all intercrop components is the definition of LER. Taking as an example Benites' maize-groundnut and cassava-rice intercrop (C-P/Ca-R), in which cassava was relay interplanted into a maize-groundnut intercrop with rice being relayed in to the cassava, LER = (0.83 + 0.35 + 0.51 + 0.32) = 2.01, and the implication is that the C-P/Ca-R intercrop uses the land some two times more efficiently than would monocultures of the intercrop components.

While LER clearly quantifies the land area requirements for growing equivalent quantities of each of the several products as monocultures, it does not, in the example, constitute a valid comparison between intercrops and monocultures with regard to land use efficiency (Fig. 1). Each of the bars in the figure is drawn to scale with hectare equivalents on the vertical scale and time

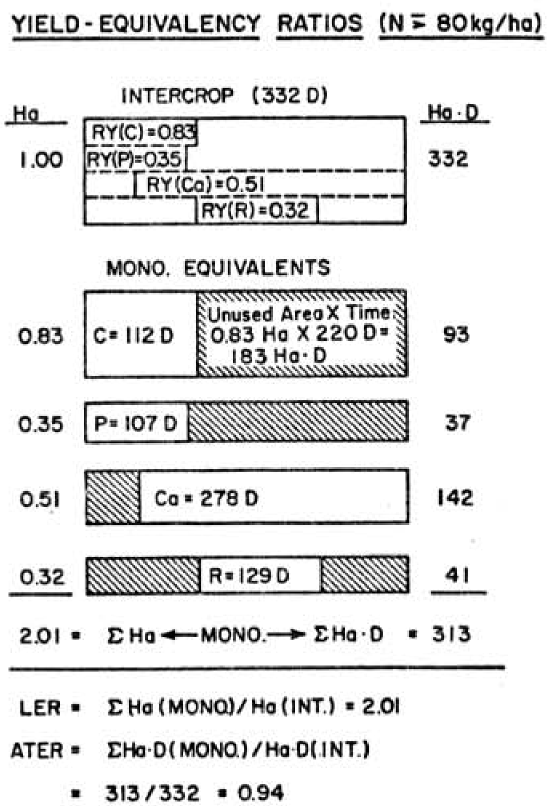

Fig. 1

Comparison between Land Equivalency Ratio (LER) and Area · Time Equivalency Ratio (ATER). Derived from absolute yields of crop components in a maize-groundnut/cassava-rice intercrop and of their monoculture checks. Yurimaguas, Peru.

C = maize; R = rice;
P = groundnuts; Ca = cassava;
D = days; Ry = relative yield = yield int./yield mono

on the horizontal. While the maize component of the C-P/Ca-R intercrop produced 83 percent of its reference monoculture, the system *per se* occupied the land for 332 days. On the other hand, 0.83 ha of monoculture maize required only 112 days and therefore 93 ha-days to grow an amount of maize equal to that produced by the intercrop. By a similar logic, area-time requirements for equivalent production by the other reference monocultures were 37 ha-days for groundnuts, 142 ha-days for cassava, and 41 ha-days for rice. The shaded bar-segments in the figure quantify "unused" hectare-days which are not accounted for in the LER concept. These unused hectare-days could be used to grow more crops and should be "counted-out" in any estimates of land use efficiency.

While the Area-Time Equivalency Ratio (ATER) is conceptually analogous to LER, it resolves the limitation inherent in the LER concept by quantifying crop production in terms of both area and time. By definition ATER = $\{(RY_a \times t_a) + (RY_b \times t_b) + \ldots(RY_n \times t_n)\}/T$, where RY = relative yield (int./mono); t = duration (days) of the growth cycle for intercrop components a, b, ...n; and T = duration of the intercrop system. Since RY_n is the area of monoculture crop "n" required to give an amount of product equal to that produced on 1.0 ha by intercrop component "n", the equation reduces to the form given in Fig. 1. When the ATER concept is applied to the example, it becomes apparent that the C-P/Ca-R intercrop was not a more efficient user of area-time than monocultures of the intercrop components. In fact, equivalent production by the four monocultures was achieved in 313 ha-days. On a "gross-product" basis, the C-P/Ca-R intercrop was therefore some 6 percent less efficient that its companion monocultures.

2.2 Rate of Yield Per Crop Within System

It is of interest to know how a given crop species performs in one cropping system (or season) relative to its performance in another. It is also pertinent to know how the rate of production by one species compares with the production rate by another (e.g. maize vs cassava). Although economic species differ in crop duration as well as in the form of harvested product, this analytical difficulty can be resolved if some "unit of commonality" can be found. For the crops involved in the example at hand, the rate of calorific production seems appropriate. Furthermore, if one defines "nutrient yield" as total accumulation of a given nutrient element during one reproductive cycle, a rate of nutrient yield can be calculated; and comparisons among species or species--within-systems with regard to nutrient demands and nutrient requirements can be made.

Table 2 summarizes the result of applying this idea to the seven systems studied by Benites (Table 1). Caloric conversions, as calories per kg of commercial product, were as follows: maize - 3432; rice - 3615; groundnuts - 5590; and cassava - 1615 (Peru Min. Agric. 1968). "Yields" of N, P and K are taken as Benites' estimate of total accumulation of these elements in vegetative and product portions by each crop during one reproductive cycle. Differences among species are obvious, especially with regard to rate of nitrogen yield; but so is the proportionality between the "yield" of nutrients and yield of food. It is of particular interest to note the position of cassava in the trends for yields of N, P and K relative to caloric production. The high rate of caloric production by this species is apparently achieved with relatively smaller demands for the nutrients than the other species.

Table 2 RATE OF YIELD (BY CROP SPECIES AND TRIMESTER) OF PRODUCT AND PLANT NUTRIENTS (N, P, K) IN INTERCROP AND MONOCULTURE DURING ONE PRODUCTION CYCLE AT YURIMAGUAS, PERU (adapted from Table 1)

Cropping System		Trimester	Rate of yield (per ha per day) K cal	kg N	kg P	kg K
				Corn (Maize)		
C-R	Intercrop	1	69	0.33	0.045	0.28
C-P	Intercrop	1	87	0.45	0.063	0.44
(CPR + CCC)/2	Monoculture	1	99	0.57	0.094	0.54
CCC	Monoculture	2	161	0.70	0.146	0.87
RPC	Monoculture	3	135	0.72	0.213	0.83
CCC	Monoculture	3	166	0.86	0.287	1.27
				Rice		
C-R	Intercrop	1	47	0.32	0.073	0.49
RPC	Monoculture	1	110	0.86	0.154	1.14
Ca-R	Intercrop	2	32	0.31	0.047	0.21
PRR	Monoculture	2	109	1.01	0.194	0.95
CPR	Monoculture	3	120	0.75	0.129	1.18
PRR	Monoculture	3	112	0.79	0.129	0.77
				Peanuts (Groundnuts)		
C-P	Intercrop	1	40	0.81	0.056	0.39
PRR	Monoculture	1	106	1.66	0.121	0.82
Ca-P	Intercrop	2	35	0.61	0.042	0.25
CPR	Monoculture	2	121	2.16	0.143	1.01
RPC	Monoculture	2	97	2.35	0.132	0.67
				Cassava		
Ca-R	Intercrop	2-3	77	0.29	0.068	0.21
Ca-P	Intercrop	2-3	68	0.33	0.079	0.18
Ca	Monoculture	2-3	140	0.45	0.090	0.39

2.3 Rate of Yield Per System

While the rate of yield (not only of product but also of nutrients) by a given species is of practical as well as biological concern, it is not enough for making meaningful decisions in multiple cropping situations. Where multiple cropping is feasible, the system itself rather than a crop within it becomes the unit of comparison. Since cropping systems as well as crop species have differing durations, the rate-of-yield concept seems equally appropriate.

In the Yurimaguas example, cropping system yields were obtained by converting product yields to caloric equivalents and summing over all crops grown in each system during one production cycle. Yields of N, P, K and dry matter were similarly obtained; and yield rates (e.g. cal/ha/day) were calculated by dividing "cropping system yield" by "cropping system duration".

Rates of N, P and K yield were poorly correlated with rate of caloric yield (this is perhaps not surprising in view of the species studied). But yield rates for nutrients as well as calories were positively correlated with the rate of dry matter production. The entire range of nitrogen fertilization (0 to 240 kg/ha/trimester) was included in this exercise, but results were the same when only the first two nitrogen levels (0 and 80 kg) were used. The highest rate of dry matter yield was achieved with three continuous crops of monoculture maize (CCC, 327 days) at 160 kg N/ha/crop, while the lowest was the CP/Ca-R intercrop without nitrogen.

2.4 Conversion Ratios

Table 3 shows "conversion ratios" for the four species studied by Benites in the Yurimaguas environment. The harvest index (wt. of dry product/total dry wt.) for maize is lower than one expects in temperate climates (about 50 percent in North Carolina). It also seems low for rice, but the principal feature is the near-negligible effect of cropping system on conversion ratios for the three major nutrients. Maize elaborated more grain per unit of P accumulated during the first and second trimester than in the third, and rice was apparently a more efficient P utilizer during the third trimester. But there is little evidence that growing these species in mixtures (intercrops) had any drastic effects on nutrient utilization efficiency.

2.5 Yield Equivalents for Calories and Nutrients in the Yurimaguas Environment

Table 4 shows effects of cropping system and nitrogen fertilization on area-time requirements for equivalent yields of calories and nitrogen in the Yurimaguas environment. The effect of cropping system on area-time equivalents for P and K yield (averaged over all plus-N levels of nitrogen) is also shown. The maize-rice/cassava-groundnut intercrop (C-R/Ca-P) is taken as the reference standard. As an example, one can say that the C-R/Ca-P intercrop without nitrogen fertilizer is a more efficient producer of calories than any other unfertilized system except monoculture cassava, and that the continuous maize system (CCC) is the least efficient unfertilized system in terms of caloric production. Once the CCC system is given 80 or more kg N/ha/crop, however, it becomes more productive than the C-P/Ca-R intercrop.

Table 3 HARVEST INDICES AND CONVERSION RATIOS FOR N, P AND K BY MAIZE, RICE, GROUNDNUTS, AND CASSAVA IN INTERCROPS AND MONOCULTURES IN THE YURIMAGUAS, PERU ENVIRONMENT (adapted from Table 1)

Cropping System		Trimester	Harvest Index[1]	kg Product/kg nutrients N	P	K
		Corn (Maize)				
C-R	Intercrop	1	39	61	448	72
C-P	Intercrop	1	43	57	410	59
(CPR + CCC)/2	Monoculture	1	36	51	315	53
CCC	Monoculture	2	41	67	322	67
RPC	Monoculture	3	34	55	185	47
CCC	Monoculture	3	40	56	169	56
		Rice				
C-R	Intercrop	1	26	40	178	27
RPC	Monoculture	1	29	35	197	27
Ca-R	Intercrop	2	29	29	192	43
PRR	Monoculture	2	27	30	155	32
CPR	Monoculture	3	39	44	258	28
PRR	Monoculture	3	39	39	241	41
		Peanuts (Groundnuts)				
C-P	Intercrop	1	-	13	182	26
PRR	Monoculture	1	-	16	224	33
Ca-P	Intercrop	2	-	16	218	35
CPR	Monoculture	2	-	14	216	31
RPC	Monoculture	2	-	10	218	37
		Cassava				
Ca-R	Intercrop	2-3	47	163	702	234
Ca-P	Intercrop	2-3	45	128	535	240
Ca	Monoculture	2-3	50	193	963	223

[1] **Harvest Index = ratio of product yield (corr. to 0% H_2O) to total dry matter at harvest expressed as a percentage.**

A similar logic applies to yields of N,P and K; and it is apparent that all systems except monoculture cassava (Ca) and unfertilized continuous maize (CCC) were more efficient "nitrogen accumulators" than the C-R/Ca-P intercrop. A likely reason for this result is the inclusion of groundnuts in all other systems, but the data at hand do not permit that kind of evaluation. The continuous maize (CCC) versus monoculture cassava (Ca) comparison provides a particularly interesting observation. In this experiment, at least, the rates of caloric yield by maize and cassava with 80 kg N/ha were virtually equal, yet the per-season rates of N, P and K yield by cassava with 80 kg of N were only 64, 54 and 45 percent respectively, of the CCC system with 80 kg N/crop (e.g. CCC vs Ca for relative rate of N yield = 0.94/1.46 = 0.64). The earlier speculation about high energy conversion and low nutrient demand by this species is again apparent.

A final feature of Table 4 concerns an apparent discrepancy in rates of

Table 4 EFFECT OF CROPPING SYSTEM AND NITROGEN FERTILIZATION ON AREA-TIME EQUIVALENCY INDICES FOR TOTAL CALORIC YIELD OR MARKETABLE PRODUCTS AND TOTAL NITROGEN ACCUMULATION IN THE YURIMAGUAS (PERU) ENVIRONMENT WITH CROPPING SYSTEM EFFECTS FOR TOTAL P AND K ACCUMULATION (Adapted from data in Table 1) (Benites 1981)

Cropping system	Index (= hectare - day equivalents)[1]									
	Nitrogen fertilization (kg/ha/crop)								N ≥ 80 kg/ha	
	0	80	160	240	0	80	160	240		
	------ caloric yield ----				------- N yield -------				P yld.	K yld.
Intercrops										
C-R/Ca-P	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
C-P/Ca-R	1.20	1.03	0.99	0.99	0.90	0.81	0.93	0.94	0.94	1.08
Sequential Monocultures										
C→P→R	1.05	1.02	0.96	1.05	0.49	0.59	0.58	0.61	0.83	0.49
P→R→R	0.01	1.08	1.27	1.62	0.65	0.60	0.56	0.58	0.79	0.61
R→P→C	1.19	1.03	0.93	0.96	0.58	0.54	0.50	0.48	0.64	0.57
C→C→C	1.81	0.88	0.74	0.78	1.37	0.94	0.74	0.78	0.67	0.55
Ca	0.97	0.83	0.78	0.74	1.64	1.46	1.65	1.57	1.24	1.23

[1] Since the C-R/Ca-P intercrop is used as the reference standard, all other tabular data represent the area-time equivalency ratio (ATER) for C-R/Ca-P relative to each of the other cropping systems. Example: ATER for C-R/Ca-P vs Ca at zero-N = 0.97.

caloric yield by the groundnut, rice, rice system (PRR) at high levels of N (160 and 240 kg N/ha/crop to the rice component). The rice cultivar was IR 4-2, and Benites points out that it is "strongly susceptible" to blast disease (*Pyricularea oryzae*) under high N regimes. Since the PRR system had two rice crops, its low rate of caloric yield (and thus high area-time requirements) is apparently a result of applying too much N to the rice crops. This view is further supported by the nutrient-yield data because per-system rates of nutrient accumulation were high (and thus had low area-time equivalents).

3. MULTIPLE CROPPING IN DETERMINATE SEASONS

Long established multiple crop systems in North Carolina are mainly of two forms: (i) a short-season vegetable crop followed by either a second vegetable (e.g. cucumbers-cucumbers) or by late-planted soybeans, both crops completing a production cycle during the frost-free season; and (ii) a three-crop-per-two year system (cropping index = 1.5), generally of maize, winter small grain, and soybeans (again late-planted). A third alternative consisting of interplanted maize and soybeans, which was in vogue in the Southeast and much of the Corn Belt some 30 to 50 years ago (before cheap nitrogen), has also been studied during the past several years because it may again have merit in the era of high-cost nitrogen and dwindling land areas. In North Carolina, maize matures around mid-August with some 50 to 70 days of frost-free weather remaining. On the other hand, net energy accumulation in soybean seeds remains positive until near frost. By planting these species as intercrop, one exploits virtually all the frost-free season. Maize-soybean seems most attractive among other intercrop systems (maize-*P. vulgaris*, sorghum-soybeans) as a possible management alternative for local producers.

3.1 Intercropped Multicrops versus Non-intercropped Multicrops

The "language" among multicroppers, especially in research, is so confused that there is no straightforward way to isolate one system to the exclusion of all others. The attempt by Andrews and Kassam (1976) helped to straighten out the terminology to some extent, and Kass (1978) had a further attempt; but confusion remains. The author's purpose at this point is to give a personal view on the place of intercropping as a multi-crop system as opposed to sequentially-planted "sole crops".

When the season is infinite (as in Yurimaguas, Peru) or, though fixed, is of sufficient duration to allow completion of the reproductive cycles by two or more crop species, intercropping in a mechanized agriculture is of questionable merit, particularly when the products of principal interest are short-season food crops. There seems to be a general consensus that intercropping is a low-input, low-technology, labour-intensive agricultural endeavour. Furthermore, Hiebsch (1980) has shown that many of the reported large intercrop advantages are misleading because the researchers failed to recognize time as a crucial factor in intercrop versus monoculture comparisons. If, however, growing-season duration exceeds the production cycle of one species of interest but is not long enough to complete the production cycle of a second (either the same species or a different one), as is the situation in North Carolina and several of the mid-Atlantic states, then intercropping in one or another of its many forms appears to have real merit. No matter what causes the growing season to be determinate (too cold, too hot, too dry, or even too wet), intercropping allows one to produce a near-complete crop of one species and a significant percentage of a full crop of another.

3.2 Ontogenetic Trends in Rates of Growth and Nutrient Accumulation

Looking only at averages over a reproductive cycle is to ignore the large, often rapid, and nutritionally significant changes in the rates at which plant processes occur during ontogeny. Rates of growth and nutrient accumulation can be estimated by periodic samplings throughout a plant's reproductive cycle. The author has made such measurements on several crop species - some in connection with the intercropping studies and some for other experimental objectives. Virtually all are consistent with two points: (i) the rate of nutrient accumulation (absolute demand) is roughly parallel to crop growth rate; but (ii) the rate of nutrient accumulation per unit of plant weight (relative demand) is a declining function of time (and thereby a declining function of plant growth stage).

Figure 2 shows seasonal trends in crop growth rate (CGR) and total N accumulation rate (TNAR) for maize from shortly after emergence until near maturity; it also shows relative growth (RGR) and "specific nitrogen accumulation rate" (SNAR = units of N accumulated per unit of existing dry matter per unit of time). The parallelism between CGR and TNAR is apparent, as is the close relationship between RGR and SNAR, and this was true also of soybeans. For grain sorghum, the high correlation between RGR and SNAR was particularly apparent during vegetative growth but less so from panicle initiation to maturity.

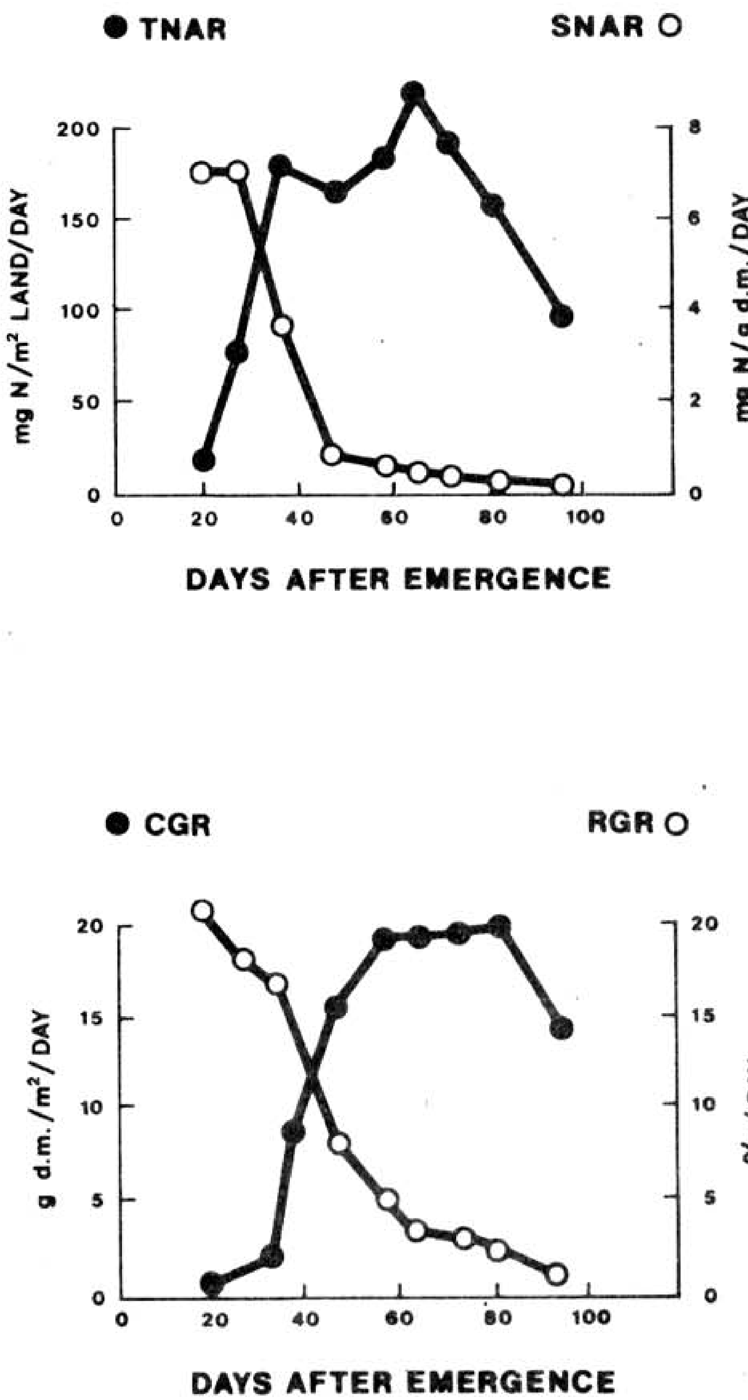

Fig. 2 Ontogenetic trends in mean crop growth rate (CGR), mean relative growth rate (RGR), total nitrogen accumulation rate (TNAR), and specific nitrogen accumulation rate (SNAR) by maize in North Carolina (Cordero 1977)

Cordero (1977) tried to determine the developmental stage at which growth phenomena by interplanted maize and soybeans became measurably different from their monoculture checks. Effects of N supply on rates of growth and N accumulation in maize were readily quantifiable, but there were no measurable effects of cropping system (intercrop <u>vs</u> monoculture), nor was there a significant "time x cropping system" interaction. As expected, growth rates of understorey soybeans were severely reduced by the dominant maize overstorey, but the effects of cropping system on rate parameters for soybeans were somewhat confounded by a prolonged mid-season.

Freites (1974) measured accumulation rates of P and K in *Phaseolus vulgaris* (snapbeans). Positive effects of band-applied fertilizer P on early-season growth are well documented, particularly if a crop is planted when soil temperatures are low; and Freites' results showed that banded fertilizer P caused a marked increase in specific P accumulation rate (SPAR). Taken together, these observations suggest that high tissue concentrations of P are essential for rapid growth of seedlings; and it seems to be generally accepted that the seedling stage of virtually all crops is one of the most critical.

4. RECOVERY OF FERTILIZER-APPLIED NITROGEN BY MAIZE AND SOYBEANS IN MAIZE-SOYBEAN INTERCROPS

In experiments using tracer N to estimate N recovery by each component of a maize-soybean intercrop (McCollum 1979), N-depleted NH_4NO_3 (80 kg/ha) was applied to monoculture maize, monoculture soybeans, and to each of two planting patterns of a maize-soybean intercrop. Total nitrogen and ^{15}N-nitrogen were then measured in both maize and soybeans at maize maturity (Table 5). Several conclusions with important implications for N fertilization of legume-non-legume intercrops are obvious:

i. By using the paired-row system, the non-legume can be fertilized in accordance with its "normal" N demands with little concern about losing costly fertilizer N to the N-fixing legume.

ii. The known inhibitory effect of high N regimes on N fixation by legumes can be avoided by the N placement scheme used in the paired-row system.

iii. With the alternating single-row system, however, there is no N placement method that will provide nitrogen to the non-legume component without also making it accessible to the legume; and rather than providing biologically fixed N to the current maize crop, these data suggest that alternate-row soybeans competed directly with maize for the fertilizer N.

This kind of experiment has been repeated with both maize-soybean and sorghum-soybean intercrops. The data are currently being evaluated, but it is already apparent that the recovery percentages are in close agreement with the results shown in Table 5.

Table 5 RECOVERY OF FERTILIZER-APPLIED NITROGEN (8 g N/m^2, CONTAINING 0.0065% ^{15}N) BY MONOCULTURE MAIZE, MONOCULTURE SOYBEANS, AND BY EACH COMPONENT OF TWO MAIZE-SOYBEAN INTERCROPS (Hiebsch 1980)

Cropping system[1]	N in plant at maize maturity		Atom % ^{15}N in plant	N from fertilizer		Recovery (% of applied)
	Conc. (%)	Total (g/m^2)		% of total[2]	g/m^2	
			Maize			
Mono. (96m rows)	0.82	10.58	0.200	44	4.66	58
Mono. (paired 48-cm rows)	0.85	9.44	0.192	46	4.34	54
Mono. (48-cm rows)	0.77	9.29	0.193	46	4.27	53
C-S intercrop (paired 48-cm rows)	0.79	8.18	0.179	50	4.09	51 (54)[3]
C-S intercrop (alt. 48-cm rows)	0.69	6.72	0.211	41	2.76	35 (46)
			Soybeans			
Mono. (48-cm rows)	2.36	13.73	0.260	26	3.57	45
C-S intercrop (paired 48-cm rows)	2.43	4.36	0.332	5	0.22	3
C-S intercrop (alt 48-cm rows)	2.32	3.60	0.265	25	0.90	11

[1] Plants/ha: maize 49 500; soybeans 150 000.

[2] % of total N from fertilizer = 100 (A - B)/(A - C), where
A = atom % ^{15}N in unlabelled plant = 0.351%
B = atom % ^{15}N in labelled plant;
C = atom % ^{15}N in labelled fertilizer = 0.0065%

[3] Numbers in ( ) show summation of % recovery by intercrop (maize + soybean)

Paper 7 STRATEGY FOR N FERTILIZER RECOMMENDATION IN MULTIPLE CROPPING SYSTEMS WITH PARTICULAR REFERENCE TO ITS USE EFFICIENCY

B.V. Subbiah and M.S. Sachdev[1]

1. INTRODUCTION

Multiple cropping is an ancient practice, whereby several crops are grown within one calendar year, wherever the climate is conducive to such practices. In India, where the land holdings are very small, multiple cropping offers a method of intensive farming to maximize crop productivity per unit area per year.

Double cropping (e.g. two crops of paddy or maize/wheat, etc.) has long been practised in areas with assured irrigation. With the introduction of high-yielding, photo- and thermo-insensitive, short-duration varieties with resistance to a broad spectrum of pathogens and pests, it has become possible to develop efficient multiple cropping systems with three or even four crops in a year. Special efforts are also being made to improve crop productivity without detriment to long-term production potential of soil.

Efficient soil fertility management is essential for continued production of high yields, and high fertilizer use forms one of its cornerstones. Yield levels of 10 to 15 tonnes of cereal grains per hectare per year have been obtained in multiple crop rotations at different centres of All India Coordinated Agronomic Experiments. Average grain production in these rotations is 40-48 kg per day and, at these high cropping intensities, the average amount of N, P_2O_5 and K_2O that must go into the plants is 1.17 kg N, 0.4 kg P_2O_5 and 1.25 kg K_2O per hectare per day (IARI 1972). The problem, therefore, is to make available a high enough level of nutrients from the soil and added fertilizers to meet the crop requirements.

2. NITROGEN THE KEY NUTRIENT FOR MULTIPLE CROPPING SYSTEMS

In the traditional agriculture, the inclusion of one legume in the multiple cropping sequence has been employed as one of the measures to restore soil nitrogen. However, since the high-yielding varieties have been bred specifically to be responsive to heavy fertilizer nitrogen inputs, and most breeders are now concentrating on varieties with linear responsiveness to nitrogen input, heavy fertilizer N use becomes inevitable for high levels of crop production. Crop production at present is highly correlated with fertilizer nitrogen input. Since this input is becoming increasingly costly with the rise in energy costs, it becomes essential that soil and fertilizer N be used at maximum efficiency and economy. Present fertilizer use efficiency, as revealed by ^{15}N tracer experiments for most field crops, does not exceed 50 percent while in the case of rice it is only of the order of 25-30 percent.

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Studies using ^{15}N-labelled fertilizers have been made under the International Atomic Energy Agency Programme in Agricultural Nitrogen Residues (Table 1). The fate of fertilizer N applied to maize and wheat crops in the three-crop multiple cropping system of maize-wheat-*moong* was followed in a series of field experiments (Arora *et al.* 1980). The wheat crop utilized 35-55 percent of the applied fertilizer N in the winter season, while the maize crop utilized on average 22 percent of the applied 120 kg N/ha in the monsoon season, ranging from 11 percent in a heavy monsoon year (1976) to around 32-38 percent in lean monsoon years (1979 and 1980). The second crop in the rotation utilized very little of the N applied to either wheat or maize, indicating that each crop has to be fertilized separately, although most of the unutilized N residues in the soil profile were probably locked up in a complex organic pool.

Table 1 IARI EXPERIMENTS ON FATE OF FERTILIZER NITROGEN IN MULTIPLE CROPPING

Experiment Number	Date of start	Rotation			Remarks
I	1975	MAIZE ^{15}N urea at 120 kg N/ha	WHEAT Unlabelled urea at 80 kg N/ha	*MOONG* No fertilizer N applied	Experiment continued up to 1981 (18 crops), with maize crop fertilized with ^{15}N urea every year in separate series and residual effects studied on succeeding crops.
II	1978	WHEAT ^{15}N urea at 90 kg N/ha alone and with 10 tonne FYM/ha	*MOONG* No fertilizer N applied	MAIZE Unlabelled urea at 120 kg N/ha alone and with 10 tonne FYM/ha	Experiment continued up to 1981 (9 crops). ^{15}N urea was applied to first wheat crop only and soil sampling was done after 3, 6 and 9 crops in separate series. The succeeding crops received unlabelled urea.
III	1980	MAIZE Three equal splits of ^{15}N urea in separate plots to make a total of 120 kg N/ha	SAFFLOWER Unlabelled urea at 50 kg N/ha		Efficiency of each split evaluated.

A small amount of the locked up N was utilized by successive crops spread over several years (Table 2). Since a substantial part of the residual fertilizer N applied to maize was found in the soil profile below the root zone (Table 3), it is most likely that this portion would be irreversibly lost from the soil-plant system if it were not retrieved either by upward movement of the nitrate formed on mineralization or by absorption by a deep-rooted crop included in the rotation.

The partial efficiencies of fertilizer N applied to maize in three equal

Table 2 UTILIZATION OF 120 kg N/ha APPLIED TO MAIZE IN A MULTIPLE CROPPING SYSTEM OF MAIZE-WHEAT-*MOONG* OVER A PERIOD OF 5 YEARS

S. No	Crop	N applied to Maize 1975	Maize 1976	Maize 1977	Maize 1978	Maize 1979
1.	Maize 1975	20.81	-	-	-	-
2.	Wheat 1975-76	6.99	-	-	-	-
3.	*Moong* 1976	0.84	-	-	-	-
4.	Maize 1976	0.56	11.21	-	-	-
5.	Wheat 1976-77	0.80	3.80	-	-	-
6.	*Moong* 1977	0.28	0.00	-	-	-
7.	Maize 1977	0.36	0.41	20.91	-	-
8.	Wheat 1977-78	0.38	-	2.34	-	-
9.	*Moong* 1978	0.20	-	0.57	-	-
10.	Maize 1978	0.25	-	0.73	24.54	-
11.	Wheat 1978-79	0.39	-	0.85	3.98	-
12.	*Moong* 1979	0.27	-	-	1.42	-
13.	Maize 1979	0.28	-	-	0.99	32.32
14.	Wheat 1979-80	0.25	-	-	0.71	3.28
15.	*Moong* 1980	0.00	-	-	-	0.73
16.	Maize 1980	0.14	-	-	-	0.90
17.	Wheat 1980-81	0.09	-	-	-	0.58
18.	*Moong* 1981	-	-	-	-	0.33

Table 3 RESIDUAL FERTILIZER-N IN SOIL FROM 120 kg N/ha APPLIED TO MAIZE CROP

Depth (cm)	After: First Crop Maize 1978			Second Crop Wheat 1978-79			Third Crop *Moong* 1979		
	Total-N	NH_4-N	NO_3-N	Total-N	NH_4-N	NO_3-N	Total-N	NH_4-N	NO_3-N
0-15	18.03	0.45	0.21	14.87	0.30	0.25	14.89	0.41	0.40
15-30	8.23	0.50	0.23	7.24	0.46	0.33	6.06	0.38	0.47
30-60	13.24	1.18	0.47	11.99	0.78	0.33	13.02	0.70	0.74
60-90	6.43	1.28	0.49	6.75	0.90	0.43	7.28	0.47	0.50
90-120	6.64	1.20	0.51	8.56	0.61	0.28	6.43	0.69	0.42
120-150	6.71	1.25	0.51	5.59	0.74	0.40	6.43	0.48	0.45
150-180	6.09	1.02	0.66	5.93	0.56	0.30	4.89	0.51	0.27
180-210	5.33	0.87	0.90	5.29	0.64	0.37		0.63	0.28
	70.70			66.72			65.23		

split dressings differed widely. The first application given as a basal dressing utilized only 22 percent, the second at knee high stage (25 days after sowing) utilized 26 percent, while the final application at tasselling stage (50 days) utilized 64 percent, the overall fertilizer nitrogen use efficiency being 38 percent.

The legume crop in the rotation (*moong*) did not receive fertilizer but gave a yield of 800-1000 kg/ha with an input of 180 to 270 mm irrigation. It also removed 65-97 kg N/ha of which about 35-50 percent was in the grain. The estimated contribution of fixed nitrogen to this uptake was 22-30 percent as calculated from ^{15}N derived data, assuming that this crop takes uniformly from different soil depths containing residual fertilizer nitrogen applied to either maize or wheat in previous seasons.

The complete balance of N input to the soil-plant system in the three-crop multiple cropping sequence of maize-wheat-*moong* and the removal of nitrogen by these three crops over a period of five years (1975 to 1980) shows that there is little net gain or loss, with some minor deviations in different years. The wheat crop receiving 80 kg fertilizer N/ha gave yields of 4.1-5.7 tonnes/ha and removed 113-125 kg N/ha. The monsoon maize crop is heavily affected by the intensity and duration of rainfall, which results in low yields and consequently lower N uptake. In 1979, when rainfall was inadequate and the maize crop was given supplemental irrigation, the yield and uptakes of N and fertilizer N showed remarkably higher figures. In the case of the *moong* crop, N removal depends on the variety.

In the cereal crop based rotations and also where a grain legume crop is included, the residual effects from nitrogenous fertilizers are either very small or negligible. Hence the strategy for increasing fertilizer use efficiency will have to be to optimize the application of fertilizer N to each individual crop in such multiple cropping systems. Some of the reasons for low efficiency are as follows:

i. Since N is taken up in the form of nitrate and its transportation to the root surface is dependent on water movement, the soil water appears to be the most important single factor influencing N uptake by crop plants. Minnotti *et al.* (1960) showed that nitrate can be taken up by plants more rapidly than water uptake in solution culture systems. Only 50-60 percent of the water held at field capacity is available to crop plants and, at moisture tensions above the wilting point, the soil solution may contain nitrate but it will not be moving to the root surface, and this inevitably limits N absorption.

ii. The available nitrogen level, which includes both the soil and fertilizer nitrogen, is fairly high (above 35 ppm in the soil solution at 50 cm mean depth) for the wheat crop in an early growth stage - the wheat crop in the multiple cropping system was fertilized with 100 kg N/ha. There was a steep fall in the nitrate content of the soil solution between the seventh and tenth weeks, after which it attained a steady value of 4-5 ppm nitrate N (Pokhriyal *et al.* 1980). This shows that, as the crop grows, available N in soil becomes a limiting factor both for N uptake and for the growth of the plant. The fact that, in general, N recovery is better under greenhouse conditions than under field conditions shows that recharging the water many times during crop growth leads to better utilization as a greater quantity of soluble N is carried to the plant root surface.

iii. In field situations another important factor possibly also accounts for low efficiency. When the field is irrigated, the incoming water from the surface partly displaces the old soil solution to a greater depth, carrying the soluble nitrate to the lower parts of the root zone. In such situations the nitrate N could reside in the soil solution in lower parts of the root zone and not be available for absorption by plants.

iv. Perennial grasses have been observed to recover fertilizer N to the extent of 80 percent. This shows that the root flux per unit volume of the soil is an important factor in bringing about a higher N recovery. Thus, breeding varieties with higher root flux and root surface will be an important factor.

The main reason for the low efficiency is rapid immobilization of the applied fertilizer N. Some recent approaches to minimize this are:

a. delaying fertilizer N application until the vegetative period;

b. phased but not reduced irrigation;

c. for crops like rice, application of ammoniacal rather than nitrate N;

d. use of large granule formulations of urea;

e. use of specific nitrification and denitrification inhibitors.

All these approaches have to ultimately result in synchronizing N availability with crop growth demands, thus leading to more effective utilization of applied N. Monitoring the inorganic N in the soil solution and keeping it at the required level for a given soil-fertilizer and soil-water management system can give information for effective fertilizer N application. The recent development and use of sturdy nitrate- and ammoniacal-N-sensitive electrodes for field use will provide an effective technique for assessing fertilizer N needs.

In a recent Fertiliser Association of India seminar (Mishra and Gupta 1981), it was felt that the present information on crop responses to nutrients in various cropping systems is inadequate. Also the beneficial effects of legumes either in rotation or in mixed cereal-legume cropping systems have not been sufficiently quantified. Special research efforts at international level are needed to bridge these gaps of knowledge so as to provide effective methods of increasing fertilizer N use efficiency in multiple cropping systems to more satisfactory levels.

Paper 8 STRATEGY FOR P AND K FERTILIZER RECOMMENDATIONS IN MULTIPLE CROPPING SYSTEMS WITH PARTICULAR REFERENCE TO THEIR USE EFFICIENCY

N.N. Goswami, I.C. Mahapatra and M.B. Kamath[1]

1. INTRODUCTION

In the last two decades, Indian agriculture has undergone a remarkable change. Self-sufficiency in foodgrains and other crops and progressive modernization of the agricultural production technology with increasing use of energy inputs to sustain increased crop production are the two outstanding features. Some estimates show that about 35 percent of the total productive capacity of crops is accounted for by fossil fuel energy input in the form of mineral fertilizers.

It is now considered that P is a major constraint for successful crop production in India because, on the one hand, the finite reserves of this non-renewable resource are being quickly used up and, on the other hand, its deficiency has become widespread. Potassium simularly plays a key role. Because crop recovery of added phosphate seldom exceeds 20 percent and potassic fertilizers have to be imported, there is an urgent need to increase the efficiency of utilization of these nutrients not only by individual crop species but also be different cropping systems. With the advent of high-yielding, short-duration, fertilizer-responsive varieties of crops, evolution of appropriate fertilizer schedules for multiple cropping under various soil and agro-climatic conditions assumes immense importance.

Many generalized guidelines have been given for efficient fertilizer use under multiple cropping systems. Goswami and Singh (1976) outlined the various approaches for studying phosphorus requirements. The FAO/FAI Seminar (1974) recommended that "In general organic manures should be applied in the *kharif* season and phosphatic fertilizer in the *rabi* (dry) season".

Five major lines of investigations were advocated by Goswami and Singh (1975) designed to study (i) direct, residual and cumulative effects of fertilizer nutrient in single-year fixed two-crop sequences; (ii) the residual effect alone; (iii) the impact of cuts in recommended fertilizer rates by *ad hoc* apportioning of the total available fertilizer to various crops in the sequence; (iv) the role of specific nutrient fractions such as Al-P, Fe-P, etc. for individual crops; (v) transformation of nutrients in the soil in relation to actual crop removal. Such generalized recommendations, however, are not conclusive as they are based on insufficient research. The results of multilocation trials have shown that P

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application only to the *rabi* crop is conclusive for the most important rice-rice and rice-wheat rotations. Phosphate application only to wheat in maize-wheat, sorghum-wheat and pearl millet-wheat rotations has been found to be economic in most situations.

2. AGRONOMIC STUDIES

Studies conducted at many locations in India by AICRIP on a rice-rice cropping sequence during the last 9-10 crop seasons indicated that response to N was uniformly widespread, although responses to P and K were significant only in specified situations (AICRIP 1980), e.g. for P at Maruteru, Rajendranagar, Patna, Raipur and Karimgang (Assam), and for K in the light soil locations of Garikapadu (A.P.), Pattambi (Kerala), Patna and Titabar (Assam). Combined application of moderate levels of N and P gave better response than the interaction of N and K at many locations.

Results of long term trials conducted at a number of Model Agronomic Centres in India on direct, residual and cumulative effects of N, P and K are summarized in Table 1.

2.1 Balance Sheet of NPK in Rice-Rice Cropping System

Recovery of added P by the first crop is reported to be around 15 percent (Roy *et al.* 1978). Although the ability of the flooded rice system to make better use of soil P is well known, precise estimates of the residual effect of added P for the succeeding crop in a rice-rice cropping system are limited. The efficiency of utilization of applied K is quite high, in the range of 80-90 percent, though several soil management factors may reduce the efficiency; no reports are available on the residual effect in a rice-rice cropping system.

2.2 Rice-based Cropping Systems

Experiments on P fertilizer use in a rice-wheat system showed that wheat was more responsive to P than rice (Meelu and Rekhi 1981), though neither crop responded in recently reclaimed salt-affected soil. Phosphate application to wheat at 60 kg P_2O_5/ha was sufficient to meet the P requirement of the succeeding rice crop. In a potato-wheat-rice cropping system the application of P could possibly be halved in wheat and dispensed with in rice, if 60 kg P_2O_5/ha was applied to the potatoes, thus ensuring overall economy of P fertilizer in the cropping system. In a rice-gram cropping system a 3-year study revealed that the total response was greater when P was applied to gram than to rice.

2.3 Wheat-based Cropping Systems

Fertilizer use research in some wheat-based cropping systems was reviewed by Bhardwaj and Tandon (1981). Cropping systems involving four crops in one year have been developed. Phosphate application in the *rabi* season was found to be more effective when the *kharif* crops were maize or *bajra*. But results for

Table 1 FERTILIZER REQUIREMENTS OF A SINGLE YEAR RICE-RICE CROPPING SYSTEM

Centre Soil type	Years' average	Phosphate (P_2O_5) (kg/ha)			Potash (K_2O) (kg/ha)			Farmyard Manure (kg/ha)		
		Season and dose	Av. yield in plots without phosphate	Response	Season	Av. yield in plots without potassium	Response	Season	Av. yield in plots without FYM	Response
SUB-HUMID TO HUMID EASTERN AND SOUTH-EASTERN UPLANDS										
Maruteru (Medium Black)	1971-77	*Kharif* 30 only	8 299	320	*Rabi* only	8 578	105	*Kharif* only	8 446	136
Tirupathi (Red Loam)	1972-76	*Rabi* 60 only	9 923	1 113	*Rabi* only	10 322	341	Every season	10 280	650
Chiplima (Red & Yellow)	1975-79	*Kharif* 60 only OR	5 388	822	*Kharif* only	5 690	323	*Kharif* only	5 567	570
		Rabi 60 only	5 422	815						
Bhubaneswar (Laterite)	1970-79	*Kharif* 60 only OR	6 419	602	Every season	6 791	343	*Kharif* only	6 456	477
		Rabi only	6 463	596						
HUMID TO SEMI-ARID WESTERN GHATS										
Karaiyiruppu (Medium Black)	1971-76	*Kharif* 60 only	8 352	313	*Kharif* only	8 411	203	*Kharif* only OR	8 385	317
								Rabi only		355
Karmana (Laterite)	1972-78	*Rabi* 30 only	8 197	poor	*Kharif* only	8 212	poor	Every season	7 886	810
Mangalore (Laterite)	1972-79	*Kharif* 60 only	8 550	poor	*Kharif* only	8 427	322	Every season	7 338	2 311
Thanjavur	1971-79	*Kharif* 60	7 381	796	*Kharif* only OR	7 673	285	*Kharif* only OR	7 745	142
					Rabi only	7 646	309	*Rabi* only	7 731	140

Source: Mahaptra *et al.* (1981)

rice-wheat were not uniform in all locations. P build-up was found more in systems containing potatoes and was governed by soil properties, but large variations were observed even in similar soils and cropping systems. Nutrient build-up has not been observed in rice-wheat systems. Removals of potassium are generally not reflected in routine soil tests and hence monitoring of K status is required.

2.4 Efficiency of P and K Utilization in Potato-based Cropping Systems

Potato is a short duration crop and fits well in multiple cropping systems. Introduction of shorter duration varieties like *kufri* and *chandramukhi* has further aided in intensification of cropping. A long-term cropping system cum manurial experiment was initiated in 1971 at Jullunder (Singh and Sharma 1981), comparing four cropping systems, potato-potato-maize, potato-wheat-rice, potato-potato--maize, and potato-potato-maize-wheat-green manuring. Averaged over 10 years the response to P was highest in potato-potato-maize and lowest in the green manuring rotation. The response to K was least in potato-potato-maize and rather similar in the other rotations. The results suggest that including green manuring in the rotation could reduce P responses but not those of K. Residual effects on potato were much smaller than the direct effects, thus stressing the need for fresh P and K application to every potato crop. Residual effects of P on spring or autumn wheat were also less than the direct effects, indicating the need for a small dressing of P to wheat additional to the residual effect of P applied earlier.

2.5 Other Cropping Systems

Studies at JARI and other jute research stations have established that jute can be grown in systems such as jute-paddy, jute-wheat, jute-mustard, under rainfed conditions in 200/300 percent intensity. Jute-paddy-wheat, jute-paddy--potato, paddy-jute-paddy, jute-paddy-mustard, etc. are remunerative systems under irrigated conditions. Maximization of fibre and food crop yields is possible with proper use of fertilizers and manures (Mandal *et al.* 1981). Fertilizer application to jute depends on the cropping system. Where jute follows potatoes, the latter receive all the fertilizers and manures and jute thrives well on the residual effect; application of P and K for jute may not be required (Mandal *et al.* 1977; Mandal and Doharey 1978).

In groundnut-based systems the fertilizer dressing for the succeeding crop (cereal or non-legume) may be reduced by at least 20-25 kg N/ha; no P application need be made if the groundnut crop has already been supplied with P (Singh and Sahu 1981). For a legume succeeding groundnuts, no nitrogen but about 15-20 kg P_2O_5/ha need be applied. Precision placement of fertilizer and maintenance of optimum plant population are essential.

Fertilizer use in cotton-based cropping systems was reviewed by Chokhey Singh (1981). In a cotton-rice system, fertilizer applied to cotton had very little effect on the succeeding rice crop. In a cotton-sorghum-*ragi* system, 45-100 kg $N+P_2O_5+K_2O$ could be saved by proper distribution in the cropping system. P applied to gram and berseem had more residual effect on cotton than when applied to wheat and cluster bean.

Long-term appraisal of the dynamics of soil fertility under different cropping systems was outlined by Ghosh (1981). In general, the growing of grain legumes in rotation with cereals reduces leaching loss of N but makes only marginal impact on yield. Winter forage legumes like berseem have a definite advantage over other species, particularly under assured favourable conditions for growth such as optimum phosphate supply (Maurya and Ghosh 1972; Patel *et al.* 1963).

3. SOIL STUDIES

Singhania and Goswami (1974) reported that there was little residual effect on wheat of P applied to the preceding rice crop and suggested that the reasons were: (a) wheat removes more fertilizer P than rice; (b) wheat cannot utilize the residual Fe-P which was the major transformation product of P after rice; and (c) rice can utilize both Fe-P and Al-P. Based on theoretical considerations and results obtained in controlled experiments, it was suggested that application of phosphate to rice may be dispensed with in favour of wheat.

3.1 Depletion of Non-exchangeable K Reserve in a Multiple Cropping System

Various forms of K in soil are in dynamic equilibrium with one another as follows:

$$\text{Soil K reserve} \rightleftharpoons \text{Non-exchangeable K} \rightleftharpoons \text{Exchangeable K} \rightleftharpoons \text{Solution K}$$

Depletion of soil K in a multiple cropping system has been monitored at IARI by Sachdev and Khera (1980) on a long-term basis under field conditions. As much as 80 percent of K removed by a wheat-*bajra*-wheat sequence with intensive application of fertilizer N and P only was contributed from non-exchangeable K sources in soil. Application of N in combination with P only at higher levels resulted in greater utilization of K. If this exploitation of non-renewable soil K is continued for several years without addition of K fertilizer at an early stage, it might lead to a large-scale deficiency which would then require higher rates of K application to compensate for the large K unsaturation in the non-exchangeable reserves leading to fixation before crop responses could be obtained.

3.2 Long-term Appraisal Based on Permanent Manurial Trials

The permanent manurial trials at Pusa (Bihar) initially laid out in 1908-09 on the lines of the Rothamsted classical experiments had the unique feature that, in addition to the normal 4-years 8-course different cropping system, there were two more cropping systems, one involving unmanured cereal cropping and the other green manuring with sunnhemp. Manure and fertilizer treatments were applied only to the normal cereal-legume cropping system except that the green manure crop in one case used to receive 90 kg P_2O_5/ha as single superphosphate (Chokhey Singh 1981). The changes in soil fertility attributes as a result of this long period of cropping are given in Table 2.

Table 2 FERTILITY STATUS OF THE SOIL AFTER 18 YEARS OF CONTINUOUS CROPPING AND MANURING IN THE PUSA PERMANENT MANURIAL EXPERIMENTS

Cropping System/Treatment	Org.C (%)	Available P (kg/ha)	Available K (kg/ha)
No manure in legume cropping system	0.33	8.4	112
No manure in cereal cropping system	0.33	9.8	110
Green manure (sunnhemp) in legume cropping system	0.45	22.1	126
Green manure in cereal cropping system	0.38	9.0	126
Green manure with 90 kg P_2O_5/ha in legume cropping system	0.51	22.9	123
Manuring in legume cropping system:			
FYM (9 t/ha)	0.47	16.3	143
$N-P_2O_5-K_2O$ (45-90-56 kg/ha)	0.40	14.8	128
$N + P_2O_5$	0.34	20.4	110
N	0.28	8.2	100

Source: Maurya and Ghosh (1972)

3.3 System of Intensive Agriculture Based on Long-term Fertilizer Experiments

Changes in soil fertility over a long period under intensive agriculture, covering 11 major agro-climatic centres, were evaluated by Ghosh and his associates (Bebreker 1979; Biswas *et al.* 1977; Rao 1979; Swarup and Ghosh 1979) in a project sponsored by the Indian Council of Agricultural Research. Based on the amount of nutrients added in fertilizers and their removal by crops during the 7 to 8 annual cycles of cropping, P depletion, where this nutrient was not applied, was greater in upland cropping than in the rice-rice cropping system. In spite of the large removal of K, the changes in the available K status were not commensurate with the crop uptake. However, this aspect of the dynamics of soil potassium has not received adequate attention (Sacher and Khara 1980). Available P and K have generally been found to follow either an upward or a downward trend for a few years and then stabilize at a particular level.

Paper 9 IMPORTANCE OF MICRONUTRIENTS IN MULTIPLE CROPPING SYSTEMS

M. Verloo[1]

1. THE ROLE OF MICRONUTRIENTS

An attractive general hypothesis for the role of micronutrients in plant metabolism is that they form stable complexes with naturally occurring ligands. A trace element is essential when biological activity occurs only with the complexed ligand (Price 1968). Thus micronutrients are mainly associated with the enzymatic plant systems, such as iron in cytochromes, catalase and peroxidase, zinc in carbonic anhydrase and hydrogenases, copper in ascorbic acid oxidase and cytochrome oxidase, molybdenum in nitrate reductase and manganese in pyruvate carboxylase. Micronutrient deficiency may provoke either inhibition or stimulation of a specific enzyme activity, so disturbing plant metabolism and resulting in growth and yield depression. Important modifications in the plant enzymatic system, causing a qualitative alteration of the plant constituents produced during biochemical processes, may occur even before visual symptoms of deficiency may be observed. For this reason the role of micronutrients on the quality factor of plants is also very important and the determination of enzymatic activity may be used as an early diagnostic tool for trace element imbalances and sublethal effects (Cottenie and Camerlynck 1979). The beneficial effects of micronutrients on hydration and resistance to higher salinity levels, as well as to viral and fungal diseases, may be related to biochemical effects.

Addition of Zn to the soil resulted in an increase of the total free amino acids in cabbages (Camerlynck and Kiekens 1981).

2. MICRONUTRIENT CONTENTS IN PLANTS

Based on values given by Chapman (1966), Bergmann and Neubert (1976) De Geus (1967) and Cottenie *et al.* (1976), approximate trace element contents in mature leaves are listed in Table 1. Judgement of micronutrient situations by this table alone may be dangerous due to year to year and location to location variations as a result of soil-climate-plant interactions. In fact plants reflect the composition of the soil, but the soil-plant relationship is complicated by genetic properties, selectivity, antagonisms and other external factors. The mineral element content of plants is the result of environmental and soil parameters, plant species and physiological age.

The relationship between nutrient concentration in plant tissues and crop behaviour as described by Finck (1968) is also valid for micronutrients. The critical concentration is used to indicate the level below which a sharp reduction of yield is noticed. With trace elements the differences between deficiency, normal status and toxicity are generally more distinctly and sharply separated and the optimal zone may be very limited. Plant analysis is therefore an indispensable tool.

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Table 1 APPROXIMATE TRACE ELEMENT CONCENTRATIONS IN MATURE LEAVES THAT MAY BE CLASSED AS DEFICIENT, SUFFICIENT OR PHYTOTOXIC

Trace element	Content in mature leaves, ppm		
	deficient	normal range	phytotoxic
Fe	<50	50 - 250	not known
Mn	<20	25 - 250	>500
Zn	<20	25 - 150	>400
B	<10	18 - 100	>200
Cu	< 4	5 - 15	> 20
Mo	< 0.1	0.5 - 5	not known
Co	-	0 - 2	>100
F	-	5 - 8	> 50
Ni	-	0 - 8	> 80
Pb	-	2 - 20	not known
Cr	-	0 - 0.5	>100
Cd	-	0 - 2	>100

3. MICRONUTRIENT EXPORT

Knowledge of critical and optimal ranges of micronutrients is only the first step. Results of trace element analysis in plant tissues must be linked to their level of availability in the soil and to their effect on crop production.

In a natural vegetation system, the cycle soil pool → available soil content → tissue content → soil pool is closed; weathering and recycling processes provide a sufficient supply of nutrients. In agricultural systems, however, crop production is the main objective and varying fractions of the total plant production are removed from the soil together with the absorbed nutrients, so exhausting the soil nutrient pool. Therefore, input of fertilizer is necessary. To maintain the natural fertility level, at least the exported amounts of nutrients must be added to the system. In intensive cropping systems the amounts of major nutrients exported per ha and per crop can be estimated at 70 to 140 kg N, 15 to 60 kg P and 70 to 300 kg K. For micronutrients an estimation of the annual export in Belgium has been given by Cottenie *et al.* (1973) (Table 2).

Table 2 AVERAGE ANNUAL EXPORTS OF MICRONUTRIENTS IN BELGIAN AGRICULTURAL SYSTEMS

Element	Annual export by crops in kg/ha	
	annual crops	pastures
Fe	1	1
Mn	0.2	0.4
Zn	0.18	0.15
Cu	0.05	0.05
B	0.07	0.03
Mo	0.01	0.005
Co	0.0004	0.0004

It is evident that intensification of the cropping rate and an increase in yield by the application of fertilizers also result in higher amounts of micronutrients exported. Thus also in multiple cropping systems the exhaustion of the natural micronutrient levels is accelerated and critical levels can be reached. Moreover, interaction reactions and antagonisms may depress micronutrient availability even when soil content seems sufficient.

Zn-P interactions are well known and are now intensively studied in acid tropical soils. Application of fertilizer P may increase plant growth, but the plants may become deficient in Zn at a later stage of growth. In such cases, the total uptake of Zn by the crop usually increases but the concentration of Zn in the plant declines to a deficiency level. Lack of Zn in the plant may reduce yield of fruit or grain.

Antagonisms arise especially when a plant absorbs large amounts of an available nutrient so that its concentration in the plant reaches excessive or toxic levels that interfere with the normal metabolic function of another nutrient. Excessive uptake of Zn by a plant may disturb the metabolic function of Fe and the plant may suffer from Fe chlorosis even though Fe is present at normal concentrations in plant and soil.

Interaction reactions may occur in the soil as well as in the plant itself and it is seldom clear at what level they really take place. In more intensive cropping systems, nutrient balances are very important as the addition of one element may affect directly or indirectly the availability, uptake or metabolism of another. Addition of nitrogen effectively increases the yield of most crops but when the rate of plant growth exceeds the rate of uptake of a particular nutrient, the concentration of that nutrient in the tissue decreases and may result in the appearance of deficiency symptoms.

4. SOIL CONTENT

Trace element problems and behaviour in soils have been widely discussed (Sillanpää 1972; Verloo *et al.* 1980; Cottenie 1980). A normal micronutrient content for soils is difficult to determine, especially as a distinction must be made between total, extractable and available amounts.

Total trace element contents are generally of geochemical interest and normally the fraction in unweathered minerals and immobilized solids has little or no biological or ecological importance. Mainly highly weathered acid soils and podsols under heavy rainfall may show very low micronutrient contents. In general, these soils are high in free iron and low in organic matter and cation exchange capacity. Only plants with low micronutrient requirements, such as rubber, can give satisfying yields on such soils and any change in cropping system, e.g. intercropping, may create trace element problems when not controlled.

Extractable contents are strongly affected by the nature of the extracting agent used but generally show a good correlation with plant uptake. Critical values below which micronutrient deficiencies are likely to occur are known for the most commonly used extracting agents, e.g.

- in 0.5 N_4NH Ac + 0.02 M EDTA (pH 4.65) : Fe – 4 ppm Zn – 2-3 ppm
  Mn – 10 ppm Cu – 2-3 ppm

- in boiling water: B 0.5 ppm
- in NH_4-oxalate (pH 3.3): Mo 0.1 ppm

When these critical values are converted to extractable amounts per hectare they are still many times the exported amounts given in Table 2, which means that only a fraction of the extractable quantity is really available. Also, soil treatments with simple salts to increase the extractable amounts will not necessarily increase crop yields, because possible unfavourable soil conditions may cause immobilization or fixation. The results of soil extraction indicate a potential which is not automatically released.

Availability is related to soil, field and climatic conditions. In some cases, sufficient extractability may accompany low availability (Cottenie 1979):

- iron availability is limited in alkaline soils, after heavy manuring and in the presence of high soil P; also in acid soils with low organic matter content;

- manganese becomes unavailable in the presence of lime at higher pH, under dry conditions, low light intensity and low soil temperature;

- zinc availability is diminished by lime, higher pH, low soil organic matter and excessive P;

- copper is less influenced by pH, but may be strongly immobilized by organic matter; in acid conditions the critical level in organic soils is about 30 ppm;

- boron is less available at increasing pH, due to Ca-antagonism. In acid soils with a tendency to sodification or salinization, boron is likely to become toxic, e.g. when the water extractable content exceeds 1.5 ppm;

- molybdenum is optimally available in neutral and slightly alkaline conditions and is much less mobile in acid and organic soils.

Since copper is mainly associated with organic matter, immobilization is not likely to occur in tropical soils where mineralization is very fast; when, however, mineralization is slowed down or even completely stopped by unfavourable conditions such as extreme acidity in peat soils, copper can be bound very strongly by organic matter.

Zinc deficiency is more frequent and many crops show a response to Zn-application. In tropical regions it should be noted that higher light intensity is accompanied by an increased zinc requirement of crops.

Interpretation of analytical results thus needs a separate evaluation in the following steps:

- analytical characterization of the micronutrients in the soil (extractable amounts);

- influence of soil and field conditions (available fraction);

- crop requirements (exported amounts);
- recommendation for treatment.

In multiple cropping systems mainly the field conditions, availability, interactions and crop requirements need special attention; also physical conditions such as water availability may vary strongly when more intensive cropping systems are practised.

5. APPLICATION OF MICRONUTRIENTS

Micronutrients may be applied either as chemically pure salts (e.g. copper sulphate, manganese sulphate, ammonium molybdate, etc), or as mixtures with complexing or chelating compounds, or in fertilizers to which micronutrients have been added, or present in fertilizers which themselves contain small amounts of micronutrients as contaminants or accompanying elements.

For well-determined deficiency problems the application of pure salts should be preferred, and rates should be carefully fixed to minimize residual and toxicity effects. In some cases addition of micronutrients to fertilizers may be advantageous as this method may give optimum balances between the various nutrients applied.

The method of application, whether for example by foliar or seed treatment, is a major factor in determining the availability of applied micronutrients. Little information is available on the feasibility of applying micronutrients through irrigation water.

Paper 10 IMPORTANCE OF SECONDARY AND MICRONUTRIENTS IN MULTIPLE CROPPING SYSTEMS - INDIAN EXPERIENCE

J.C. Katyal and A.N. Pathak[1]

1. MICRONUTRIENT DEFICIENT AREAS

An understanding of deficient soils and their extent is the pre-requisite to obtain precise information on the nutrient needs of crops whether individually or in a multiple cropping system.

The critical limits for certain micro and secondary nutrients in Indian soils are given in Table 1. Those other than Zn are worked out on a limited basis. Zn deficiency is the most widespread in Indian soils (Table 2). The variation of the critical limits of Zn between crops is of great significance when deciding Zn fertilization of different crops in a sequence.

Table 1 CRITICAL LIMITS OF MICRO AND SECONDARY NUTRIENTS IN INDIAN SOILS[1]

Test crop	Zn	Cu	Fe	Mn	S
Wheat	0.60	-	-	-	10.0[2]
Rice	0.83	0.10	-	-	-
Maize	0.83	0.14	2.0	-	-
Pearl millet	0.56	-	-	-	-
Groundnut	0.50	-	-	-	-
Sorghum	1.00	0.40	-	-	-
Oats	-	-	-	3.3	-

[1] Extractants: Zn - DTPA
Cu & Mn - $\underline{N}$ NH_4OAc (pH 7.0)
Fe - $\underline{N}$ NH_4OAc (pH 4.3)
B - Hot water soluble

[2] As SO_4-S for several crops

Several factors lead to insufficiency of micro and secondary nutrients in soils and these largely control the extent of the deficient area in any geographical region. The contribution of total micronutrient reserves to their available levels seems to be erratic (Katyal and Sharma 1979). Increasing pH has been shown to depress plant available Zn, Fe, Mn, Cu and B (Rai *et al.* 1972; Mishra and Pande 1975; Shukla *et al.* 1975; Rajagopal *et al.* 1977; Khetawat and Vishishtha 1977; Haldar and Mandal 1979; Brar *et al.* 1980). Calcareous soils are

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Table 2 DISTRIBUTION OF MICRONUTRIENT DEFICIENT SOIL SAMPLES FROM 10 INDIAN STATES

State	Zn		Cu		Mn		Fe	
	No. of samples	Def. %	No. of samples	Def. %	No. of samples	Def. %	No. of samples	Def. %
Andhra Pradesh	2 753	54	2 076	0	2 076	1	2 076	<1
Bihar	7 929	40	7 397	<1	6 150	2	6 375	3
Gujarat	11 146	26	11 146	8	11 146	2	11 146	11
Haryana	8 494	74	7 761	2	6 457	14	6 800	20
Karnataka	2 153	21	2 153	4	2 153	1	2 153	<1
Kerala	592	34	592	32	592	4	592	<1
Madhya Pradesh	1 601	58	3 744	2	3 759	8	4 028	7
Punjab	8 323	52	7 423	5	7 292	0	7 435	21
Tamil Nadu	4 272	32	4 277	3	3 986	16	4 543	17
Uttar Pradesh	4 911	67	3 916	<1	3 592	<1	4 388	6
Total	55 180	47	50 428	1	47 203	5	49 476	11

Def. = Deficient

Source: All India Coordinated Scheme of Micronutrients in Soils and Plants. Katyal *et al.* (1980)

generally deficient in these nutrients due to their high pH (Sakal and Singh 1979; Katyal 1980). Almost all the alkali soils from U.P. analysed by Agarwala *et al.* (1970) contained inadequate Zn for normal crop performance. Subsequently it was shown (Bhumbla 1972) that Zn application was critical for successful reclamation of the 2.5 million hectares of Indo-Gangetic alluvium soils. Despite the high pH and low available Cu and Mn found in alkali and saline alkali soils (Bhumbla and Dhingra 1964), wide incidence of deficiencies of these two elements has not been reported. In contrast, iron chlorosis is an acute problem of alkaline calcareous soils and several crops have been shown to benefit from the application (Agarwala and Mehrotra 1963; Singh 1973; Shahi *et al.* 1976; Takkar and Nayyar 1979). Calcareous soils are also generally low in available B (Singh and Sinha 1976).

Increasing pH favours Mo availability (Pathak *et al.* 1968; Gupta and Dabas 1980); available Mo in the acidic hill soils of Almora, U.P. (Pathak *et al.* 1968), acid Grey Brown Podzolic soils of erstwhile Punjab (Grewal *et al.* 1969) and acid Latosols from Bihar (Verma and Jha 1970) are in the critical range. Typical acid soils (pH > 5.5) are also invariably deficient in Ca and Mg (Tomar and Verma 1970; Mandal 1976). Low Ca and Mg can be a problem even in alkali soils.

The availability of the secondary nutrients (Kanwar 1976) and micronutrients (Shukla *et al.* 1975; Khotawat and Vashishtha 1977; Rajagopal *et al.* 1977), with the exception of Mo (Gupta and Dabas 1980), falls as the proportion of sand in the soil increases. Low organic matter is often the cause of micronutrient (Katyal and Sharma 1979) and S deficiencies (Kanwar 1976) in arid and semi-arid soils. Unusually high organic matter in humid tropical soils, however, adversely affects the availability of Zn (Nambiar 1977) and Cu

(Rajagopal *et al.* 1977); most Cu-deficient acid soils in Kerala owe their deficiency to this cause (Katyal and Randhawa 1980). With submergence, availability of Fe, Mn, Ca (Katyal 1977) and Mo (Nayyar *et al.* 1977) increases and that of Zn (Katyal 1977) and Cu (Haldar and Mandal 1979) decreases in anoxic rice soils. Thus, lowland rice soils are liable to Zn and Cu deficiencies.

2. CROP TOLERANCE

Mehta (1974) presented a list of crops in different response categories based upon work done outside India. Experiments conducted in farmers' fields under the auspices of the All India Coordinated Scheme of Micronutrients in Soils and Plants revealed that rice (lowland) and maize may be more prone to Zn deficiency than either *Kharif* (wet, summer) pearl millet or *Rabi* (dry, winter) wheat. Tiwari and Pathak (1976) found that lowland rice but not wheat benefitted from Zn application to alluvial soil containing 0.8 ppm DTPA-extractable Zn, but that, once the extractable Zn was depleted to 0.58 ppm by continuous cropping, wheat responded also.

Shukla and Singh (1979) quoting work at HAU, Hissar, reported that on a low Zn Sierozem soil maize suffered from acute Zn deficiency while pearl millet was practically free from Zn deficiency. Differential susceptibility of crops was noted in a nutrient survey of wheat and groundnut in selected villages in Punjab (Table 3) (Sekhon *et al.* 1975, 1978). A remarkable improvement in the yield of groundnut (Brar *et al.* 1980) in comparison with no response of wheat (M.S. Brar, personal communication) to applied B confirmed the need for B application to groundnut in a groundnut-wheat rotation. Kanwar (1976), too, reported that cereals in general were more tolerant to B deficiency. Likewise, higher needs for S by groundnut and other oil seed crops have been established. Das and Datta (1973) reported that onion suffered earlier than maize from S deficiency in a continuous cropping experiment.

Table 3 RESULTS OF NUTRIENT DEFICIENCY SURVEY OF WHEAT AND GROUNDNUT IN 5 SELECTED VILLAGES, LUDHIANA AND KAPURTHALA DISTRICTS, PUNJAB

Micro or secondary nutrient	Percentage deficient samples	
	Wheat	Groundnut
Zn	92	71
Cu	30	47
Fe	-	13
Mn	-	55
S	-	74
B	-	95

Source: Sekhon *et al.* (1975, 1978)

Differences in sensitivity to Fe stresses have also been noted. On a Sulfaquept (loamy sand, pH 8.0, 13 ppm DTPA-extractable Fe) upland rice suffered severely from Fe deficiency whereas sorghum and pearl millet did not. There was a strong need for iron fertilization, and this was previously unknown, once rice replaced groundnut in a groundnut-wheat rotation in Punjab (Takkar and Nayyar 1979). Iron chlorosis proved as disastrous for sugarcane (Singh 1973) as for rice (especially upland). Ratooned sugarcane was an early casualty (Tomer *et al.* 1965).

Leguminous crops exhibit more response to Mo than other crops in a rotation. Legumes also need more Ca than cereals (Kanwar 1976).

Table 4, which is based upon the foregoing information, lists those crops which are more likely to show deficiencies.

Table 4 CROPS MORE LIKELY TO SHOW MICRO AND SECONDARY NUTRIENT DEFICIENCIES

Nutrient	Crop
Zn	Rice (lowland), maize
Fe	Rice (upland), sugarcane
Cu	?
Mn	Gram, oats
Mo	Cabbage
B	Groundnut
S	Groundnut, *raya*, alfalfa, onion
Ca	Pigeonpea, soybean, cotton
Mg	Potato

3. NUTRIENT NEEDS OF FOLLOWING CROPS

Sharma and Deb (1974) found more depletion of soil Cu when wheat was rotated with *bajra* (Pearl millet) than when it was followed by rice. Gajbhiye and Goswami (1980) showed that in a *bajra*-wheat rotation, the net effect of *bajra* cultivation was a gain in available Zn, Fe and Mn. On the other hand, after the wheat harvest, the soil was depleted of Zn, Fe and Mn but was enriched with Ca.

Takkar *et al.* (1975) studied the residual effect of 50 kg $ZnSO_4$/ha (and other levels) applied to a light textured Punjab soil in a wheat-groundnut rotation. From the available Zn status of soil after 3 crops, they deduced that the residual effect might last for a further 3 crops. Pathak *et al.*(1978), however, did not find a significant residual effect of a corresponding level of Zn application even in the third rice crop in a rice-wheat rotation. Recently, Bhardwaj and Prasad (1981) confirmed these findings. Earlier, Takkar and Randhawa (1978) had shown that available Zn was depleted faster when wheat followed rice than when it was preceded by groundnut. How rice shortens the duration of residual effect as compared to an upland crop is not clearly understood, although a fall in Zn availability in anoxic soils has been recorded (Brar and Sekhon 1976; Katyal 1977; Haldar and Mandal 1979).

In a rice-rice rotation the build up of Fe availability during lowland rice culture was shown to benefit even upland rice - a crop known for its easy susceptibility to iron chlorosis (Katyal, unpublished data). Recently, it was found that DTPA-extractable Fe, which had accumulated under conditions of intense soil reduction, remained available at least for 8 weeks after the initiation of aerobic soil culture (Table 5). Consequently, upland rice seedlings which would otherwise have failed as a result of Fe deficiency could be raised successfully. In contrast, the introduction of lowland rice in place of a *kharif* upland crop on light-textured, arid Punjab soils low in organic matter has been alleged to result in loss of Mn by leaching. This would explain the recently observed Mn deficiency in the following wheat crop (Takkar and Nayyar 1981).

Table 5 CHANGES IN DTPA-EXTRACTABLE IRON (ppm) UNDER OXIDIZED SOIL CONDITIONS[1]

Treatment	Days				
	0	14	28	42	56
Iron sulphate (20 kg Fe/ha)	18	23	22	23	20
Green manure (10 t/ha)	50	58	58	51	36
Control	16	23	23	24	19

[1] The build up of this iron was achieved previously by submergence for 10 days.

4. CROP YIELD

Regardless of crop, nutrient uptake from the soil is likely to be greater when the total biomass production of a multiple cropping sequence is high (see Table 6). Similar results were obtained by Mehta (1974) who noticed the greatest decline (26 percent) in available Zn, followed by Mo (14 percent). Thus, in high production regions, the soils may quickly become exhausted of at least their Zn reserves. This is in line with the widespread occurrence of Zn deficiency since the introduction of high yielding crop varieties.

Table 6 TOTAL NUTRIENT UPTAKE BY 3 DIFFERENT CROP ROTATIONS

Sr. No.	Rotation	Dry matter t/ha	Uptake (g/ha)					
			S	Fe	Mn	Zn	Cu	Mo
1	Cotton-cowpea+mung	12.1	6 179	1 608	771	187	113	10
2	Groundnut-wheat-*guar*	26.2	13 648	6 966	754	504	223	32
3	Cowpea-cotton-pearl millet	28.2	17 975	7 293	1 219	482	279	30

Source: All India Coordinated Scheme of Micronutrients in Soils and Plants.

5. BULKY ORGANICS AND GREEN MANURING

Kharif crops in general and maize in particular receive liberal dressings of bulky organic manures. Whether due to their direct contribution of micronutrients or to their favourable effect on micronutrient availability through chelation (Katyal 1980), application of organic manures has been shown to enhance micronutrient availability both to the crop to which they were applied and to the succeeding crop (Sharma and Meelu 1975; Biswas *et al.* 1977). Regular application results in a build-up of available Zn, thus countering the imbalance created by crop removal of Zn. Similar advantages occur in respect of available Fe (Honora *et al.* 1979) and S (Swarup and Ghosh 1980).

Introduction of a green manure between main crops in a sequence can have a very large effect on the micronutrient needs of the subsequent crop (Tiwari *et al.* 1980). For example, incorporation of green manure into soil and subsequent submergence is considered the most economic way to alleviate iron deficiency in rice grown in calcareous, sandy soils low in organic matter (Katyal and Sharma 1980).

6. FERTILIZERS

Mineral fertilizers, particularly those of low analysis, contain a number of micro and secondary nutrients either as constituents or as contaminants (Randhawa and Arora 1970; Prasad *et al.* 1979; Swarup and Ghosh 1980). One reason for the wide incidence of S deficiency in Indian crops is the use of S-free fertilizers (Kanwar 1976). Swarup and Ghosh (1980) found that about 50 percent higher build-up of sulphate S could be achieved by application of single superphosphate in place of diammonium phosphate. Likewise, Prasad *et al.* (1979) showed that initially available Fe, Mn, Cu and Zn, which declined in untreated soil, accumulated in soil treated regularly with mineral fertilizers, despite significantly higher crop removal of these nutrients than their addition in fertilizer. Swarup and Ghosh (1980) also observed build-up of Fe, Mn and Cu as a result of fertilizer use, although in their study Zn availability declined after five successive crops (2 wheat, 2 pearl millet, and 1 cowpea), regardless of fertilizer treatment.

Mineral fertilizers can also influence nutrient availability by altering soil pH (Dev and Mann 1972) or by causing an accumulation of particular ions, e.g. the well-known adverse effect of high phosphate on Zn availability.

7. OTHER FACTORS

Several irrigation waters, especially from underground sources, are potent sources of B and S. In contrast to the dramatic response of rainfed groundnuts to B reported by Brar *et al.* (1980), the lack of response of irrigated wheat in Punjab may be explained by the contribution of B to the soil from tubewell water. Similarly, incidence of S deficiency in wheat in a good rainfall year may be due to lack of additions in irrigation water.

Land levelling involving removal of surface soil and exposure of Zn-deficient sub-soil will magnify the need for Zn in the following crop.

Because mineralization of micronutrients to available forms varies with temperature, the micronutrient requirements of crops are affected by the season. In a rice-rice rotation, Samui and Bhattacharya (1973) and Raju *et al.* (1978) reported that *Boro* (spring) rice benefitted more than *Kharif* (summer) rice from

Zn application. Even the responses to B, Cu and Mo were higher in the former than in the latter season (Samui and Bhattacharya 1973).

Upland rice varieties when grown under lowland conditions suffer more from Zn deficiency (Katyal, unpublished data). On the other hand, lowland rice varieties introduced to upland culture can suffer from severe iron chlorosis which is normally absent in the uplands (Kumbhar and Sonar 1979). Samui and Bhattacharya (1973) observed that dwarf IR 8 rice responded to B application while the traditional tall *indicas* did not. Thus, the need of a crop in a rotation for supplemental additions of micronutrients will depend upon the susceptibility of its genotype.

Paper 11 MAJOR RICE-LEGUME COMBINATIONS AND THEIR FERTILIZER MANAGEMENT

J.W. Pendleton[1]

1. PROBLEMS OF ESTABLISHING LEGUMES IN RICE-BASED CROPPING SYSTEMS

An ideal soil environment for the rice plant favours few other plants and especially not legume crops. Growing legumes either before or after rice offers far more challenges than are encountered in most cropping patterns in the temperate zones or non-rice patterns in the tropics or sub-tropics.

Rainfall in many tropical rice areas includes a wet and dry cycle within each year. The monsoon rains start slowly and reach a peak in about 2-3 months. Traditionally rice is transplanted at the peak of the rainfall months so that 2-3 months are available for growing another crop before rice.

Such crops must have at least two important characteristics:

i. early maturity, preferably less than 70 days so land may be adequately prepared for rice;

ii. the ability to tolerate heavy rains during late vegetative growth and during grain formation, i.e. be tolerant to poorly aerated, waterlogged soils and produce grains that do not deteriorate or break dormancy in conditions of high humidity.

Very few legumes meet these requirements. Mungbean, for example, though maturing early, is severely affected by heavy rains at harvest (Godilano and Carangal 1981). The few legumes that may be used are cowpea, vegetable soybeans and other vegetable beans; these can be harvested in less than 75 days and pod deterioration is avoided by harvesting green.

Establishing a legume crop after rice is often more difficult because of a widely used cultural practice called puddling. This is beneficial for rice growing because it minimizes water loss by percolation (Duff and Bandyopadhyay 1966), increases nutrient availability (Ponnamperuma 1977), facilitates transplanting and, when combined with flooding, suppresses weed infestation; but, because of puddling and continuous flooding, the soil is very wet after rice harvest, may remain reduced for a considerable time (Melhuish *et al.* 1977) and can become hard and compact after drainage (Sanchez 1976). Upon drying, phosphate becomes less available than it was before puddling (Melhuish *et al.* 1977; Willet 1977). Most upland crops require a non-compact granular structure permitting aeration for good root growth. Also, after the rice harvest the soil is too wet for land preparation and the planting of upland crops must be delayed, which may cause them to be subjected to drought later, leading to lower yield. Conditions also are

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not favourable for the nitrification process; moreover, little N residues will remain from N fertilizer on the rice.

Under unirrigated and dry season conditions puddled soil develops high moisture stress, so both shoot and root growth are adversely affected and plant nutrient availability reduced (Viets 1972).

Harwood (1975) suggested that bulk density would be a useful parameter in determining the double cropping potential of soils to grow upland crops after puddled flooded rice. He noted that groundnut and maize can be double cropped after puddled rice only in coarse textured soils whereas soybean, mungbean and cowpea can tolerate a wide range of soil physical conditons; vine crops such as watermelons and squash can be grown if mounds are made to improve aeration.

The conversion from puddled to pulverized, well aerated soil is expensive, time consuming (often as much as 1-2 months) and wasteful of residual soil moisture. This can be avoided by seeding legumes in uncultivated paddy fields. Possible ways to increase soil moisture availability to the plant are to induce the roots to grow deeper or to minimize evaporation from the soil surface. Deep fertilizer placement might aid the former, mulching will minimize the latter.

For planting either before or after rice, legume cultivars must have low sensitivity to both temperature and photoperiod. They must be vigorous germinators and have the ability to grow fast. Additionally, resistance or tolerance to the indigenous pests is needed, and an economic yield return.

2. LEGUME NITROGEN CONTRIBUTION TO THE FOLLOWING CROP

Research has shown that legumes improve the soil primarily through symbiotic N fixation although some researchers (Schrader *et al.* 1966; Baldock and Musgrave 1980) have reported additional benefits even when N is not limiting.

Bouldin *et al.* (1979) in a summary of tropical green manures reported:

i. large amounts of nitrogen are fixed provided the legume crop is well managed (Table 1);

ii. from 20 to 60 percent of this accumulated N will be mineralized during a subsequent growing season under a non-legume crop;

iii. soil organic N often accumulates at a faster rate under a legume fallow than other fallows.

Furoc *et al.* (1979) found in the Philippines that dry-seeded rice differed in response to applied N according to the previous crop; after sorghum the rice yield response increased up to the 120 kg N/ha rate whereas after soybean it stopped at about 90 kg N/ha.

Table 1 NITROGEN YIELD OF TROPICAL GREEN MANURE LEGUMES

Legume	Period (months)	Sample	N-fixed (kg/ha)	Place
Cassia leschenaultiana	3.5	Tops + roots	86	Philippines
Phaseolus calcaratus	2.5	Tops + roots	226	Philippines
Desmodium intortum	12.0	Tops only	123	Philippines
Calopogonium mucunoides	6.0	Tops + roots	370	Philippines
Crotalaria usaramoensis	6.0	Tops + roots	535	Philippines
Indigofera spicata	6.0	Tops + roots	331	Philippines
Mucuna deeringiana	-	Tops only	134	Nigeria
Cajanus cajan (L.) Mill	5,5	Tops + roots	228	Hawaii

Source: Bouldin *et al.* (1979)

3. IRRI RESEARCH

Multiple cropping experiments started at IRRI in 1966 and primarily are concerned with rainfed rice since 70 percent of the world's rice is this type.

Aerobic conditions are needed by the dryland crops that succeed rice for germination and root growth. Syarifuddin (1979) drained puddled flooded rice 21, 11 and 1 day(s) before harvest and imposed certain tillage treatments before planting soybean. The earlier the drainage, the lower the soil moisture content, and these differences were present up to 60 days after planting soybean. Early drainage significantly reduced rice yields but shortened turnaround time.

In other IRRI field trials where water was drained one day before rice harvest and the rice straw removed, soybean stands were highest (92 percent) when planted at 6 days after harvest and then decreased to 56 percent at 18 days after harvest; dry weight per plant also decreased.

In a greenhouse experiment, soybeans were planted on the surface and dibbled into puddled flooded rice pots drained 0, 3, 6 and 9 days before rice harvest. Generally dibbling the seed at 3 cm depth gave significantly higher plant stands, higher dry weight per plant and plant height. The earliest drainage decreased plant stands, height, dry weight and number of days to permanent wilting (Syarifuddin 1979).

If minimum tillage or dibbling is practised there should be a several day delay until the soil is drier and more oxygen is present. High tillage (rotavation) resulted in lower soil moisture content for the soybean crop than only row tillage or no tillage treatments (Syarifuddin 1980). Legume plant stands after rice were related to the soil moisture content of the 0-5 cm layer at planting. Syarifuddin (1979) found maximum stand establishment for soybean if the soil moisture content was about 50-60 percent oven dry weight; maximum stand was obtained at 4-6 days after rice harvest when the water was drained one day before. Leaving a high stubble (15 cm) extended the planting date for soybean about 10 days because of the reduction in evaporation.

Planting legumes on ridges has often been beneficial. According to Sahu (1974) green gram, black gram and red gram produced 48, 58 and 30 percent more grain when planted on ridges than when sown in flat beds.

Hundall and De Datta (1981) found at IRRI that mungbean gave relatively higher grain yields following lowland rice than grain sorghum although both extracted similar amounts of water (above 20 cm) from the 0-90 cm root zone. Rooting depth was less when a shallow water table was present. Tillage and water table levels did not seem to greatly affect mung yields.

Relay cropping is a way of conserving moisture when entering a dry period. Simple broadcasting of the legume crop into standing rice before harvest is a least cost way practised by some farmers. Standing water must not be present when this is done.

Studies of seeding methods, rates, and seed soaking of soybean after wetland rice (Syarifuddin 1979) indicated that increasing seeding rate from 60 to 120 kg/ha increased soybean stand by 35-62 percent; drilling instead of broadcasting increased stands by 11-35 percent; and soaking seed for 24 hours increased stand by 9-31 percent.

Tsuboi (1981) found that a rice straw mulch particularly, and inter-row cultivation, increased mungbean yields after rice; there was a significant linear mungbean yield response to increasing rates of rice straw mulch up to 7.5 t/ha. In general, mulches are useful in moisture conservation and tend to increase yields.

IRRI is involved in the testing of small implements that allow crop establishment with zero or minimum tillage following wetland rice. The most promising manual planter appears to be the Rolling Injector Planter (RIP) originally designed at IITA, which has been successfully used to plant mungbean, soybean, sorghum and maize and is believed, with minor modification, to have potential as an injector of granular fertilizer beside the seed (5 cm away) and at approximately the same depth.

4. OTHER CONSIDERATIONS

4.1 Fertility

Liming is essential to obtain legume establishment and maximum nitrogen fixation and yield on acid soils. Prasad and De (1980) reported that the addition of phosphate fertilizer is the first step toward increasing legume production in India. Srivastava and Pathak (1970) also noted that in a rice-legume cropping pattern P fertilizer was more economically beneficial when applied to the legume than to the rice. On soils low in phosphorus, 30-50 kg P_2O_5/ha should be applied. Many studies show a small amount of N applied at planting will stimulate early growth of a legume and make a larger plant more capable of fixing N. Rates of 10-20 kg N/ha are sometimes recommended, but the question remains whether a small farmer would be better off spending his limited funds on N fertilizer for cereals. Band placement of fertilizer is generally more efficient than broadcasting, particularly with a small amount. Deep placement is generally beneficial, especially when the surface layers become dry, but this is difficult for the small farmer with limited animal power.

4.2 Inoculation

Use of the proper *Rhizobium* culture is recommended unless the legume is frequently grown. It may be added either to the seed or to the soil (in the latter case, spreading granular forms in the row may be preferable).

Subba Rao (1980) summarized All India Coordinated *Rhizobium* Project field experiments 1979–80 and reported legume yield from inoculated seeds to exceed the uninoculated control by 5 to 65 percent depending on species and location. Mung and cowpea showed greatest response to inoculum.

Multi-strain inoculants are becoming of increasing interest as a safeguard against inferior performance. Recent IRRI research by Torres and Morris (1981) indicated significant advantages for using certain strains to inoculate seeds of soybeans and a further increase when additional inoculum was placed in the row at planting.

4.3 Cultivars

Less attention has been paid generally to improving dryland crops, particularly legumes, than rice. Secondly, dryland crop improvement in the past has been aimed at monoculture conditions; little effort has been made to develop dryland crop varieties suited specifically for the generally poor physical condition of heavy-textured rice soils. Kanwar (1970) reviewed different responses of crop species and cultivars within fertilizer application and made a strong plea that soil scientists and plant breeders cooperate more closely in the development of cultivars suitable for adverse soil conditions.

4.4 Legume Interplantings

Both laboratory and greenhouse experiments have generally shown little or no direct transfer of N between an associated annual legume and non-legume. Thus, in intercropping combinations of annual legumes and non-legumes grown in separate rows, the latter would be unlikely to benefit from the N fixed by the legume. Only in a perennial grass/legume association has a symbiotic effect occurred. Thus in food crop sequences one is more interested in the contribution of the legume to the following crop.

4.5 Legumes for Forage

In many monsoon tropical areas the availability of forage for ruminants is frequently restricted in the dry season. In high population animal areas there is a need to identify forage legumes to seed into the rice paddies immediately after rice harvest to utilize stored soil moisture and to perhaps benefit both the livestock performance and the long-term maintenance of rice yields.

Shelton and Humphreys (1975a) interplanted upland rice with 2 kg/ha *Stylosanthes guianensis* for several years in Thailand and Laos. The *Stylo* grew slowly and did not influence rice yields, but it accumulated a fair amount of N, which presumably would become available for a succeeding crop. High density planting of *Stylo* (Shelton and Humphreys 1975b) reduced rice yields compared with rice monoculture but *Stylo* production was directly related to planting density.

5. FUTURE

A great potential exists to increase the use of legumes in rice-based cropping systems. A vigorous programme to assemble and screen existing cultivars and legume species for growing before and after rice must be initiated. The first priority should be to improve the grain legumes for food, but strong efforts should concurrently be directed at improving green manure and/or forage types. Perhaps a concerted effort should be made to identify rice genotypes that have the capacity to yield well at moderate fertility levels. The small farmer could thereby get a greater return for a small fertilizer input and more food for his family. However, such a low level approach and resulting low to moderate productivity will not in the long run, feed the millions in the cities or keep food prices low.

All fertilizer research on cropping systems must include careful economic analysis, for the farmer is not interested in more crops per year but in more profits from his land each year. He is also concerned about stability of yield.

Paper 12 FERTILIZER MANAGEMENT IN MULTIPLE CROPPING SYSTEMS UNDER DRYLAND CONDITIONS

R.P. Singh[1]

The experience gained in the All India Coordinated Research Project for Dryland Agriculture has shown that intercropping is a distinct possibility in areas receiving 625 to 800 mm annual rainfall. Double cropping is possible in areas receiving more than 800 mm of rainfall with a storage capacity of more than 20 cm of available water. As a result of concerted research efforts stable and remunerative intercropping systems have been identified for different agro-- climatic regions of the country. Sorghum + pigeonpea; pearl millet + pigeonpea sorghum + green gram; sorghum + soybean; groundnut + pigeonpea; foxtail millet + pigeonpea are some of the examples where it is possible to harvest almost the full yield of the cereal component and a bonus yield, of the order of 60 percent, of the companion legume crop.

A great boost to the programme of increasing pulse and oilseed production in the country could be given by the following double cropping systems in the Vertisols of Vidarbha and the Malwa plateau, Gangetic alluvial belts, and the sub-humid red soils of the North-East India. Chickpea could follow rice in the Gangetic alluvial plains and maize in the Kandi belt. Sorghum or green gram can be followed by safflower in the Vidarbha region. Maize-safflower, sorghum-chickpea and maize-chickpea are some of the possible crop sequences which can be followed in the Malwa plateau. Rice-lentil and rice-horsegram are suitable crop sequences for the Chotanagpur plateau and Orissa sub-humid red soils, respectively.

Two major constraints have been moisture stress and nutrient stress. Extension of irrigation systems to provide partial supplemental irrigation to drylands is one potential means to release moisture stress. However, with all the best efforts put in by all concerned, more than 50 percent of the cultivated area in the country will continue to be rainfed. The best solution seems to lie in the balanced use of manures and fertilizers tailored to soil moisture status and cropping system.

1. PROBLEM NUTRIENTS IN DRYLAND CROP PRODUCTION

Most of the drylands are deficient in nitrogen. Experience has shown that given an optimum rate of N the response of dryland crops, in particular cereals, has been as good as, if not more than, on irrigated lands in normal and above normal rainfall years. Nitrogen use efficiency has been found to increase manifold by placing the nutrient in the moist zone for post-rainy season crops and as split applications for monsoon season crops. Phosphorus has been found to be deficient in red, laterite and acid soils, and low to medium in black and

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alluvial soils. Phosphorus use efficiency is improved by placing water-soluble phosphate below the seed or by the side of seeded rows in the moist zone. With intensive cropping in more assured rainfall areas K and Zn deficiencies are likely to appear in future. In the Saurashtra region of Gujarat, S deficiency limits production of groundnut. Al toxicity poses a serious problem in acidic soils. Liming has shown distinct promise in the establishment, growth and productivity of dryland crops in acidic and lateritic soils.

2. FERTILIZER MANAGEMENT IN INTERCROPPING SYSTEMS

Research initiated in the early fifties and intensified in the early sixties was mainly directed towards finding suitable crop mixtures and intercropping systems for drylands. Systematic efforts were made in the mid-seventies to work out the optimum plant populations of the principal and companion crops suitable for a given region. Fertilizer management in intercropping systems first received attention in 1975 at the Central Arid Zone Research Institute, Jodhpur (Singh and Singh 1977). Application of N to sunflower grown either as a pure crop or in association with green gram or cowpea gave a significant seed yield response in both 1975 and 1976. The results suggest that the inclusion of legumes like green gram and cowpea in the intercropping systems can lead to a saving of nitrogen to the extent of 30 kg/ha. The total productivity amd monetary returns obtained from the intercropping systems increased with an increase in the level of nitrogen application.

In the sorghum + pigeonpea (2:1) intercropping system on red *'chalka'* (sandy loam) soils of Hyderabad it was found that P applied either all to sorghum or half each to sorghum and pigeonpea did not affect the yield of pigeonpea significantly, but application of the full dose of phosphorus to sorghum gave these rows a definite advantage (Table 1).

Table 1 GRAIN YIELD (T/HA) OF INTERCROPPED SORGHUM AND PIGEONPEA (2:1) AS AFFECTED BY N AND P, HYDERABAD (1976-80)

Treatment	Yield (t/ha)	
(N + P_2O_5 kg/ha)	Sorghum	Pigeonpea
45 (sorghum) + 30 (sorghum + pigeonpea)	1.73	0.67
45 (sorghum) + 30 (sorghum)	2.19	0.61
30 (sorghum) + 30 (sorghum + pigeonpea)	1.85	0.68
30 (sorghum) + 30 (sorghum)	2.02	0.61

Studies carried out on fertilizer management in wheat + chickpea seed mixture (2:1) grown under different fertility levels on loamy sand, sandy loam, and clay loam soils revealed that application of N and P resulted in the highest total productivity on clay loam soil, followed by sandy loam and loamy sand soils, suggesting that the response is directly related to moisture storage capacity of the soil and available water. In general, the response to N application up to 60 kg/ha was linear, whereas except on the clay loam soil, the response to 20 kg P_2O_5/ha was not discernible. Recent experimental evidence from the Hissar centre has revealed that application of half the recommended rates of N and P resulted in almost the same yield levels of principal and companion crops, irrespective of the quantity of rainfall received during the season. The results are encouraging in as much as a saving of nutrient could be effected.

3. FERTILIZER MANAGEMENT IN SEQUENTIAL CROPPING SYSTEMS

3.1 Semi-arid seasonally dry conditions

3.1.1 Alluvial soils

Among the short duration fodder crops, the fodder legumes (cowpea, clusterbean and dewgram) tried at the Indian Agricultural Research Institute, New Delhi (Giri and De 1981), produced less biomass than the non-legume pearl millet fodder. However, the soil fertility enrichments from the legume fodders, equivalent to 40 kg N/ha or more, were highly beneficial to the succeeding barley crop. In a previous study Giri and De (1979) reported benefits from grain legumes like groundnut or cowpea grown for the full season to be equivalent to 60 kg N/ha on the subsequent crop of pearl millet. Studies at the Agra Dryland Centre showed that post-monsoon mustard seed yield was significantly higher when taken after pearl millet + cowpea, than after pearl millet + clusterbean or sorghum + cowpea or sorghum + clusterbean combinations, and that increased levels of N applied to the monsoon crops led to significantly increased yields of mustard.

3.1.2 Medium black soils

Recent experiments at Hyderabad showed that in the sorghum-sorghum cropping system the grain yield of the second sorghum crop increased progressively with increasing N. For fallow-sorghum, cowpea (grain)-sorghum and cowpea (green manure)-sorghum, application beyond 15 kg N/ha did not confer any additional advantage in sorghum yield. This could be explained by the higher nitrate-N build up in the fallow and cowpea plots, preceding sorghum. The harvest index for sorghum-safflower was invariably higher than for fallow-safflower, irrespective of fertilizer treatment. For sorghum-safflower the harvest index was highest with 40 kg N and 30 kg P_2O_5/ha, followed by 40 kg N/ha. This suggests that in order to obtain the full yield potential, both crops in the sequence should be judiciously fertilized (Das *et al.* 1982). For sorghum-sorghum, application beyond 30 kg N/ha to sorghum (CSH-6) taken after sorghum receiving 60 kg N/ha did not give any additional grain yield, neither was there any significant difference whether N was applied to the preceding sorghum as urea or CAN. In studies at the Akola Dryland Centre of fertilizer use for sequence cropping systems of green gram-safflower and black gram-safflower, the beneficial effect of taking a green gram crop in the monsoon was reflected in the seed yield of safflower.

3.1.3 Red soils

At Bangalore, timely-sown (July) finger millet had a definite advantage over finger millet taken after a grain legume, fodder legume or green manured legume, in which case the sowing of finger millet gets considerably delayed.

3.2 Sub-humid Conditions

3.2.1 Submontane soils

In sequential maize-wheat on sandy loam and loamy sand soils of Ludhiana, N application to maize at 60 kg/ha benefitted the maize but not the succeeding wheat crop; N application to the wheat up to 80 kg/ha resulted in progressively higher grain yields of wheat on both soils. For sequential maize-wheat on silty loam soil, P application to both maize and wheat is indicated.

3.2.2 Alluvial soils

Trials at the Varanasi Centre on N management for sequential cropping of maize-wheat, maize-barley, maize-mustard, black gram-wheat, black gram-barley and black gram-mustard gave response data fitting the following response equations (Chetty 1981):

i. Wheat after maize : $y = 13.7158 + 0.115427\ x$

ii. Barley after maize : $y = 13.088 + 0.37328\ x - 0.00244126\ x^2$

iii. Mustard after maize : $y = 3.752 + 0.05492\ x$

iv. Wheat after black gram : $y = 14.863 + 0.8820\ x$

v. Mustard after black gram: $y = 4.277 + 0.14520\ x - 0.0017954\ x^2$

where y = expected yield (100 kg/ha) and x = N kg/ha

There was a linear response to N applied to wheat in both the systems. Optimum N to barley after maize was 76 kg N/ha. No equation could be fitted for barley after black gram, but there were indications of a significant response up to 90 kg N/ha. Mustard gave a linear response up to 60 kg N/ha after maize, but the optimum after black gram was 40 kg N/ha. Only mustard seems to have benefitted by residual fertility after black gram, to the extent of about 20 kg N/ha.

3.2.3 Medium black soils

At Rewa, there was no significant advantage to pigeonpea from increasing N applied to the preceding monsoon crop of paddy.

3.3 Arid Sierozem Soil Conditions

Under arid conditions modest annual fertilizer application (20 kg N + 10 kg P_2O_5/ha) to pearl millet is indicated for continuous pearl millet cropping.

In a long-term study at the Central Arid Zone Research Institute, Jodhpur (Singh *et al.* 1981), the highest productivity was obtained when green gram was inoculated with *Rhizobium* and fertilized with 40 kg P/ha, followed by pearl millet top-dressed with 20 kg N/ha.

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Paper 13 TRANSFER OF SOIL TESTING TECHNIQUES USED FOR SINGLE CROPPING TO MULTIPLE CROPPING AND FORMULATION OF FERTILIZER RECOMMENDATIONS - PROSPECTS AND PROBLEMS

M. Velayutham and A.B. Ghosh[1]

The determination of optimal fertilizer rates is largely based on multi-location one season fertilizer rate trials for individual crops separately. These often reveal great variation in response to the major nutrients from site to site, season to season and crop to crop.

A new technique of soil test crop response correlation investigation has been developed in the All India Coordinated Project based on the initial results obtained at the Indian Agricultural Research Institute by Ramamoorthy and his associates. The details of this approach are as follows: the needed range in soil test values and responses is established in a field of about 0.5 hectare which is divided into four strips lengthwise and given graded levels of fertilizers. An exhaust crop is grown on this field and in the subsequent season the test crop is taken up, using a fractional factorial design with 21 N, P K fertilizer treatments distributed at random in each of the four strips. A few control plots (6 to 9) are also distributed at random in each of the four strips. The relationship between soil test values, fertilizer rates and crop yield is established by quadratic multiple regression (Ramamoorthy and Velayutham 1971). From significant relationships of such soil test/crop response field experiments having an R^2 value above 0.66, adjustments are derived for varying soil test values for obtaining maximum yield, maximum profit per hectare and maximum profit per unit investment in fertilizer as illustrated by Ramamoorthy *et al.* (1974). Fertilizer calibrations for different soil-crop situations in India as derived from such studies were reported by Velayutham *et al.* (1980).

By this field experimentation technique, Ramamoorthy *et al.* (1967) showed that Liebig's Law of the Minimum operates equally well for N, P and K for the high-yielding varieties of wheat, rice and pearl millet although it is generally believed that this law is valid only for N and not for P and K. Their work with Sonora-64 wheat showed the importance of the associated nutrients in determining the value of response to N and the need for balanced nutrition in making efficient use of fertilizers. The significant correlation between nutrient uptake and grain yield substantiated the idea of a definite nutrient requirement for any given yield target. This formed the basis for <u>fertilizer application for a target yield of crops</u>, taking into account (i) nutrient requirement in kg per 100 kg of produce (grain or other economic part); (ii) percent contribution from soil available nutrients; and (iii) percent contribution from the applied fertilizer nutrients. In this way, benefits due to the real balance between nutrients both applied and native and the priming action of fertilizer on the utilization of soil

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nutrients are maximized, as discussed by Ramamoorthy and Pathak (1969). In the national Soil Test Crop Response Project, the fertilizer recommendations derived for targetted yields of crops have been tested in follow-up trials on experimental farms and cultivator's fields which show that achieved and targetted yields agreed with each other within about ± 10 percent. The dimensions of this concept and prospects for fertilizing multiple cropping systems were discussed by Velayutham (1979).

1. FERTILIZER RECOMMENDATIONS

Farmers grow crops in a set sequence in a field and not in isolation. Therefore, whether it is a general fertilizer recommendation or a soil test-based fertilizer recommendation, the needs of the cropping sequence as a whole have to be taken into account. Even the refined soil test-based fertilizer calibrations are normally derived from field experiments that are conducted separately both in the context of time and space. Fertilizer use practices and changes in soil fertility during the course of the cropping sequence are influenced by: (i) the nature of the crop and its effect on the succeeding crop in the sequence; (ii) the nature of the cropping sequence itself: cereal-cereal rotations or rotations involving legumes for seed/fodder/green manures and various other combinations; (iii) the residual effect of fertilizers and organic manures; (iv) the extent of nutrient fixation in different soils; and (v) the dynamics of soil fertility status at intervals of the cropping sequences. Although the effects of these factors have been studied separately in agronomic field experiments, seldom has their composite effect during the cropping sequence as a whole been investigated. In the absence of such studies, the only recourse left is to use the available soil test-based fertilizer calibration information on individual crops and modify it for the effects of the above-mentioned factors. Sekhon (1974) had emphasized the agronomic inferences that could be utilized in making fertilizer recommendations for multiple cropping.

Ideally the optimum fertilizer requirements of multiple cropping systems have to be determined *per se* at a given site on a medium-term basis and also integrated for calibration of fertilizer requirement with soil test values for the crops involved in the system. The importance of such complex field experiments was emphasized by Kemmler and Malicornet (1976). The technique of field experimentation being adopted under the National Soil Test Crop Response Project will be suitable for such investigations not only for predicting fertilizer requirements but also for predicting the changes in soil test values between crops in the sequence. The latter is all the more important because, in practice, it will not be feasible to provide timely soil testing to farmers at the beginning of each crop season. Ramamoorthy *et al.* (1971) and Singh and Ramamoorthy (1974) showed that it was possible to predict the changes in soil test values after each crop so that fertilizer recommendations for a target yield of crops in different rotations could be made, based only on the initial soil test values of the field. They also showed that, for the sandy loam alluvial soils of Delhi, a pearl millet-wheat rotation is inferior to a rice-wheat rotation when the value of the resultant soil fertility of the land is taken into account. Aggarwal and Ramamoorthy (1978) reported how multiple regression analysis of the initial soil test values and other soil parameters could be used to predict post-harvest soil test values with sufficient agreement between the calculated values and the analytically determined values. Velayutham and Rani Perumal (1976) were also able to predict post-harvest soil test values from multiple regression analysis for the three major nutrients in the alluvial soils of Tanjore district in Tamil Nadu which can form a basis for making fertilizer recommendations for a rice-rice sequence.

2. SOIL FERTILITY MAINTENANCE UNDER MULTIPLE CROPPING

Soil fertility maintenance and fertilizer use efficiency have two opposing dimensions. If soil fertility is to be maintained or even increased, heavier rates of fertilizer have to be used so that enough residuals are left in the soil. But this will not make the most economic return from investment because part of the added fertilizer is allowed to remain in the soil for a longer period thereby increasing the chances of unavailability by leaching and fixing. Work under the Coordinated Soil Test Crop Response Correlation Project has shown that the greatest profit per unit of fertilizer investment would accrue if fertilizer is applied on the basis of targetted yield. In this approach, the available nutrients unutilizable under unfertilized conditions will become fully utilizable. The native soil nutrients will make a large contribution to increase yield at low yield targets with no additional investment. This would mean application of lower rates of fertilizer and exhausting of the unutilized excesses from the soil. The soil fertility would, therefore, decrease as a result of this exhaustion. By choosing appropriate yield targets in relation to the soil fertility status, the twin objective of achieving high yields with high profit from fertilizer investment and maintenance of soil fertility can be realized (Velayutham and Singh 1981).

Paper 14 ROLE OF LEGUMES IN MULTIPLE CROPPING SYSTEMS WITH REFERENCE TO N FIXATION AND SOIL MANAGEMENT

N.S. Subba Rao [1]

1. INTRODUCTION

In 1904, Hiltner, a German scientist, recognized the fact that plant roots influence the abundance or the decline of microorganisms in their vicinity. Subsequently, a good deal of work has been done in Canada, Australia, UK and India to establish the fact that the 'rhizosphere', the soil under the influence of plant roots, harbours more microorganisms than the 'non-rhizosphere' soil away from the influence of the root system by virtue of amino acids, organic acids, sugars, vitamins and growth factors elaborated in the root region (Katznelson 1946; Clark 1949; Subba Rao *et al.* 1961, 1962; Rovira 1969). Currently, the rhizosphere has regained its pre-eminence as the crucial region where plant--microorganism interaction can be judiciously manipulated to satisfy the plants' nutritional requirements at an optimum level, so that fertilizer application may be minimized to save non-renewable resources of energy on the farm (Subba Rao 1977, 1979, 1982a, 1982b). Equally important is the need to scientifically tailor the microbial requirements of the rhizosphere by applying tested microbial inoculants to seed or soil.

The structural status of soil is vital to crop growth and is indeed more vital to root establishment. Even a fertile land is rendered barren by poor soil structure. A good water-stable aggregation of soil particles is a precursor to an ideal soil structure. Soil aggregation is a product of many physical, chemical and biological processes. Factors contributing to the cementation of soil particles are many and include the clay content, soil organic matter, the ligno-protein complexes, sugar polymers, waxes, resins, mucilaginous compounds, a host of organic compounds exuded by plant roots and the microbially synthesized polysaccharides. Fine rootlets, root hairs, fungal mycelia notably those of *Cladosporium*, *Penicillium* and *Trichoderma*, actinomycete propagules and bacterial slime aid in holding the soil particles together and let the roots breathe (Prabhakara 1970, 1974). The available data do not permit us to overemphasize the role of soil polysaccharides, much less the microbially synthesized polysaccharides in soil aggregation (Mehta *et al.* 1960; Allison 1968), but it is clear that such microbially synthesized gums act in conjunction with the root biomass to maintain soil structure at the desired level.

2. RHIZOBIUM INOCULANTS IN MULTIPLE CROPPING

The microbial inoculants which can be used in multiple cropping are shown in Tables 1 and 2. Many of the legumes (cowpea, red gram, *guar*, mung) demand

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Table 1 LEGUMINOUS CROPS USED IN MULTIPLE AND RELAY CROPPING AND RECOMMENDED BACTERIAL INOCULANTS UNDER INDIAN CONDITIONS

Mung *(Vigna mungo)*	*Rhizobium* sp. (cowpea group), effective strain
Cowpea *(Vigna sinensis)*	"
Berseem *(Trifolium alexandrinum)*	*Rhizobium trifolii*, effective strain
Arhar or red gram *(Cajanus cajan)*	*Rhizobium* sp. (cowpea group), effective strain
Peas	*Rhizobium leguminosarum*
Guar (Cyanopsis tetragonoloba)	*Rhizobium* sp. (cowpea group), effective strain
Soybean *(Glycine max)*	*Rhizobium japonicum*
Lucerne *(Medicago sativa)*	*Rhizobium meliloti*
Senji (Trigonella foenum-graecum)	*Rhizobium meliloti*
Gram or chickpea *(Cicer arietinum)*	*Rhizobium* sp.

Table 2 SOME NON-LEGUMINOUS CROPS USED IN MULTIPLE AND RELAY CROPPING AND RECOMMENDED BACTERIAL INOCULANTS UNDER INDIAN CONDITIONS

Maize *(Zea mays)*	*Azotobacter*	*chroococcum*	
Bajra (Pennisetum americanum)	*Azospirillum*	*brasilense*	
Cabbage *(Brassica* sp*)*	*Azotobacter*	*chroococcum*	
Radish *(Raphanus sativus)*	"	"	
Sorghum or *Jowar (Sorghum bicolor)*	*Azospirillum*	*brasilense*	
Cotton *(Gossypium* sp*)*	*Azotobacter*	*chroococcum*	
Onion *(Allium cepa)*	"	"	
Tomato *(Lycopersicon esculentum)*	"	"	
Brinjal (Solanum melongena) (eggplant)	"	"	
Rice *(Oryza sativa)*	"	"	and/or blue-green algae

specific serotypes of *Rhizobium* sp. which possess the ability to outcompete the native inefficient rhizobial strains because these legumes are generally nodulated by *Rhizobium* sp. (cowpea group). However, *Cicer* rhizobia nodulating *Cicer arietinum* appear to be different because they do not show cross-inoculation affinity with any of the members of the known cross-inoculation groups such as alfalfa, clover, pea, bean, soybean, lupin-lotus and the cowpea miscellany except for some loose non-reciprocal kinship with *Sesbania*, which in its turn has a strong affinity with the cowpea miscellany. Therefore, it has been suggested that *C. arietinum* and its root nodule bacteria should be considered in a separate cross-inoculation group (Gaur and Sen 1979).

The work at IARI has shown that maximum benefit from *Rhizobium* inoculation can be obtained when the strain used for inoculation is a highly efficient nitrogen fixer and is able to compete successfully with native rhizobial strains in attempting to occupy infection sites on the root system. Conventional screening methods do not reveal the identity of strains which possess high competitive ability. It is quite often for this reason that inoculation with a highly efficient N-fixing strain fails to produce a significant increase in yield over native rhizobial strains. Serological methods have enabled us to distinguish the dominant serotypes of *Cicer* rhizobia in Indian soils and so to select the most efficient N-fixing *Cicer Rhizobium* which has also the best competitiveness for a particular soil. Grain yield increases of 112 to 120 percent in chickpea by *Rhizobium* inoculation with such strains have been demonstrated.

In groundnut the problem of 'promiscuity' of cowpea rhizobia, which enables this group to cross-infect several host plants and produce nodules, has posed problems in realizing maximum benefits from rhizobial inoculation. Rhizobia from different legumes have been found to nodulate roots of groundnut and, likewise, rhizobia from root nodules of groundnut have been found to nodulate roots of several species of indigenous legumes (Gaur *et al.* 1974).

3. CULTIVAR AND RHIZOBIUM SPECIFICITY

There seems to be specificity of rhizobial strains to cultivars which has to be borne in mind in inter, multiple and relay cropping. For example, strains isolated from root nodules of the cultivated species of groundnut (*Arachis hypogea*) and other wild species of *Arachis* such as *A. duranensis*, *A. prostrata*, *A. villosa*, *A. glaberata* and *A. marginata* differ in effectiveness on one another. Some isolates from *A. duranensis* were most effective on *A. hypogea* whereas all the isolates from other wild *Arachis* species were least effective. No cross-reaction was observed between isolates from *A. hypogea* and the antisera of isolates from *A. marginata* and *A. glaberata*. Similarly, the antisera of isolates from *A. hypogea* did not react with the antigens of *A. glaberata* and *A. marginata* strains. On the other hand, the antisera of isolates from *A. villosa* and *A. prostrata* showed a wide spectrum of cross reactivity (Dadarwal *et al.* 1974).

Continuing these studies at the field level, it was conclusively demonstrated that a serotype isolated from *A. duranensis* proved to be highly competitive and exerted selective displacement of native strains for nodulation and increased grain yield of cultivated *Arachis hypogea* (Singh *et al.* 1976).

Similar varietal specificity for rhizobial serotypes has been shown with chickpea (*Cicer arietinum*), pea (*Pisum sativum*), soybean (*Glycine max*) and green gram (*Vigna mungo*) (Dadarwal and Sen 1974).

4. INOCULATING THE PRECEDING CEREAL CROP WITH *RHIZOBIUM* FOR IMPROVED LEGUME-*RHIZOBIUM* SYMBIOSIS

In a cereal-legume crop rotation system, better *Rhizobium* symbiosis was obtained by double inoculation, i.e. when the preceding maize was also inoculated with the same *Rhizobium* strain which was used to inoculate the following legume crop of green gram or groundnut (Gaur *et al.* 1980). This was reflected in the greater volume of nodules, more dry weight of shoot and final grain yield.

5. SURVIVAL OF RHIZOBIA IN CARRIERS

Soil based cultures were in use till 1960 which was not desirable in view of the low moisture-holding capacity of soil. In 1972, peat-soil from Ootacamund was found to be a good substitute. Although inferior in quality to its counterpart in USA, Australia and other places, Indian peat provides more water-holding capacity than soil. Lignite from Neyveli in Tamil Nadu is another carrier. Among other carriers tried, charcoal or charcoal-amended carriers appear to be desirable for longer survival of the organism (Tilak and Subba Rao 1978).

6. A LOW COST INCUBATOR FOR SMALL FARMERS FOR STORING CULTIVARS

There is an urgent need to devise inexpensive means to store cultures at the small farmers' level. Work at IARI has clearly shown (Philip *et al.* 1982) that a mudpot (20 l cap., with a wide mouth and lid), buried in soil under the shade of a tree and covered with a thick layer (6-8 inches) of river sand (except the lid), would serve the purpose of reducing the atmospheric temperature in the pot by about 7°C. The numbers of rhizobial cells which survived in the mud pot were higher than outside.

7. INOCULATION OF CEREALS AND MILLETS IN MULTIPLE CROPPING

The use of *Azotobacter* and *Azospirillum* can be recommended in multiple cropping wherever they have shown clear benefits either in improving plant stands or in increasing grain yields even marginally. The IARI scientists have demonstrated the benefits of *Azotobacter* inoculation on cotton (Shende, unpublished). The utility of *Azospirillum brasilense* inoculation on millets has been shown conclusively in the All India Coordinated experiments with millets. The field results obtained with sorghum (*Sorghum bicolor*) and pearl millet (*Pennisetum americanum*) have been noteworthy.

8. BLUE-GREEN ALGAE AND AZOLLA INOCULATION TO AUGMENT RICE YIELDS IN MULTIPLE CROPPING

The ability of blue-green algae to fix atmospheric N in rice fields has been explored recently (Venkataraman 1972; Singh 1977; Shrinivasan and Ponnayya 1978), showing that yield increases by these inputs are indeed worthy of exploitation at farmer level.

Paper 15 THE NEED FOR SUITABLE IMPLEMENTS FOR FERTILIZER APPLICATION IN MULTIPLE CROPPING SYSTEMS WITH SPECIAL REFERENCE TO SMALL FARMERS

G.E. Thierstein and T.J. Rego[1]

1. INTRODUCTION

The most common forms of fertilizer used by small farmers are organic manures and solid inorganic fertilizers (powder, crystals or granules). There is good machinery available for applying organic solids on large tractorized farms but virtually nothing has been done along similar lines for the small farmer. His options are usually limited to manually loading the FYM on a cart, transporting it to the field, and again manually unloading and spreading it. Most of the machinery development, including that at ICRISAT has been devoted to applying inorganic solids (Bansal and Thierstein 1982; ICRISAT 1979, 1980).

2. FERTILIZER USE IN THE INDIAN SEMI-ARID TROPICS

There are few estimates of fertilizer use in dryland crops in India. A recent study from ICRISAT (Jha and Sarin 1980) estimated inorganic fertilizer consumption in 192 Indian districts classified as semi-arid tropics (SAT). In 14 "unirrigated" (less than 25 percent of the area irrigated) districts the average usage was 18.5 kg N + P_2O_5 + K_2O/ha as against 57.5 kg/ha in 78 "irrigated" SAT districts. In fact less than 18.5 kg/ha nutrients have probably been used on dryland crops because farmers in those "unirrigated" areas normally use more fertilizer on their irrigated lands than on the unirrigated area. Also in rainfed areas the spread of fertilizer use is probably in the sequence of cotton and groundnut > sorghum and mustard > mustard > millets pulses (Tandon 1981).

Much of the fertilizer use appears to be directly related to the introduction and acceptance by farmers of high-yielding varieties (HYVs). As an example, Jha *et al.* (1981) used data from 21 SAT districts in India growing sorghum and 23 SAT districts growing pearl millet. In 18 districts at least 75 percent of the farmers fertilized their unirrigated HYV sorghum and in 10 districts 30 percent or more of the farmers fertilized their HYV pearl millet (the latter is generally grown in areas of lower rainfall and therefore the response to fertilizer is likely to be lower than in sorghum). In 12 districts growing sorghum the application rate for this crop was more than 30 kg N + P_2O_5 + K_2O. In 17 districts growing pearl millet the rate was over 30 kg/ha.

3. CROP RESPONSE TO FERTILIZERS

Significant response of crops to fertilizer application under rainfed

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conditions has been obtained both on research stations (Choudhury 1979; De 1979; ICAR 1979; Kanwar 1977, 1980; Randhawa and Venkateswarlu 1980; Spratt and Choudhury 1978; Venkateswarlu 1979; Venkateswarlu and Spratt 1977) and from trials conducted in farmers' fields (Kanwar *et al.* 1973; Mahptra *et al.* 1973; Singh *et al.* 1979). Response to N is almost universal under good growth conditions. For example, the grain yield responses to N application vary from 3.4 to 43.4 kg grain/kg N in sorghum and 2.1 to 24.8 kg grain/ha N in millet (ICAR 1982).

Similarly sizeable responses to applied P have been obtained. In sorghum 2.4 to 59 kg and in millet 1.7 to 14.3 kg of grain/kg P_2O_5 have been obtained (ICAR 1982). Trials on farmers fields also recorded impressive grain yield responses to applied N and P.

4. FACTORS AFFECTING FERTILIZER RESPONSE

A large number of factors affect the growing conditions of crops and thus affect the response to any nutrient (ICAR 1979), e.g. variety, soil and crop management, time and method of fertilizer application, and water management. Preliminary work done at ICRISAT where the average rainfall is about 780 mm/year indicates that in deep Vertisols there is enough moisture in most years to take two crops per year. However, positional availability of plant nutrients in the post-rainy season is very important for the success of a crop planted at that time. Deep placement of fertilizer in the moist zone is essential under such receding soil moisture conditions (Moraghan *et al.* 1981, Rego *et al.* 1982). Therefore the need of a suitable implement to place the fertilizer in the deep moist zone is critical. Even in the rainy season, band placement of N fertilizer has resulted in better utilization of N than broadcasting (Moraghan 1981). In order to place the fertilizer in a band uniformly at a given depth a suitable seed-cum-fertilizer drill is required. Dry planting in Vertisols is considered a pre-requisite for the success of the double cropping system and timeliness of sowing is very crucial, which again emphasizes the need for suitable equipment.

There is little benefit of intercropped legume on adjacent cereals especially when the cereals are fertilized. However, a sole legume or intercropped legume does have some residual effect on the subsequent crop in a rotation (Rao 1981). Thus in fertilizer management of intercrops one should ideally apply different quantities of nutrients to cereals and legumes and also one may need to top-dress the cereal. Therefore a fertilizer drill which applies a uniform rate of fertilizer for each row of a sole crop is probably inefficient in the application of fertilizer in an intercrop. In relay cropping the problem will be still more complicated. One needs low cost, efficient, and simple seed and fertilizer placement machinery for improved cropping systems.

5. TRADITIONAL METHODS OF APPLYING FERTILIZER

The Indian farmer has traditionally applied fertilizer in several ways. The simplest method is to broadcast by hand. The disadvantages are that application is often not uniform and for many conditions the crop makes less efficient use of fertilizer than when it is banded near the major crop root zone.

Indian farmers also practise banding of fertilizer. The local wooden plough is commonly used to make a furrow into which the seed is manually dropped. In some cases fertilizer is also dropped into the same furrow. With low application rates this is acceptable but at higher rates it can depress and even prevent seed germination (Smith 1965). An alternative is to place the seed in one furrow and the fertilizer in the adjacent furrow. The disadvantage is that seed and fertilizer are then separated by at least 10-15 cm, causing considerable delay before the seedling roots can reach the fertilizer and accelerate growth. It is important that the seedling receives a quick and vigorous start. This helps to ward off insect attacks, provides better competition against weeds and ensures the development of a strong, healthy root system which allows the seedling to tap a greater volume of soil moisture.

Some Indian farmers use a multi-row (usually three-row) seeder in which the seed is metered by hand into a funnel with three hollow bamboo tubes to the furrow openers. Some attempts have been made to use this type of seeder to apply fertilizer simultaneously by adding a second funnel system (Venkata Nadachary and Kidd 1981). In theory the fertilizer should be placed below the seed but it depends very much on the condition of the soil as to whether there is adequate separation of the seed and fertilizer. In methods where fertilizer is manually metered the rate of application is usually variable and quite low. For a uniform and higher application rate mechanical metering is necessary.

6. MACHINES FOR FERTILIZER APPLICATION

Machinery used for the application of fertilizer can be categorized in several ways:

i. Fertilizer can be broadcast or it can be placed in bands.

ii. Fertilizer can be metered through a simple gravity flow orifice or a positive metering mechanism can be used.

iii. Machines designed for placing fertilizers in bands can have single or multiple row applicators.

iv. The fertilizer can be applied in proximity to the seed or it can be placed at specified horizontal and vertical distances from the seed.

A good fertilizer distributor should be capable of:

- applying a wide range of application rates,
- applying different types of material accurately and evenly,
- easy alteration of the application rate,
- placing the fertilizer in the soil so it will not injure the seed,
- easy dismantling and cleaning, as metal parts are quickly corroded.

Two other criteria are important considerations when developing fertilizer distributors for small farmers:

- The draft requirement of the machine should not exceed the power available, which is usually one or two animals.

- Cost is a major factor in successful adoption. Economy in the use of materials and simplicity in design to keep manufacturing simple and production costs low are important factors to be considered (Bansal and Thierstein 1982).

The proper application of fertilizer is the key to efficient fertilizer use (Harris *et al.* 1974; Smith 1965). In broadcasting, fertilizer is spread as uniformly as possible to the entire soil surface area that is to be cropped. If the fertilizer is to be incorporated into the soil it must be followed by the use of a tillage implement. Banding application can be either on the soil surface or in the soil. Bands are usually placed near the crop so the roots can reach the fertilizer easily and quickly.

Fertilizer distributors are either unit or continuous machines. In a unit distributor there is a separate hopper, metering mechanism and rate adjustment device for each crop row. Thus the type and quantity of fertilizer applied can be varied for different crops planted simultaneously in adjacent rows. In the continuous type, the same type and quantity of fertilizer is distributed across the entire width of the machine. The hopper is not divided or compartmentalized to permit more than one type of fertilizer to be applied. The mechanism for altering the application rate is designed so that a single adjustment mechanism controls all the discharge points simultaneously.

Because fertilizer is hygroscopic, the flow rate through a machine depends on the atmospheric relative humidity unless a positive metering device is used. Metering is also dependent on whether the fertilizer is in powder or granular form. Granular fertilizer is easier to meter accurately.

A number of fertilizer drills with mechanical metering devices have been developed and are being manufactured in India (Chauhan and Kumar 1972). Some use a gravity feed in which the orifice size is varied to control the application rate and an agitator is provided to keep the fertilizer flowing. The metering device is simple and relatively inexpensive but it has the disadvantage of uneven metering which depends on the roughness of the terrain over which the machine is travelling (rough terrain increases the flow rate) and on the speed of forward travel. In some of these machines it is possible to use a different orifice size for different rows so that the application rate can be varied for different crops.

Other fertilizer drills use positive metering devices so the rate of fertilizer application can be more precisely controlled. Most are multiple row machines and the metering device is usually controlled in such a way that the same fertilizer rate is applied to all the rows. Very few of the multi-row fertilizer hoppers are divided or compartmentalized to permit different fertilizers to be applied to different cultivars in one pass across the field.

7. PROBLEMS OF APPLYING FERTILIZER IN MULTIPLE CROPPING

One of the problems in applying fertilizer to multiple cropping systems is to apply different types and/or quantities to the different crops being planted in adjacent rows. This can be overcome by using unit fertilizer distributors, but a separate drive mechanism is then required for each unit which increases the complexity and cost. Our initial efforts at ICRISAT were along this line, but this has been abandoned in favour of a simple design and lower cost system which has the disadvantage of applying the same fertilizer to each crop row, with the only option of applying no fertilizer to certain rows. It would be easily possible to separate the hopper into different compartments so that different fertilizers can be applied simultaneously but they would still have to be applied at the same rate.

The second problem is that during the post-rainy season it is necessary to place both the seed and fertilizer at a considerable depth, possibly down to 15 cm. In planting three to five rows at a time considerable draught is required to pull furrow-openers at that depth. The available draught is limited when using bullocks as the source of power. The task can be made easier if fertilizer and seed can be applied in separate operations; but when operating under normal flat conditions, it is difficult to operate a machine in the same line twice to ensure that the seeds are placed in close proximity to the fertilizer. The use of a bed and furrow system alleviates much of this problem as the animals and machine wheels use the furrows as tracks (Thierstein 1979; Krantz 1978). Thus furrow-openers can track each other within a few centimetres in subsequent passes across the field.

Paper 16 CONSTRAINTS TO INCREASED FERTILIZER USE IN MULTIPLE CROPPING SYSTEMS IN DEVELOPING COUNTRIES AND MEANS TO OVERCOME THEM

J. de la Vega [1]

1. INTRODUCTION

Optimum use of fertilizers is recognized to be a primary factor towards a healthy national agricultural economy and a higher standard of living for the farmer and his family. It is now generally accepted that proper management of a combined set of factors such as soil moisture, nutrient availability and crop husbandry is the key to increasing production in both sole and multiple cropping farming systems.

All the above three factors are certainly important, but contribution by mineral fertilizers usually accounts for the largest increase in production under any farming pattern. Twenty-one years of experience of the FAO Fertilizer Programme all over the world indicates that any strategy for increasing production from farming should primarily aim at increasing consumption and improvement of efficiency of use of fertilizers, together with organic and biological sources of plant nutrients.

To put into practice such a strategy, a number of constraints need to be removed. The challenge for the agronomist is to determine how food production under traditional farming systems (either sole or multiple cropping) can be increased by better management, including more intensive use of agricultural inputs, which must be timely available and of the right type. To meet this challenge, one needs first a thorough knowledge of the basic principles guiding soil and crop management and then, of how these principles apply, or need to be adjusted, as cropping intensity approaches environmental or practical limits.

2. GENERAL OUTLOOK ON MAJOR CONSTRAINTS

This implies first the removal of a series of constraints of various kinds by the concerted effort of researchers in soils, plant physiology and breeding, geneticists, agronomists and extension officers able to transfer the acquired knowledge to the farmers.

A number of socio-economic constraints also have a severely limiting influence, and the agronomist can unfortunately do very little or nothing to overcome them. These are mainly factors such as (i) lack of capital; (ii) lack of price incentives; (iii) lack of marketing facilities; (iv) lack of credit; (v) climatological uncertainties and hazards, etc.

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The overall pattern of constraints to increased crop yields under a multiple cropping system does not differ basically from that found in the case of sole cropping patterns. The only difference is perhaps that problems related to fertilizing multiple cropping systems are even more serious, since knowledge on fertilizing these systems under average farmers' conditions is still insufficient. Most multiple cropping patterns originated from, and continue to persist in, subsistence farming. Many other problems are associated with small holders' multiple cropping farming, particularly input procurement, and to when this sector of the rural population has to market some yield surplus. Under these circumstances, marketing costs for agricultural inputs and produce are in general high because of the wide, efficient network of collecting stations, marketing centres and service units that is required.

Although scarcity of information on fertilizing multiple cropping systems is a major limiting factor, some general principles, based on the information accumulated from research work on sole cropping, can also be applied to multiple cropping situations, though in general, fertilization practices for ensuring adequate nutrient availability to the crops are more complex and should be more rigorous when soils are multicropped.

The first problem which the agronomist has to face relates to the determination of the requirements for each crop to ensure that nutrient availability is not a limiting factor.

After deciding what nutrients are needed for a certain multiple cropping situation and in what amounts, a number of decisions have to be taken relative to the source of nutrients, timing of application and adequate placement, in order to ensure the continued availability of the plant nutrients according to the specific needs of each crop involved in the system.

Needless to say that crops differ widely in their nutrient requirements, their patterns of nutrient uptake and in their capacity to respond to applications of specific plant nutrients. The situation is still more complicated if one takes into account that the periods of maximum nutrient demand for one crop may not necessarily coincide with that of another which is intercropped with it. It is important to know, or to be able to determine, the pace of accumulation of dry matter for the associated crop species, especially for the most intensive systems.

The risk of drought is another important limiting factor and imposes severe restrictions on the use of modern inputs, especially mineral fertilizers. Capacity of the various species to withstand short or extended dry periods is equally important. In other words, information on drought tolerance and the influence of mineral fertilization on it is essential. Farming practices which contribute to promoting deep root penetration may become especially pertinent in vast areas of the tropical regions where soil moisture is insufficient over extended periods of the year. The water-holding capacity of the soil, which determines, to some extent, the rate at which plant nutrients can be lost by leaching, is also important in an intensive farming pattern, in which two or more crops have to take their required nutrients from the soil stock and applied fertilizers. Other physical properties of the soil are no less important as they can have a definite influence on the timing of application and the type of fertilizers to be applied.

The economic burden that the use of mineral fertilizers represents to the farmer dictates that this input should be used as judiciously as possible and at the highest level of efficiency; this also entails efforts to bring their losses to a minimum. Consequently, when developing fertilization practices for multiple cropping patterns, it is essential that the economics of the practices be carefully looked at simultaneously with their potential for increasing crop yields.

3. MAJOR CONSTRAINTS

Constraints to increased crop yields under multiple cropping patterns may in the first instance be divided into the following categories:

- climatic constraints
- soil-related constraints
- plant-related constraints
- technological constraints
- socio-economic constraints
- infrastructural constraints

The devising of a strategy aimed at removing all possible constraints under the above listing would create an ideal situation. However, it is unthinkable that all these limiting factors could be removed at once and simultaneously. The agronomist should be realistic and try to develop a pragmatic approach aimed at alleviating some of them, especially those which may be most seriously affecting production under each set of circumstances. Numerous field results accumulated by the worldwide FAO Fertilizer Programme from trials on multiple cropping patterns (e.g. the maize-beans association) show that improvement of only one or two of the various crop husbandry practices, which contribute to production, already has an effect on yields, resulting in a high value/cost ratio. To try to solve all the problems in a hurried way may result in a considerable waste of time and effort.

3.1 Climatic Constraints

The most common is related to the uncertainty and variability of rain, both in space and time. Drought and floods, of varying degrees of intensity, are also more serious where cropping intensity is high. Unfortunately, these factors cannot be influenced by the small farmer in rainfed conditions. However, more thorough use can be made of recorded meteorological data to predict the probability of rains, which would help in choosing more appropriate cropping systems and varieties, and fertilization practices.

3.2 Soil-related Constraints

These refer basically to limitations derived from nutrient and moisture stress. There are other factors such as poor drainage, soil salinity, soil alkalinity, alluminium toxicity, etc. which can also strongly influence the development of adequate fertilizer practices for multiple cropping patterns in areas where they occur.

Nutrient stress is a major limiting factor for crop production under most tropical soil conditions. Chemical amendment of soil fertility is essential if a permanent agriculture is to evolve. Soil characteristics which influence the availability of applied nutrients are also likely to become critical more often than elsewhere. An important feature of the nutrient regime of tropical soils, which must be taken into account, is their highly dynamic pattern of nutrient supply/availability.

As regards the applicability of results from routine soil analysis to multiple cropping systems, a first approximation would obviously be to try to apply to multiple cropping patterns results related to sole cropping situations. Unfortunately, information on crop responses to nutrients in multiple cropping systems is quite inadequate and soil test interpretation should take into account the entire cropping sequence. More meaningful information will therefore have to be collected to arrive at appropriate fertilizer recommendations, based on soil tests and the determination of critical values adapted for the various multiple cropping situations.

Much applied research is still to be done, for example:

- What is the importance of nutrients left in the soil by preceding crops in a sequential cropping pattern?

- To what extent do legumes contribute to the general nutrient status of the soil?

- What is the most appropriate schedule for fertilization of mixed or row intercropping systems involving species differing basically in their patterns of nutrient uptake, dry matter formation and specific nutrient needs?

One would imagine that the optimum fertilizer requirements for any multiple cropping system would be less than the sum of the optimum fertilizer requirements for each individual crop. Are critical limits different for each crop? And do they differ for soils of different textures?

Moisture stress is as serious a constraint as nutrient stress in many situations. Every farmer growing crops on lands which may suffer from moisture stress is fully conscious of the importance of such practices as moisture conservation (e.g. controlling runoff to reduce water loss; soil conservation measures, mulching to diminish evapotranspiration; etc.), water harvesting and re-use of water.

3.3 Plant-related and Crop Husbandry-related Constraints

The farmer has also to face a number of other problems that may become serious obstacles to his business. Among these limiting factors, a few may be mentioned:

- lack of genotypes capable of producing high and stable yields when grown in competition with other plants in a multiple cropping situation;

- lack of highly fertilizer-responsive varieties;
- lack of advice and guidance concerning the most remunerative cropping patterns of sequences under the prevailing socio-economic conditions;
- insufficient research advice on pest and disease problems connected with intercropped systems;
- lack of guidance on integrated weed control;
- lack of appropriate tools and implements for seeding and fertilizer application at the proper depth for each type of plant in the system.

3.4 Socio-economic Factors

i. Unfavourable price ratios: The farmer's decision on investment in fertilizers depends upon the expected additional income associated with the additional cost of the input, in other words, on the "value/cost ratio". The FAO Fertilizer Programme has accumulated considerable experience over the last 21 years to conclude that an attractive value/cost ratio is essential to motivate farmers to use fertilizers. Whether this ratio should be at least 2.0, 3.0 or more, will depend on circumstances related to the particular situation prevailing in each country. The value/cost ratio depends on both the relationship between crop and fertilizer prices and the efficiency of fertilizer use or, in other words, the "productivity index" (i.e. the physical response of the crop to the nutrients applied). Very often there is no guaranteed market price for the crops (mainly food crops) and therefore farmers refrain from using fertilizers because of uncertainty concerning the market situation when they have to sell their crops. This is in many cases related to the education of farmers who are ready to assume more economic risk when they have been convinced of the economic value of using more fertilizer, provided it is used in the right way, at the right time and according to the crop needs.

ii. Shortage of credit: Shortage of cash is a chronic problem among small farmers, who have a very limited amount of money, if any, to purchase fertilizers. Price therefore determines to a great extent the quantity they buy. Under these circumstances, it is obvious that provision of credit on favourable terms helps to alleviate the situation. However, shortage of institutional credit is a common problem in most developing countries. On the other hand, credit-granting procedures are generally lengthy, tenant farmers cannot in many countries apply for loans, and banks may charge high rates of interest.

iii. Tenancy patterns: The lack of legal titles to land ownership and forms of land tenure such as sharecropping make access to agricultural credit difficult, precisely for those farmers who most need it. In these situations the farmers, once motivated to use fertilizers, may need to resort to local money lenders in order to get cash and this aggravates their already precarious financial situation because of the high rates of interest charged.

3.5 Infrastructural Constraints

Any effort towards encouraging fertilizer use under multiple cropping systems implies actions in various areas, e.g. supply at national level and distribution down to the farmer level, including adequate transport and storage facilities at all levels. Proper movement of fertilizers needs special attention in the case of multiple cropping systems, because the possibly different needs of two or more crops have to be met simultaneously.

The first obvious requisite for encouraging fertilizer use is that they should be available in the vicinity of the farmer's homestead or at least within a distance which should permit buying without too much effort. Experience shows that fertilizer consumption is, to a great extent, a function of its ready availability near to the point of consumption. Main reasons for the lack of fertilizers at farmer's village level are the absence of a local dealer, too long a distance to the nearest sales point or, where there is a local dealer, insufficient stock of the recommended type. The problem may become even more acute where the road and railway systems are deficient and may be aggravated by mountainous topography, as in Nepal, Peru, etc. Solution in these instances usually goes beyond normal fertilizer use development activity since it involves, in general, heavy investment by the public sector. However, such measures as the appointment of small dealers, and the adoption of policies aimed at decreasing the burden of transport costs to village level might help in creating favourable conditions to make fertilizers readily available within the farmer's reach.

Fertilizer consumption is of a seasonal nature. Experience shows that, in general, the farmer does not keep any fertilizer stock, which means that it is virtually impossible for dealers to meet demand at peak times. Unfortunately, funds for increasing storage capacity in the tertiary sector are very limited, and consequently investment in storage capacity at farmers' level cannot keep pace with the increased demand generated by promotional campaigns by governments or by international programmes like the FAO Fertilizer Programme.

In general, the transport system in most developing countries has proved insufficient to move the total consumption needs within the required time span, usually of four to six weeks. This situation can only be relieved to some extent by establishing buffer storage facilities at strategic points in each region and by encouraging farmers to store at least a considerable part of their requirements themselves.

Low Level of Extension Services

Technical assistance services to farmers are frequently unsatisfactory because of:

- lack of adequate staff and resources;
- poor working conditions, especially low salaries and lack of necessary means of transportation, resulting in:
    - insufficient contact with the farmers, lack of interest in their work and poor credibility,

- lack of in-service training and remoteness from practical research findings to keep their knowledge up-to-date.

4. CONCLUSIONS

The position is greatly simplified when seen from the farmer's viewpoint, as follows:

- The farmer, all over the world, regardless of the size of his holding, is profit-minded.

- Demonstration to him on his own or community's fields of correct, i.e. profitable, use of fertilizers, is enough to generate his intention to use fertilizers. This will be transformed into decision-making provided that:

    - the fertilizer material is available to him;

    - the value of the demonstrated yield increase is at least double the price of the fertilizer used to obtain this increase; and

    - credit, at an institutional rate of interest is, in most cases, offered together with the fertilizer material.

Paper 17 FERTILIZER DISTRIBUTION AND CREDIT STRATEGIES FOR MULTIPLE CROPPING ORIENTED AGRICULTURE

G.K. Sohbti[1]

1. DEVELOPING PATTERN OF DISTRIBUTION

A drastic change has come about with the need to optimize the utilization of the transportation capability and ensure the timely availability of the material nearer the points of consumption in the interest of stimulating consumption. Railways have been and will continue to be the bulk carriers of fertilizer, particularly on long leads. The pattern in the past was that fertilizers could be despatched to any railway destination station. This no doubt was convenient but the total quantity moved was limited. Fertilizer consumption was, however, rising fast and other measures to improve the system had to be devised. It has now been agreed by all concerned that the fertilizer will move only to selected strategically located destinations (termed 'nodal points') and in full train loads. Once the material has reached the selected nodal points in loads of around 2 thousand tonnes per train, it can be disbursed either to field warehouses and thence to wholesale or retail points or to wholesale and retail points direct. In order to effect economy in distribution and to ensure availability all the time nearer the points of consumption, warehousing at nodal point is inescapable. Since a number of manufacturers/suppliers will receive material at a nodal point, a common agency like CWC/SWC will need to operate nodal point warehouses. Furthermore, regular storage at wholesale/retail points in the interior would be feasible if adequate storage capacity is available at all such points. This is not the case at present.

Movement by road would follow the same flow as that by rail except that Nodal Point Storage will not figure.

An effective and economic system could perhaps be a close tie up between nodal point storage and block level storage with minimization of the utilization of intermediary field storage. This would succeed if the requisite infrastructure is available in the system. The loading point at the factory/port and the unloading railway nodal point at the destination need to have facilities and conveniences to load and unload a full trainload within a stipulated period which may not be more than 8 hours. The railway nodal point must have a covered platform to receive the full train; it also needs to have a fair-sized transit warehouse to receive a number of full trainloads and facilities to transfer the material quickly from the platform to the warehouse. Adequate transportation and labour capabilities to transfer the material from the transit warehouse to the block storage point or the dealer outlets then becomes necessary. A block is the lowest administrative unit comprising about 100 villages.

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- Cost is a major factor in successful adoption. Economy in the use of materials and simplicity in design to keep manufacturing simple and production costs low are important factors to be considered (Bansal and Thierstein 1982).

The proper application of fertilizer is the key to efficient fertilizer use (Harris *et al.* 1974; Smith 1965). In broadcasting, fertilizer is spread as uniformly as possible to the entire soil surface area that is to be cropped. If the fertilizer is to be incorporated into the soil it must be followed by the use of a tillage implement. Banding application can be either on the soil surface or in the soil. Bands are usually placed near the crop so the roots can reach the fertilizer easily and quickly.

Fertilizer distributors are either unit or continuous machines. In a unit distributor there is a separate hopper, metering mechanism and rate adjustment device for each crop row. Thus the type and quantity of fertilizer applied can be varied for different crops planted simultaneously in adjacent rows. In the continuous type, the same type and quantity of fertilizer is distributed across the entire width of the machine. The hopper is not divided or compartmentalized to permit more than one type of fertilizer to be applied. The mechanism for altering the application rate is designed so that a single adjustment mechanism controls all the discharge points simultaneously.

Because fertilizer is hygroscopic, the flow rate through a machine depends on the atmospheric relative humidity unless a positive metering device is used. Metering is also dependent on whether the fertilizer is in powder or granular form. Granular fertilizer is easier to meter accurately.

A number of fertilizer drills with mechanical metering devices have been developed and are being manufactured in India (Chauhan and Kumar 1972). Some use a gravity feed in which the orifice size is varied to control the application rate and an agitator is provided to keep the fertilizer flowing. The metering device is simple and relatively inexpensive but it has the disadvantage of uneven metering which depends on the roughness of the terrain over which the machine is travelling (rough terrain increases the flow rate) and on the speed of forward travel. In some of these machines it is possible to use a different orifice size for different rows so that the application rate can be varied for different crops.

Other fertilizer drills use positive metering devices so the rate of fertilizer application can be more precisely controlled. Most are multiple row machines and the metering device is usually controlled in such a way that the same fertilizer rate is applied to all the rows. Very few of the multi-row fertilizer hoppers are divided or compartmentalized to permit different fertilizers to be applied to different cultivars in one pass across the field.

7. PROBLEMS OF APPLYING FERTILIZER IN MULTIPLE CROPPING

One of the problems in applying fertilizer to multiple cropping systems is to apply different types and/or quantities to the different crops being planted in adjacent rows. This can be overcome by using unit fertilizer distributors, but a feasible. But in a country the size of India, estimates are made statewise on the basis of estimated areas under different crops and estimated average nutrient consumption for each. This is done twice a year in consultation with state governments and the fertilizer industry. The statewide estimates are then broken down to districtwise estimates and the suppliers are required to despatch materials accordingly. For the blockwise delivery scheme to succeed, the estimates will have to be further broken down blockwise.

3.2 Government Controls and Policies

The main objective of a good distribution system is that the required quantities of the right type of the material reach the farmer at the right time and at minimal cost. The other equally important objectives are equitable distribution of given availability to all states and all types of consumers and optimum utilization of available transport capability. To take care of unforeseen circumstances, it is necessary to ensure that no state is dependent on one source of supply and no manufacturer has only one state as an outlet for its material. All these objectives necessitate an overall discipline between different suppliers of domestic production as well as imports. The magnitude of the problem being collosal, the distribution of fertilizers in India is regulated through governmental policies and controls. The gap between domestic production and consumption is bridged by imports and the allocation of imports statewise is also a part of the supply plan. The progress of the deliveries against the supply plan is monitored regularly at monthly review meetings.

The dealership network is also controlled. Every prospective dealer has to obtain a registration certificate for each point of sale. This has been of help in exercising quality control, avoiding overcharging and getting field data.

3.3 Pattern of Fertilizer Consumption

In order to develop an effective and efficient distribution system, study in depth of the pattern of consumption is necessary. The pattern in India is indicated in Table 2. The average number of outlets per block or fertilizer consumption per outlet may be misleading, knowing that only 45 percent of the farm households in India use fertilizers and the quantity used varies widely between households, but the table gives a broad indication of the magnitude of the problem and the variation between zones.

3.4 Channels of Distribution

Fertilizer use in India dates back to the beginning of the twentieth century. Domestic superphosphate producers and private trade importers were the pioneers through whose untiring efforts the farmer in India became aware of the benefits of fertilizer use. The government came into the field in 1944 with the intention of equitable distribution of available fertilizer material at fair prices and set up a 'Central Fertilizer Pool'. Institutional agencies came into existence and increasingly distributed fertilizers. They had a near monopoly up to the mid-sixties. A "New Agricultural Strategy" in 1965 resulted in an extension in the

Table 2 PATTERN OF FERTILIZER CONSUMPTION IN INDIA 1980-81

Particulars	Central	East	North	South	West
Number of blocks	1 566	1 478	348	1 020	514
Number of villages	237 234	207 760	45 623	76 889	57 358
Number of dealer outlets	24 420	28 468	8 144	34 083	14 363
Number of villages per block	151	141	131	75	112
Average number of dealer outlets per block	16	19	23	33	28
Average fertilizer consumption in terms of material					
- tonnes per dealer outlet	114	43	230	116	155
- kg per hectare	45	38	136	115	74

area under fertilizer-responsive HYV crops, increased use of fertilizers and pesticides and better management of various inputs. A "New Fertilizer Policy" enunciated at the same time threw open investment in fertilizer production to the domestic and foreign private sector and liberalized marketing and pricing policies. The private trade distribution channels started developing once again. Installed capacity of N + P_2O_5 increased by nearly 136 percent during the 6-year period that followed, mainly in the private sector. The number of retail outlets increased by 26 000, also mostly in the private sector. Fertilizer consumption more than trebled. The result of these developments was the emergence of two strong channels of distribution, namely, institutional agencies and the private trade. The dealer network today comprises 42 and 68 thousand outlets of the institutional agencies and the private trade respectively. The mere distribution efforts gave place to marketing efforts which helped stimulate fertilizer consumption. Importance of market surveys and well-planned extension and promotional efforts and efficiency in fertilizer distribution were recognized.

The private trade has four distinct patterns of operation. One is the three-tier bulk marketeer system where the well-established marketing organizations take over the material from fertilizer manufacturers for marketing and then operate through wholesale and retail dealers. The second, which is the most prevalent system, is the two-tier wholesale and retail network where the manufacturer has his own full-fledged marketing organization and the material is distributed through the wholesale and retail dealers. The third is the one-tier retail dealer system where the manufacturers deal directly with the retailer. The fourth is the company-operated Agro Service Centres which retail the material to the farmer. The strength of the private trade lies in the commercial approach to the problem and the flexibility in operation in terms of hours of work. They generally have closer social links with the farmer and are not much influenced by local pressures.

The major strength of the cooperatives lies in their objective of dedicated service to the farmer irrespective of the cost involved, the support they receive from the Central and State Governments and the facility of substantial credit availability at concessional rates of interest. Their weakness generally is the lack of commercial approach and inability to resist local pressures.

The multichannel approach has paid good dividends and needs to be sustained in the interest of stimulating consumption and improving the system. The institutional agencies and the private trade currently enjoy a 50:50 share. It is unlikely that this ratio may undergo any major change during the eighties.

4. AGRO SERVICE CENTRES

The company-operated Agro Service Centres not only provide all inputs under one roof but also the latest technical know-how for efficient fertilizer use and are an excellent medium for stimulating consumption. They have, however, not multiplied and have also not been established in the interior areas. The major constraint is the high cost of manning and running these centres with company staff. A concept which can develop faster and does not involve the company staff directly is the dealer-operated Composite Input Distribution Centre (CIDC), which has the advantage of availability of all inputs under one roof and it also receives guidance from the company technical staff from time to time. CIDCs should be located at the block level. Dealers should be motivated into converting their outlets to CIDCs, not only to increase their sales but also to improve their economic viability. Custom hiring of equipment and implements will further increase their viability.

5. IMPORT OF FERTILIZERS

Nearly 30 percent of the total fertilizer consumption during 1982-83 is likely to be met though imports. This percentage may reduce to 29 and 25 during 1984-85 and 1989-90 respectively.

Imports have some special characteristics and functions to perform and as such these need to be treated slightly differently from domestic production. Imports may not arrive evenly throughout the year and the discipline of regular and even flow of material from ports to nodal points may not be feasible in their case. Imports also have a component of buffer storage which has to be kept warehoused all the time. The warehousing system, therefore, differs to some extent from that of domestic production.

6. INVENTORY COST

With the maximum selling price of Urea at Rs. 2350 (US$ 255.44) per tonne, the inventory cost of holding the material for one month in a warehouse in India works out at Rs. 43 (US$ 4.67) per tonne on the basis of a 20 percent interest rate, warehousing at Rs. 4 per tonne per month and an exchange rate of Rs. 9.20 per US Dollar. The average inventory holding of Urea is 2 to 2½ months. Taking 2½ months as the norm, the inventory cost would be Rs. 108 (US$ 11.74) per tonne, representing about 5 percent of the selling price. Whereas the private trade has been able to manage with the average inventory levels below 2 to 2½ months, the average with the institutional agencies has been above this level. It is recognized that extraneous pressures at times compel institutional agencies to over-stock but efforts must be made to avoid and resist such pressures.

7. CREDIT

Credit in the fertilizer trade is required at two stages. 'Distribution Credit' is required in the distribution system to cover mainly the inventory costs and 'Production Credit' is required by the cultivator to enable him to purchase fertilizers.

The main sources of distribution credit are commercial and cooperative banks, government, fertilizer manufacturers, own resources, etc. Production credit is made available by cooperatives and commercial banks, government, dealers, local moneylenders, farmers' friends and relatives, etc.

The role of credit is to help stimulate fertilizer consumption. It is an effective promotional medium which needs to be exploited to the maximum extent possible. It is, therefore, necessary that adequate credit is made available in time at a reasonable rate of interest through a simple credit disbursal procedure. The objective should be to attract dealers and farmers to avail themselves of credit. This is unfortunately not the case in actual practice in the developing countries. The attitude on the part of credit disbursal agencies appears to be to release credit only when it is inescapable. The need is for a positive approach to replace the present negative approach to the problem. Some of the constraints in the system are discussed below.

7.1 Accessibility

Credit is not easily available, particularly to small and marginal farmers and small dealers. The credit sanctioning and disbursal procedures are so cumbersome that the poor farmer and the small dealer prefer not to even try for it. The procedure must be simplified and the loan should be made available to the small farmer/dealer virtually at their doorsteps. In some interior areas, mobile credit disbursing units may be helpful.

7.2 Credit in Kind

Credit for purchase of inputs by the farmer must be made available in kind. This is the only way to ensure that the credit will be used for the purpose for which it is extended. Credit availability must also be timely so that the farmer makes productive use of it.

7.3 Security

The small farmer is generally not able to offer security of the type asked for by the credit extending agency. The process is also time-consuming. If credit is to play its due role, the credit-worthiness of a farmer could perhaps be judged from his reputation within his community, the package of practices he has planned to adopt and the gains that he is likely to make from their use. If necessary in certain cases, the usual group guarantee may be accepted.

7.4 Margin Money

This is particularly relevant in the case of dealers where the demand for margin money is anywhere between 20 and 40 percent. The need is to reduce the margin money level to 10 to 15 percent, particularly in the case of small dealers.

7.5 Lack of Knowledge

This applies both to the small dealer and the farmer. Some are not even aware of the source of credit or the formalities involved in obtaining it. The credit-extending agencies should accept this as a challenge.

7.6 Overdues

This is the most vital factor which inhibits the developmental role of credit. The reasons for high overdues in the system are:

- crop failure through natural calamities,
- serious genuine unexpected events,
- inability to repay due to lower than expected returns,
- gestation period, particularly for horticultural crops (the small farmer may not have a disposable surplus of his produce for 2 years or more),
- wilful default.

The credit system should be flexible enough to take care of the first four factors and not be too rigid in forcing repayment within the first committed period. The loans could in such cases be rescheduled. As regards the last factor, there is a need to educate the farmer about the problems that can be caused for him and his community by delay in repayment of the loan. Pressure on him by his community can be tried to resolve the issue. Firm measures could then be taken if repayment is not forthcoming. If there is wilful default by the community as a whole because of outside interference (and this is not uncommon), it becomes the duty of the government to remove such interference forthwith.

7.7 Cost of Credit

A range of interest rates on different types of credit for the same end use is a cause of inefficiency and misuse. There is no doubt a necessity for special treatment for backward and poor members of the community but the system needs to be geared to avoid misuse.

8. SUGGESTIONS FOR IMPROVEMENTS

i. The assessment of credit requirement may be made for a total cropping sequence in a year and this should normally hold good for a period of 3 years. For any change in the cropping pattern, a mid-term adjustment should not be difficult. In order, however, to avoid duplication of effort, a single agency like the Block Development Officer (BDO) should be made responsible for assessing farmer requirements based on the uniform norms approved by the respective state governments.

ii. Farmer requirements should be endorsed by the BDO on either a credit card or a passbook containing requisite particulars of the farmer. It should indicate seasonwise credit limits for a period of 3 years.

iii. It should be open to the farmer to register his card/passbook with either the cooperative channel or the private trade. In the latter case, the credit card or passbook would have to be guaranteed by the credit-extending bank. The credit in each case should be disbursed in kind.

iv. The existing credit channels could be further supplemented and strengthened by recognizing and accepting the system of credit release by the private trade to the farmer. To enable the dealer to extend and systematize this arrangement, he would need to depend on commercial banks for extended credit. Fertilizer manufacturers could help by vouchsafing the credit-worthiness of the dealers. As an extension to this arrangement, the manufacturers should be extended additional working capital to enable them to extend credit to the dealer who in turn could release the material on credit to the farmer.

v. The arrangements could perhaps be further strengthened by the establishment at the grass roots level of a unified agency for meeting all the credit requirements of the farmer.

vi. The credit system should be not only simpler but also flexible enough to permit rescheduling of loan repayment in the wake of circumstances beyond the control of the farmer.

vii. The problem of overdues could be minimized by repayment of loan through agricultural produce. The produce procurement agencies would need to operate in close liaison with the credit extending agencies. The proposed unified credit extending agency could perhaps perform both functions.

viii. The commercial banking system should take on the responsibility of encouraging the distribution channel to take credit and expand their activities. The banks should in fact fix targets for achievement even in the fertilizer distribution sector.

9. TRAINING

For the maximum efficiency in fertilizer distribution, strategic positions must be manned by experts. Training programmes tuned to specific disciplines need to be developed. The time is ripe for each organization to make it compulsory for all levels to go through specifically identified programmes. Training should not be treated as a one-time exercise but as a continuing exercise. The fast developing changes in the marketing discipline require an indivual to go through training at specified intervals. Expenditure on training should be treated as a long-term investment.

Training of dealers and farmers is equally important. Their curriculum should also include education on sources and cost of credit, advantages of availing themselves of credit facility, credit disbursal arrangements, need for prompt repayment of loans, etc.

Paper 18 REVIEW OF SOIL FERTILITY AND FERTILIZER USE RESEARCH IN MULTIPLE CROPPING SYSTEMS IN BANGLADESH

M.M. Rahman[1]

1. INTRODUCTION

Bangladesh is the largest deltaic plain in the world with a total land area of 14.4 million hectares and a population of about 100 million (1981 census) which is increasing at an annual growth rate of almost 3 percent against 1.7 percent annual growth in agriculture. Soils are broadly grouped into 20 physiographic units within 7 major Soil Tracts having 20 different soil types. Most of these are noncalcareous grey, dark grey and brown floodplain soils, and calcareous dark grey and brown soils. Topsoils are mainly acid, but subsoils are slightly acid to mild alkaline and are mostly calcareous on the Ganges floodplain. The floodplain sediments cover more than 80 percent of the country as piedmont, riverine, estuarine and tidal landscapes. They are predominantly silts and clays, with sands occurring mainly in the extreme west and north-west. The second major soil type is the calcareous and non-calcareous alluvium. Others include acid basin clay, acid sulphate, peat, black terai soils, grey terrace and piedmont soils, and brown hill soils.

Bangladesh soils are generally fertile because of annual siltation due to seasonal flooding and increased biological activities in the floodwater. This situation is, however, fast changing in the context of increased cropping intensity and use of HYVs. Recent studies show that N content of the soil varies from 0.02–0.25 percent; available P_2O_5 from 1.0-3.0 ppm, and available K_2O from 27-410 ppm. The average total N, available P_2O_5 and K_2O are assumed to be 0.09 percent, 8.6 ppm and 137 ppm respectively. Under forest and seasonally flooded areas, topsoil is rich in humus but, in general, the organic matter content in most soil is low averaging about 1.47 percent. Depending on the soil type, pH of the topsoil (15 cm) ranges from 4.7-7.8 and cation exchange capacity is between 7.68 and 52.3 meq/100 g.

In many studies, sulphur and zinc deficiency has been detected. In some, the problem is serious. This deficiency is mainly due to reduction problems associated with continuous rice culture under flooded conditions. Preliminary survey data show that about 1.6 million hectares are affected by sulphur and Zn deficiency (Fig. 1); the actual figure is suspected to be more than this.

2. FERTILITY STATUS UNDER MULTIPLE CROPPING SYSTEMS

There is no study as such on fertility status under multiple cropping systems. In the past, the cropping systems and the crop sequences were more or less static, and the necessity of investigations into the status of soil fertility under different cropping systems and crop rotations was not felt as strongly as it

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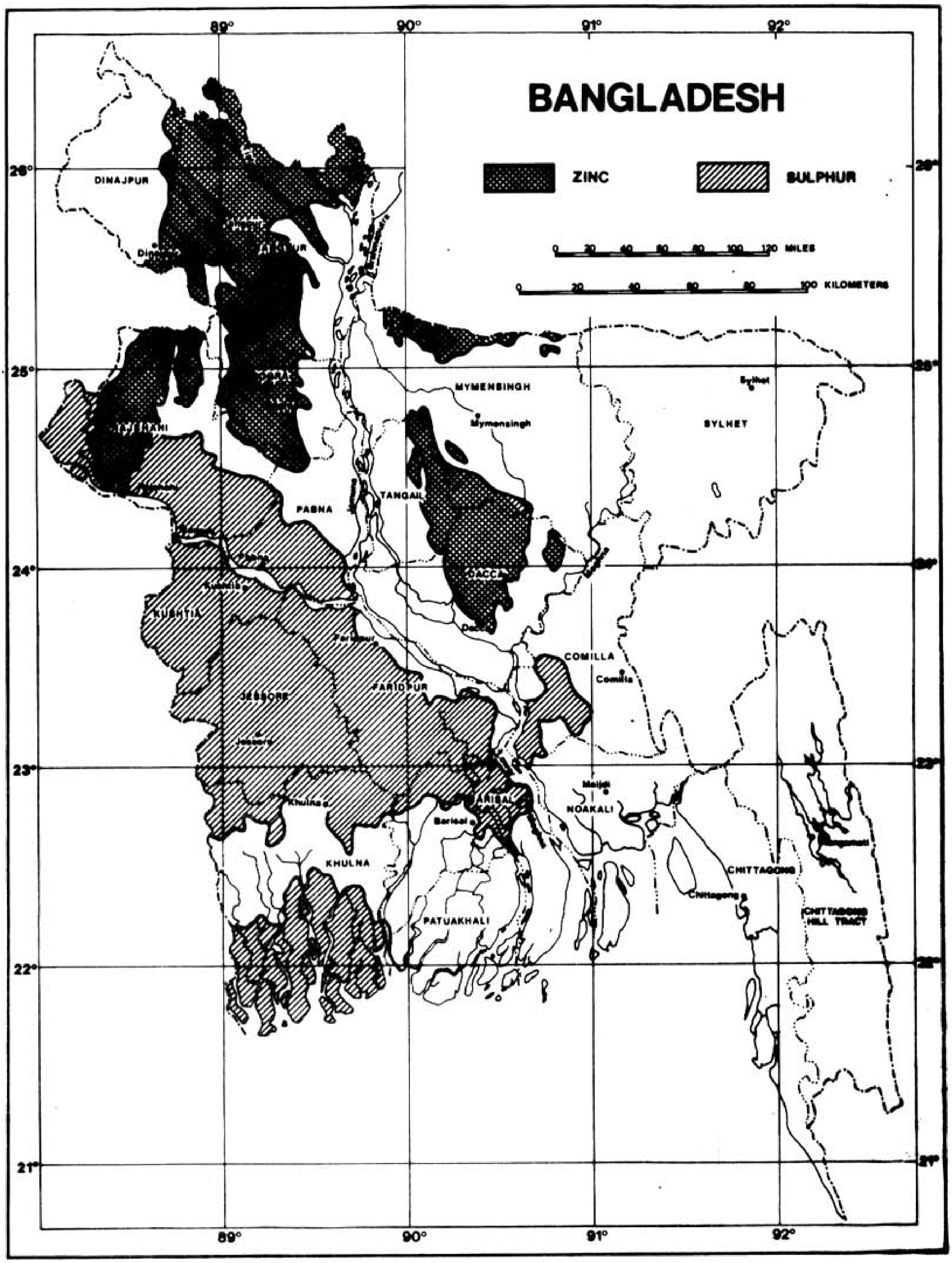

Fig. 1 Area showing zinc and sulphur deficiency

is now with the dynamic changes in the cropping patterns. Bangladesh farmers used to follow these cropping patterns under mono and double cropping systems:

Rice (*Aus*/Jute)	–	Fallow	–	*Rabi* crops
Rice (*Aus*/Jute)	–	Rice (T. *Aman*)	–	Fallow
Fallow	–	Rice (T. *Aman*)	–	Fallow
Rice (Mixed *Aus* and broadcast *Aman*)			–	*Rabi* crops
Fallow	–	Rice (Broadcast *Aman*)	–	Fallow
Fallow	–	Rice (*Boro*)	–	Fallow
Fallow	–	Rice (T. *Aman*)	–	Rice (*Boro*)
Sugarcane (Sole crop)				

Added to this basic system now is the triple cropping system, especially in the irrigated areas. The area under double cropping has also increased considerably. A great many new patterns have evolved over the past few years mainly with the introduction of HYVs, use of fertilizers, availability of irrigation water and as a result of increasing demand for food from limited land. Some of these are given in Table 1.

Table 1 SOME NEW CROPPING PATTERNS

Rice	–	Rice	–	Rice
Rice	–	Rice	–	Wheat/Barley
Rice	–	Rice	–	Mustard
Rice	–	Rice	–	Pulses
Jute	–	Rice	–	Wheat
Jute	–	Rice	–	Pulses
Jute	–	Rice	–	Vegetables
Rice	–	Rice	–	Fallow
Rice	–	Fallow	–	Mustard
Rice	–	Fallow	–	Potato
Rice	–	Fallow	–	Pulses
Jute	–	Rice	–	Fallow
Jute	–	Fallow	–	Wheat
Jute	–	Fallow	–	Vegetables
Jute	–	Rice	–	Fallow
Jute	–	Fallow	–	Potato
Jute	–	Fallow	–	Mustard
Jute	–	Fallow	–	Chili/Onion/Garlic
Fallow	–	Rice	–	Fallow
Rice	–	Fallow	–	Fallow
Sugarcane (sole crop)				
Sugarcane with intercrops				

This situation has greatly altered the fertility level of all soils. The complexity of the problem has also increased. Under present cropping practices, the fertility of the soil is constantly changing as a dynamic process with the use of each new crop variety and cropping pattern under different soil, water and fertilizer management conditions. It is often the practice to grow a local rice variety followed by an HYV, or *vice versa*, or an HYV followed by another HYV followed by a third crop of wheat or mustard or pulses or a vegetable. Each of these patterns variously alters the fertility. Growing of crops, with different fertility requirements, on the same soil in different seasons of the year is as important as the changes occurring in the chemistry of the same soil under flooded and non-flooded conditions in influencing fertility. Seasonal submersion and non-submersion of the same soil in the same year create physical, biological and chemical conditions that differently affect release, retention and loss of soil nutrients. Poor management of soil, water and fertilizer by the farmers is further complicating the problem of soil fertility under multiple cropping systems in Bangladesh. In general, the fertility status is gradually decreasing with increasing intensity of cropping, reduced use of organic manures and decreasing trend of returning crop wastes to the soil.

3. FERTILIZER USE RESEARCH UNDER MULTIPLE CROPPING SYSTEMS

3.1 Past Research

Fertilizer use studies with different crops have been carried out for many many years. Voluminous research results are available with the crop research institutes. Based on these results, fertilizer recommendations with reference to identified soil types have been published recently by the Bangladesh Agricultural Research Council as a guide for major crops. These have been developed from results of studies on an individual crop which forms only a part of a given cropping system. They did not take into account the residual and cumulative effects of nutrients applied to the previous crop, nor the effect of crop combinations in a system. As a result, they are not precisely applicable for diverse cropping patterns under multiple cropping systems practised by farmers. Specific studies on multicrop sequence were not done in the past.

3.2 Future Programme

While single crop-oriented fertilizer studies for new cultivars will continue in the breeding stations, the new programme, which was initiated in 1981 through a coordinated national cropping systems research project, is directed toward the problem in the farmer's field on a system approach. Initially, the fertilizer research component of the programme will deal with superimposed fertilizer trials in relation to different cropping patterns. Legume as a component crop in the pattern, and returning crop residues to the soil as a regular practice are included as factors influencing soil fertility and fertilizer use efficiency. In addition, agronomic field experiments, long-term soil fertility experiments supported with proper soil and plant analysis are being planned to provide a basic understanding of the residual effects of applied nutrients in a multicropping system. The objectives are to economize fertilizer use, and improve and maintain soil productivity.

There is no standard method available for designing field trials for fertilizer studies under multiple cropping systems. Present investigations are conducted on purely trial and error basis.

The immediate need is to develop suitable methods for farmer field studies and also for station-based long-term fertilizer trials to improve and calibrate fertilizer recommendations for cropping systems rather than for component crops of the system.

Paper 19 REVIEW OF RESEARCH ON MULTIPLE CROPPING SYSTEMS TO INCREASE AGRICULTURAL PRODUCTION AND MAINTAIN A PROPER SOIL FERTILITY STATUS IN PAKISTAN

S.A. Qureshi[1]

Production and income per unit area per year can be increased by enhancing the cropping intensity to as large an extent as possible. Ordinarily in Pakistan, fairly high intensity of cropping in a given area is annually attained by growing a crop in each of the two crop seasons, *Rabi* and *Kharif*. However, the exigencies of the times ahead demand that ways and means should be found to raise the intensity higher still. The object of greatly enhanced intensity of cropping can be achieved either through relay cropping or diversified multiple cropping. The idea is to devise a system by which a given field is kept under some crop all the year round. The sequence should be so arranged that an earlier sown crop may be about to be harvested while the succeeding crop would be germinating in the same field so that wastage of available solar energy could be avoided. The idea also implies raising or sandwiching some short duration crop between two major crops and/or growing minor crops in the major crops at the same time in the same field without, of course, affecting their yield potentials.

Quite a few practices based on similar aims and objectives are presently in vogue in many parts of the country, especially in the neighbourhood of cities and towns where vegetables and truck crops are intensively grown. Severe reductions in the farm sizes in the rural areas have also induced many farm families to try to make their livings from their smallholdings through multiple cropping. Such a system is highly labour-intensive and the small farm holders can gainfully employ their spare family labour in suchlike pursuits.

1. EARLIER RESEARCH ON MULTIPLE CROPPING IN PAKISTAN

Most of the previous research work in respect of agricultural techniques and practices relating to multiple cropping systems in Pakistan has been done with the purpose of production of more than one crop in the same field at the same time and to determine their feasibility and economics. Also, some of the minor crops were sown in the major crops for the sake of their expected healthy effects on soil conditions and their benefit to the major crop, e.g. cotton intercropped with *Phaseolus aconitifolius* to help to reduce root rot of cotton, or short duration crops such as maize, chillies and vegetables (onions, watermelon, muskmelon, etc.) sown in sugarcane or cotton fields as additional crops. Recently, as a result of investigations showing September–October as the more beneficial time of sowing of sugarcane, a winter crop of wheat, brassica or sugarbeet has also been experimented upon.

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In addition, in problem areas like Thal and areas with erratic rainfall, mixed cropping has been practised to ensure successful growing of at least one of the crops. This is still in vogue in the *'barani'* areas where wheat is sown mixed with gram or lentils or rapeseed. Similarly in some *'barani'* areas sorghum, maize and *bajra* are intercropped with *'Kharif'* pulses like mung and *mash* (*Vigna mungo*).

2. NEW LINE OF RESEARCH ON MULTIPLE CROPPING

Multiple cropping systems, in addition to being more labour-intensive, need also larger inputs of plant nutrients. Because purchased nutrients may not be within easy reach of small farmers, the idea was developed to investigate the possibilities of intercropping the major crops with grain legumes or legume fodders so as to make use of their N-fixing properties, if possible for the benefit of the main crop, as also to enrich the soil for the succeeding crop (Table 1).

Such a system involves direct advantages in that it can help in weed control, provide badly needed fodder for the livestock to improve protein use, and, as an additional crop, lead to improved soil fertility.

Table 1 FERTILIZER REQUIREMENT IN WHEAT/LUCERNE MIXED CROPPING

Fertilizer applied kg $N-P_2O_5-K_2O$		Average yield (kg/acre) Wheat	Lucerne	Total income (Rs)[1]
0-0-0	Single	683	-	1 024
	Mixed	443	1 694	1 003
25-25-0	Single	1 089	-	1 633
	Mixed	887	2 138	1 758
75-50-0	Single	Lodging	-	-
	Mixed	1 210	2 204	2 256
0-0-0	Single	1 014	-	1 521
	Mixed	815	917	1 406
60-100-0	Single	1 421	-	2 131
	Mixed	1 114	1 075	1 886
120-100-0	Single	1 099	-	1 648
	Mixed	1 307	950	2 150

[1] Wheat at Rs 60 per 40 kg; lucerne at Rs 8 per 40 kg.

The necessity of such work becomes more demanding when one considers the costs of energy inputs and huge financial outlay for the manufacture of nitrogenous fertilizers. Wheat being the most important crop requiring the largest amounts of fertilizer nitrogen in the country (60 percent or more), work on this crop was called for immediately. In preliminary experiments for the last two crop seasons, wheat was intercropped with berseem, lucerne, gram, lentils and groundnut.

More refined experiments were laid out in the present season (results expected June 1982) which involve:

i. wheat variety with erect leaves responding to wider spacing;

ii. planting method to meet water requirements of both crops,

iii. rates and method of fertilizer application to determine nutrients levels for optimum or acceptable yields of both crops,

iv. determining nutrient uptake and residues in the soil.

Various foreign workers have estimated the amounts of N fixed by leguminous crops in the field, averaging, for lucerne, 450 kg N/ha; clover, 260; sweet clover, 270; soybean, 160; and field beans, 70 kg N/ha. From similar work in the former Punjab Agriculture College and Research Institute Faisalabad (Lyallpur), Madhok and Fazal-ul-Din (1940) reported the following estimates of N-fixing capacities under local conditions: lucerne, 60-460 kg N/ha; berseem, 122-400; *shaftal*, 90-212; *senji*, 50-103; gram, 16-63; *guara*, 103; *janter*, 85; and *arhar*, 39 kg N/ha[1].

In our trials lucerne, gram and lentil were sown in conjunction with wheat because, in addition to their good N-fixing capacities as indicated above, these also have water requirements almost similar to wheat and there appear to be great possibilities to standardize suitable technology and agronomic practices to grow them as intercrops in wheat fields.

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[1] *Shaftal* - Trifolium; *senji* - Medicago; *guara* - Cyamopsis; *janter* - Sesbania; *arhar* - Cajanus cajan - red gram.

Paper 20 REVIEW OF SOIL FERTILITY AND FERTILIZER USE RESEARCH IN MULTIPLE CROPPING SYSTEMS IN SRI LANKA

W. Ratnayake[1]

1. PREDOMINANT MULTIPLE CROPPING SYSTEMS PRACTISED IN SRI LANKA

By definition of multiple cropping (Harwood 1974), the existing practices in Sri Lanka, where more than one annual crop is grown on the same piece of land in one year, broadly fall into the following systems of cultivation:

- shifting cultivation
- settled highland cultivation
- rice-based cropping systems in typical paddy lands
- continuous vegetable cultivation in lowland bog soils

1.1 Shifting Cultivation

Shifting cultivation is the term used for agricultural systems that involve an alternative between cropping for a few years on selected and cleared plots and a lengthy period when the soil is rested (Rothenberg 1980). In Sri Lanka about 0.2 M ha are annually planted to assorted field crops on an estimated 1 M ha of slash and burn land locally called *'chena'*. Under this system, clearing of secondary forest starts as early as June/July and planting is done with least disturbance to the soil with the onset of *Maha* rains. Minimum cash inputs are used and the main resource used is family labour. This practice has been often described as wasteful since it has proved to be detrimental to land use and soil fertility due to severe erosion hazards. However, many investigators consider it a rewarding practice in low population density areas as it minimizes the farmers' risks and optimizes their meagre resources. An agricultural extension programme backed by intensive research is in progress in many dry zone districts to transform the *'chena'* system to a more viable system of settled farming.

An attempt to develop the dry zone agriculture was recognized as far back as the turn of the past century. An experimental station was established at Maha Illuppallama in 1903 and later developed into a full fledged Agricultural Research Station, which was assigned the task of investigating the technical feasibility of settled, rainfed, arable farming in the dry zone. The most rational system of land use has been described by Abeyratne (1956).

A massive Extension Programme was launched recently in the dry zone district of Anuradhapura to transfer a package of practices to stabilize multiple cropping under shifting cultivation. Preliminary observations were found to be encouraging. A fine blend of a few low risk, low cost practices introduced without ignoring the socio-economic background of the shifting cultivator could be the

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essence of its success. The biggest challenge was to wean away the shifting cultivator from the traditional practices. The extension programme was backed by a carefully designed demonstration programme on increasing farm productivity through an acceptable system of multiple cropping. A few low cost soil conservation practices to sustain the soil fertility under such intensive cultivation too were demonstrated.

1.2 Settled Highland Cultivation

This constitutes about 0.6 M ha under a wide range of settled rainfed farming and home gardens. This type of farming is restricted to most parts of the dry zone and up-country intermediate zone vegetable farming. Over the years with the change in Government fiscal policies, such as price incentives for farm produce, and the dearth of agricultural land, a small proportion of land has gradually evolved into a more stable system of farming, in which the following broad categories of agricultural activities can be identified:

- temperate vegetable and potato production, mainly utilizing rainfall in the wet zone and intermediate zone (Ultisols of high elevations);
- highly intensive lift irrigated vegetables, tobacco and other field crop production in the peninsula (Oxisols);
- stabilized rainfed cultivation of vegetables and other field crops under rainfed conditions in the dry zone (Alfisols).

1.3 Rice-based Multiple Cropping Systems in Typical Rice Lands

Next to the plantation crops, rice is the most important crop grown in the country. The rice lands occur in almost all agro-ecological regions, except the few wet uplands. The systems of multiple cropping and the crop combinations vary according to the agro-ecological conditions. They may be broadly classified into:

i. rice-rice system
ii. rice-fallow system
iii. rice-other field crops/vegetable system

i. Rice-rice

The total area of rice lands in the dry zone is about 275 000 ha. For soil drainage characteristic reasons in the inland valleys, the rice-rice combination both in the wet (*Maha*) and dry (*Yala*) seasons is the only feasible cropping system.

Rice lands in the intermediate zone constitute about 125 000 ha distributed in the low country, mid-country and up-country. The majority of the soils where traditionally a double cropping of rice is practised are imperfectly drained Low Humic Gleys of low base saturation.

In about 180 000 ha of rice lands in the wet zone the rice-rice cropping pattern has become the mainstay due to drainage problems often associated with flash flood hazards.

ii. Rice-fallow

About 65 percent of the country's rice lands depend on irrigation water. A considerable extent in the dry zone is left fallow because of shortage of water due either to lack of rainfall or to lack of irrigation in the dry season. A certain proportion in the dry zone lies fallow due to restricted resources, mainly draught power to commence cultivation with the onset of monsoonal rains.

Indirect advantages are derived from these fallow lands by utilizing them for grazing cattle. Natural fertility built up during the fallow periods is exploited by rotation of land during the subsequent season. This idling land has resulted in a cropping index of 175 percent in the wet zone and about 100 percent in the dry zone.

iii. Rice-other field crops/vegetables

In the past, the cropping pattern on the major fraction of the dry zone was a monoculture of paddy. About a decade ago a new experience with an Agricultural Extension Programme on Crop Diversification in Elahera Special Project (in the North Central Province) clearly suggested that a rational use of the available water resource could result in increasing the cropping intensity close to two. Recent changes in price policies, improvements in the marketing network and strengthening of research and extension activities made this a rewarding practice in the dry zone. A typical cropping pattern consists of rice in the wet season followed by a short duration pulse crop, onions, chillies, vegetables or tobacco in the dry season. These crops are largely restricted to well drained Reddish Brown Earths. About 10 185 ha of similar rice lands have been located in the semi-dry, intermediate zone. Where double cropping is feasible, potato and vegetables like beans, kohlrabi and cabbage are grown in rotation with wetland rice, predominantly on Red-Yellow Podzolic soils.

2. COMMON FERTILIZER USAGE PATTERNS UNDER MULTIPLE CROPPING

Until recently the necessity to apply fertilizer was not realized in major areas where multiple cropping is practised under rainfed conditions in the dry zone. Results of a recent survey conducted by the Agricultural Extension Service of Anuradhapura District, reveal some interesting fertilizer usage phenomena under shifting cultivation (Ratnayake 1981). In certain *'chena'* lands in the process of transformation, a restricted amount of N (14.6 kg N/ha) is applied to non-leguminous crops, as urea. About 100 kg/ha basal fertilizer (3 percent N, 30 percent P_2O_5 and 10 percent K_2O) together with farmyard manure is applied to high value crops like chillies, red onions and vegetables. This restricted application of basal fertilizer could be a sound economic judgement of low response to P and K in the transforming *'chena'* land.

Soybean is the exception. Practically all soybean growers inoculate their seeds with a commercial *Rhizobium* preparation supplied by the Department of Agriculture. The majority use some form of basal fertilizer. This is a clear indication of an attempt to utilize the residual effect of the basal fertilizer (particularly of P and perhaps N, through the association of Rhizobia). Sequentially planted sesame soon after harvesting soybean is claimed to benefit.

2.1 Traditional Practices of Soil Fertility Maintenance

The primary objective of shifting cultivation is to establish a relatively weed-free seedbed on a soil whose fertility has been regenerated during the fallow period. Although this practice still prevails in certain areas, its inherent benefits cannot be fully realized due to limitations of new land for expansion.

2.2 Carefully Selected Crop Combinations

i. Mixed cropping: usually practised under shifting cultivation in the dry zone e.g. simultaneous cultivation of finger millet, chilli, maize, vegetables and pulse crops in mixed stand.

ii. Relay cropping: common practice in intensive vegetable growing areas where short-duration, small-statured crops like spring onion are interplanted with an already maturing annual crop, e.g. under shifting cultivation, short-duration cowpeas (variety M.I.35) between maturing maize.

iii. Sequential planting - e.g. thick sowing of sesame immediately after soybean, or tobacco after maize in the dry zone.

Such multiple cropping practices allow a fuller use of light, nutrients and water (crops having different root distribution offer less competition for nutrients). Mixed cropping also tends to produce less erosion than solo stands under the same circumstances and so contains an element of resource maintenance (Norman 1973). Moreover, non-leguminous crops seem to perform better when associated with pulse crops.

2.3 Matching Time of Planting to Harness Peak Periods of Nutrient Availability

Maize is among the first crops to be planted with the first rains during the wet season. Such timely planted crops look healthier than late planted maize. Experiments conducted at the Dry Zone Research Station at Maha Illuppallama have demonstrated that N and other nutrients liberated by mineralization of the soil organic matter could be readily exploited by the crop before being leached out by subsequent rains (Abeyratne 1962).

2.4 Utilization of Organic Material

Farmyard manure is commonly used in the cultivation of high cash crops like vegetables, chillies and red onions. Adding green leaves and tender stems of plants like *suriya* (Thespesia), *madera* (Gliricidia) etc. is a common practice among Jaffna farmers (north Sri Lanka) and rice growers of the mid-country and wet zone.

3. SUGGESTED FUTURE SOIL FERTILITY AND FERTILIZER USE RESEARCH

3.1 Maintenance of Soil Fertility

Intensive cultivation of the same piece of land in a multiple cropping situation could aggravate the depletion of soil fertility. Thus research on retention of soil fertility, not only in terms of chemical parameters, but also in terms of physical properties, becomes important.

3.2 Fertilizer Recommendations

Present fertilizer recommendations have been studied and formulated for individual crops. The rationale of future experimentation should also cover a few typical crop combinations as well.

3.3 Utilization of Non-traditional Forms of Nitrogen

Practical solutions have to be explored on the following lines:

- possibility of extending benefits of Rhizobial inoculation to a wide range of common grain legumes, e.g. cowpea and green gram;
- investigations of the effect of residual N on the yields of cereals in rotation with pulse crops. This aspect is gaining in importance with the introduction of soybean to multiple cropping systems in the highlands as well as in rotations with lowland paddy.

3.4 Replenishment of Micronutrients

Continuous and intensive cultivation would demand replenishment of major nutrients. In the process, the depletion of micronutrients may occur unnoticed.

3.5 Optimum Exploitation of Rainfall

The most limiting factor in the dry zone is water. A cropping system has to be developed to ensure the best use of the incident rainfall, both in maintaining soil fertility and achieving optimum crop production. Panabokke and Walagama (1974) have demonstrated how matching the crop water requirement with the confidence limits of expected rainfall can permit the choice of crops and their management to satisfy the crop water demand. Future research is necessary in selection of varieties and cultural practices to achieve the best use of the incident rainfall to retain soil fertility under intensive management by multiple cropping.

Paper 21 GREEN MANURES IN MULTIPLE CROPPING SYSTEMS IN CHINA

Chen Shiping[1]

1. HISTORICAL RETROSPECT

China has a very large population and a limited cultivated area averaging not more than 0.13 ha per capita. Since there is little potentiality of reclamation, we depend mainly on raising yield per unit area to produce more food and industrial material on limited land. One of the important measures to utilize the land resource intensively and raise output is to carry out multiple cropping systems and increase the cropping index.

Multiple cropping occupies a special position in our agricultural production. Over thousands of years of development of agriculture, multiple cropping systems with distinctive Chinese features with rice, maize and cotton as staple crops in summer and wheat and rape in winter have been shaped gradually. The present average cropping index in China as a whole is about 150 (230-240 in south China, 160-200 in middle China and about 120 to the north of the Huanghe River).

Increasing the cropping index and growing two or more crops on the same field in a year will undoubtedly hasten the consuming of soil fertility. Chinese farmers have devoted much attention to this problem through the ages and have accumulated a wealth of valuable experience of combining utilization and conservation of soil to make it "always fertile and productive". The most notable is adding green manure crops, especially legumes, into multiple cropping systems, growing green manure crops on waste land or water surfaces and utilizing extensively various kinds of wild green manure plants to fertilize and improve the soil.

According to "Shi Jing" ("The Book of Odes") in the Western Zhou Dynasty (1066-771 BC), "When bitter vegetable and knotweed rot, broom-corn millet and millet will flourish", indicating that people then already realized the relation between rotted weeds and flourishing crops.

A passage in "Fan Shengzhi Shu" ("Book of Fan Shengzhi", Western Han Dynasty, 206 BC - AD 24): "Wait for the growth of weeds until the time of ploughing, plough as it rains, let them mix up with the soil, leave the seedlings of crops to grow. When the weeds rot, all the fields will become rich land", indicates that farmers had consciously begun to use natural weeds as green manures.

As for cultivated leguminous green manure crops, the earliest detailed report may be the description in "Guang Zhi" ("Comprehensive Report") by Guo Yigong (Western Jin Dynasty, AD 265-315) of "Tiao" (Chinese milk-vetch) grown in

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rice fields. In the early 6th century (533-544), Jia Sixie, an agronomist of the Northern Wei Dynasty, emphasized the role of leguminous green manure crops in improving soils. In his famous book "Qi Min Yao Shu" ("Essential Ways for Living of the Common People") he wrote: "To improve the soil, the best way is to plough down green beans (*Dolichos*), next, the lesser beans and sesame. All these should be densely broadcast in the 5th or 6th month and ploughed in during the 7th or 8th. The yield of spiked millet sown next spring on such ground will be 10 shi per mu[1]. The effect is as good as silkworm-manure or well-fermented compost." He also pointed out that, in using this method of enriching soil, much labour is saved.

Up to the early 17th century, leguminous crops such as milk-vetch, burclover, broad bean, common vetch and green bean, as well as *Azolla*, were widely used as green manures in the south of the lower reaches of the Changjiang River. Some very densely populated and intensively cultivated areas, such as the Tai Lake Region, maintain high yields and high soil fertility over a long period of time, one of the important reasons being that farmers there not only apply organic manures, such as animal wastes and human habitation wastes regularly, but have also grown and utilized green manure crops in the rotation system for many years.

Since the establishment of New China, under the energetic advocacy of the Party and the Government, green manure production has expanded rapidly. According to the National Programme for Agricultural Development: "Energetic efforts should be put into growing green manure crops according to local conditions". In the early post-liberation period, the total planting area of green manure crops amounted to more than 1.7 million ha, mainly along the Changjiang Valley. It has now developed to nearly 10 million ha, all over north and south of the Changjiang River, inside and outside of the Great Wall, even in cold districts such as Xinjiang, Inner Mongolia and Heilongjiang where only one crop can be grown in a year. In some provinces such as Jiangsu, Zhejiang, Jiangxi, Hunan and Hubei, the planting area of green manure crops amounts to 20-50 percent of the total farmland.

2. MAJOR GREEN MANURE CROPS

Green manure crops used in multiple cropping in China can be roughly divided into:

i. Leguminous green manures, mainly:

Chinese milk-vetch (*Astragalus sinicus* L.);
Common vetch (*Vicia sativa* L.);
Hairy vetch (*Vicia villosa* Roth.);
Southern burclover (*Medicago hispida* Gaertn.),
Broad bean (*Vicia faba* L.);
Field pea (*Pisum arvense* L.).

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[1] 1 shi = 22 litres, 1 mu = 0.066 hectares.

(These are chiefly used as winter green manures, sown in autumn and ploughed under in spring or early summer for rice, maize, cotton or other principal crops.)

Sesbania (*Sesbania cannabina* (Retz) Pers.);
Sunnhemp (*Crotalaria juncea* L.);
Sweet clover (*Melilotus* spp.);
Green bean (*Phaseolus aureus* Roxb.);
Cowpea (*Vigna sinensis* (L.) Savi.); etc.

(These are chiefly used as spring and summer green manures, sown in late spring or early summer and ploughed under in autumn for late rice or winter wheat, or ploughed under in summer as side-dressing for maize, cotton or other principal crops in the same season.)

ii. Non-leguminous green manures, mainly:

Rape (*Brassica napus* L.);
Radish (*Raphanus sativas* L.).

iii. Aquatic green manures, mainly the so-called "Three aquatic plants and azolla". "Three aquatic plants" refers to:

Water lettuce (*Pistia stratiotes* L.);
Water hyacinth (*Eichornia crassipes* Solms-Laub.);
Water groundnut (*Alternanthera philoxeroides* (Mart.) Griseb.).

These are planted on waste water surfaces (ponds, river branches) and dredged up for compost or fodder. "Azolla" refers to *Azolla pinnata* R. Br. or *Azolla imbricata* (Roxb.) Nakai. In recent years another species, *Azolla filiculoides*, was introduced and has spread rapidly in Zhejiang, Fujian, Jiangsu, Sichuan and other provinces.

3. PATTERNS OF PLANTING AND UTILIZATION OF GREEN MANURE CROPS IN MULTIPLE CROPPING SYSTEMS

Multiform patterns of multiple cropping and farming systems have been formed due to complicated climate and soil conditions, diverse crops and varieties, different levels of production and habits of cultivation. Green manure crops are alternated into multiple cropping systems through different patterns such as intercropping, mixed cropping, relay intercropping and sequential cropping, as in the Chinese saying, "Grasp the two ends and exploit the gap". "Grasp the two ends" means to grasp the potential spare time beside the growing period of the principal crops (pre-sowing and post-harvest) to rush-sow a season of green manure crop. This is intensification of cropping in the time dimension. "Exploit the gap" means to make full use of gaps between rows and between the plants of principal crops through appropriate adjusting of the spatial arrangement to "squeeze in" one, even two, kinds of green manure crops. This is intensification of cropping in the space dimension.

The major pattern of utilization of green manures is "ploughing in green",

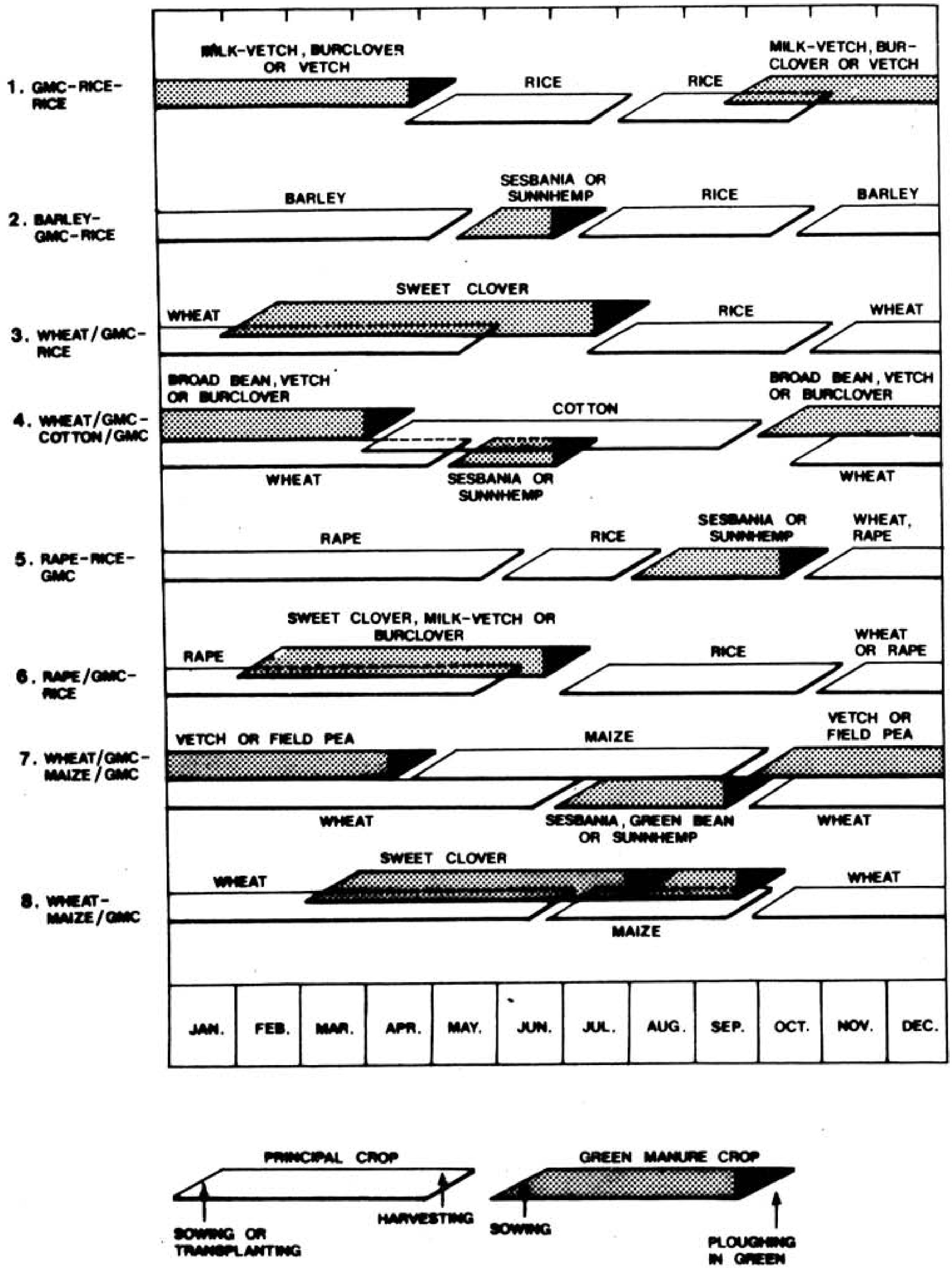

Fig. 1 Some examples of planting patterns of green manure crops in multiple cropping systems

i.e. to plough the whole plant under and bury it in the surface soil, let it rot and then use it as base manure for the succeeding principal crop or as side--dressing for the then principal crop in the same field. In some areas, people cut the canopy of the green manure crop when still growing and bury it near the roots of the principal crop as a side-dressing; then allow the green manure to ratoon and finally plough it under as basemanure for the succeeding crop. Another method is to harvest the canopy of the green manure crop and directly bury it in other fields or compost it, or feed it to animals, or to biogas plants, leaving only the roots to be ploughed under to enrich the original field.

The cropping patterns of green manure crops in multiple cropping systems are many and vary from place to place. A few typical examples are listed below and in Figure 1.

i. GMC (green manure crop)-rice-rice: Changjiang Valley and south China. Milk-vetch, burclover or vetch is undersown in late rice; or, in some places, leguminous crops which can be used both as green manure and pod harvest (e.g. broad bean or field pea) are sequentially sown after harvesting late rice. They are ploughed under in the next spring as base manure for early rice.

ii. Barley-GMC-rice: Chingjiang Valley and north of the Huaihe River. Barley or naked barley is grown in winter; in late May of the next year, a summer green manure crop (e.g. sesbania) is sown after harvest and ploughed under in early June as base manure for delay transplanted medium rice.

iii. Wheat/GMC-rice: north of the Changjiang River and the Huaihe River. Sweet clover is undersown in winter wheat in early spring, or sesbania undersown in early summer. They are allowed to continue growing for some time after harvesting the wheat and then ploughed under as base manure for rice.

iv. Wheat/GMC-cotton/GMC: Changjiang Valley arid land. Winter green manure (broad bean, vetch or burclover) is intercropped with winter wheat and ploughed under in spring. Then cotton is undersown in the wheat rows. After harvesting wheat, summer green manure (sunnhemp or sesbania) is undersown in the cotton rows. After a month more of growing, it is ploughed under as side-dressing for the cotton.

v. Rape-rice-GMC: north of the Changjiang River. Rice is transplanted sequentially after rape. Autumn green manure (sesbania or sunnhemp) is grown after harvesting the rice, in early August, and ploughed under in late October as base manure for winter wheat.

vi. Rape/GMC-rice: Changjiang and Huaihe Valley. Sweet clover, milk-vetch or burclover is undersown in winter rape in February and allowed to continue growing for some time after the rape harvest, then ploughed under in middle to late June as base manure for rice.

vii. Wheat/GMC-maize/GMC (generally called "two grain crops and two green manure crops system"): Huanghe Valley and north China plain. Vetch is intercropped with winter wheat and ploughed under in April before maize is sown. In early or middle July, after harvesting the wheat, sunnhemp or green bean is undersown between the rows of maize and ploughed under after the maize harvest as base manure for the succeeding wheat.

viii. Wheat-maize/GMC: Huanghe Valley medium fertility fields. Maize is grown after harvesting winter wheat, and sunnhemp or green bean is undersown at the same time, or sweet clover may be undersown in advance of the wheat harvest. A certain amount of green material is cut in late July or early August and buried as side-dressing for maize. The GMC are then allowed to ratoon and are ploughed under after the maize harvest as base manure for the succeeding wheat.

4. ROLE OF GREEN MANURING IN IMPROVING SOIL

The rate and amount of accumulation of soil organic matter after ploughing green manures under depends on factors such as climate, soil type, time of ploughing, amount of green matter ploughed under, cultivation practice and the C/N ratio of the green manure. Generally speaking, it is higher in the north than in the south, and on aquatic land than on arid land. It was calculated from 34 analytical data in north China that every 1500-3000 jin[1] of green matter ploughed under increased the organic matter content in 30 cm cultivated soil by 0.076 percent. On low-yielding paddy clay in south China, growing vetch in a winter fallow field for several years increased the soil organic matter content by 0.15-0.20 percent. The effect was more significant when the leguminous green manure was mixed sown with a graminaceous crop (e.g. ryegrass). The yield of *Azolla* in rice in Zhejiang Province amounted to about 3000 jin per mu in one season. About 39 percent would transfer to soil organic matter in the same year.

Mineralization of organic matter together with nitrogen fixation of symbiotic nodule bacteria of leguminous green manure crops, and the *Azolla-Anabaena* symbiosis and phosphorolysis of their root system, improve soil fertility remarkably. Every 3000 jin of green matter ploughed under per mu adds 13-15 jin N and 5-6 jin P_2O_5 to soil. Results of a pot experiment of relay intercropping of wheat and sweet clover carried out by Shaanxi Soil and Fertilizer Institute indicated that even if all the above-ground part were removed and the root system were picked out, the total N content of the soil increased by 0.0034 percent more than the check pot (single cropping of wheat), equivalent to a net increase of 10 jin N/mu. The content of quickly available N was 27.0 ppm (11.6 ppm ammonium N) while that of the check pot was 23.8 ppm (2.8 ppm ammonium N). An experimental result from Jiangxi Province indicated that after six years of growing green manure crops, the soil organic matter content in the cultivated layer of arid land red loam increased from the original 0.64 percent to 1.62 percent, i.e. an annual increase of 0.16 percent; total N from 0.040 percent to 0.088 percent, and P_2O_5 from 0.036 percent to 0.080 percent.

Owing to the penetration activity of the strong root system of green manure crops together with the rotting of a huge amount of ploughed fresh organic

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[1] 1 jin = 0.0550 kg.

material, the physical structure of the cultivated layer soil is improved (i.e. water-stable aggregate, total porosity and water-holding capacity increased; soil volume weight and resistance to penetration decreased).

Planting green manures in multiple cropping systems is an effective measure for ameliorating alkali-saline soil. According to a report from Shandong Soil and Fertilizer Institute (1977), when sesbania was grown on alkali-saline soil containing 0.2-0.7 percent salt, it covered the field closely and thus decreased water transpiration, improved soil structure and controlled the accumulation of salt in the surface soil. The salt content of 10 cm · soil decreased at 25-64 percent, and that of 20 cm soil decreased by 10-30 percent. At Xinyang Agricultural Station, Yancheng Prefecture, Jiangsu Province, when vetch was grown for one or two seasons on saline soil containing 0.2 percent salt, the salt content of the soil decreased to 0.07-0.11 percent. After three seasons of growing vetch, it decreased to 0.03 percent.

Growing green manure crops also plays a special role in solving some micronutrient deficiency problems. When vetch was grown on Zn-deficient red soil in Yunnan Province, it activated the zinc in the soil through its cumulative effect. The Zn content of the surface soil (0-10 cm) increased from 92.5 ppm to 170 ppm after growing vetch for three years and the available Zn content increased from 2.9 ppm to 4.9 ppm. This controlled Zn deficiency of maize and increased its yield by 20-70 percent.

Green manure crops are good for soil and water conservation on account of their densely covering canopy and deep, strong root system. Observation at Bakouzi Station indicated that the surface runnoff from second year sweet clover was 26.2 percent less than that from soybean and 43.8 percent less than from bare soil; soil erosion was 77.7 percent less than from a soybean field and 39.9-90.8 percent less than from bare fallow. At the Soil and Water Conservation Station, Suide County, Shaanxi Province, after a rainstorm of 54.3 mm in less than an hour in early August 1956, soil erosion from a sorghum and millet field was 12.56 tons/mu while that from sweet clover was only 1.94 tons/mu.

5. YIELD INCREASING EFFECT OF GREEN MANURING

During the growing period, green manure crops excrete N through their root system to soil and benefit the principal crops intergrowing with them in the same season. Analysis by Jiangsu Soil and Fertilizer Institute showed that the N content of leaves of wheat intercropped with broad bean was 0.12 percent more, and of wheat intercropped with southern burclover 0.388 percent more, than of single-crop wheat.

In rice fields of south China, where *Azolla* is planted and ploughed under in summer, the manurial effect can be observed in about seven days and the utilization ratio of *Azolla* N by rice in the same season amounts to 25-40 percent. Results of 422 experiments in 47 counties of Zhejiang Province (1964) indicated that rice yield increased on average by 18.6 percent where *Azolla* was planted and that every 2000-3000 jin of fresh *Azolla* ploughed under produced an additional 95.7 jin of rice grain on average.

The effect of green manuring is shown, after a period of decomposition, in the succeeding crops. According to 143 data from Guangxi Province, each 1000 jin of ploughed green matter increased the yield of succeeding rice by 60–100 jin. In Jiangsu Province, each 1500–2000 jin of ploughed green matter increased the yield of the succeeding grain crop by 100–160 jin. Averaging 109 data from north China, each 1216 jin of ploughed green matter increased the grain yield of the succeeding crop by 108.4 jin. Averaging 24 data from five Provinces in northwestern China, each 2132 jin of ploughed green matter increased the grain yield of the succeeding crop by 197.8 jin. The effect of green manuring in cotton fields is also very remarkable. According to reports from Jiangsu, Hubei and Henan Provinces, each 1000 jin of green matter ploughed under increases the yield of lint by 15–25 jin. In Liuzhou district, Guanxi Province, green manure rape intercropped with autumn planted sugarcane is ploughed under in spring (late February/early March). In an experimental field where 1000 jin of green matter had been ploughed under, the yield of sugarcane was 13 659 jin/mu, 12.5 percent higher than the check plot; where the amount ploughed under was 2000 jin/mu, the yield was 14 425 jin, i.e. 18.8 percent increase; and with 3000 jin ploughed under, the yield was 15 600 jin, i.e. 28.5 percent increase.

Green manuring not only has a yield-increasing effect on the intergrowing crop and the succeeding crop, but also has a rather prolonged effect. According to experiments carried out in Shaanxi and other provinces, on low-yielding fields where sweet clover was undersown in wheat rows, the yield of the first succeeding crop increased by 50–100 percent, of the second succeeding crop by 24–50 percent and of the third by 10–20 percent. Therefore, in spite of the replacement of one season of grain crop by a green manure crop in multiple cropping systems, the total output increases. In general, the saying of "one thousand jin of ploughed green matter increases one hundred jin of grain" is reliable. For example, the yield of "Two grain crops and one green manure crop" system (sesbania-maize-wheat) in the suburbs of Beijing was 923.7 jin/mu/year. "Three harvests a year" syste yielded 739.1 jin. At the Shanxi Soil and Fertilizer Institute in a "Four grain crops and two green manure crops in two years" system, in which two grain crops were replaced by two green manure crops (common vetch and sunnhemp), the total output of wheat and maize in the whole rotation cycle was 2427 jin/mu which was 276 jin/mu or 12.8 percent more than the "Three harvests a year" control. The quantity of farmyard manure applied was half that for the control and the amount of mineral fertilizer required was reduced by 17 percent. Moreover, the improved soil fertility also had some effect on the third year crop.

6. REMAINING PROBLEMS

Although China has a long history of green manuring, there is still a need for further investigations. For example, in north China, there is a shortage of proper species or varieties with a short growing period, quick early growth, cold resistance and a high yield of green matter, suitable for intercropping or sequential cropping. The problem whether green manuring can increase soil organic matter and how to increase it rapidly awaits further research and discussion. The relationship and proper ratio between green manures, mineral fertilizers and other kinds of organic manures are to be studied extensively. New and improved varieties of legumes and *Azolla* with high N-fixing capacity are needed; and so on. There is still a long way to go.

Paper 22 SOIL FERTILITY AND FERTILIZER USE RESEARCH IN INTERCROPPING SYSTEMS IN NORTHEAST BRAZIL

M. de A. Lira[1], M.A. Faris[2] and R.C. Mafra[1]

1. INTRODUCTION

The Brazilian Northeast covers an area of 1 548 672 km and has a population of more than 35 million people. The region is located between 2° and 27°S and 34° and 47°W. Fifty-two percent of the land and 41 percent of the population are in the semi-arid region. The area is subject to periodic droughts which have affected the social and economic structure of the region. In many areas, low rainfall and/or low level of soil fertility limit agricultural production potential with the technology currently in use. Topography, shallow soils, and rocky soils in some areas limit production alternatives and inhibit the use of mechanical power. While 65 percent of the area's inhabitants are employed in agriculture, the region still imports much of its food from other parts of Brazil.

The Region comprises six main agro-climatic zones: the semi-arid zone, the Setentrional zone, the litoral or "Zona da Mata", the Agreste zone, the valleys and humid mountains, and finally the "cerrado" zone (Aguiar *et al.* 1981).

2. SEMI-ARID FARMING SYSTEMS

The farming systems in the semi-arid tropics of the Northeast are characterized by a subsistence agriculture in which cattle raising, cotton and subsistence cropping are the basic predominant activities. The agricultural activity is mostly devoted to the family's own supply of the main crops, namely maize, beans and cassava. The most important cash crops are cotton, followed by castor bean and sisal. On some areas carnaúba, babaçú, oiticica and caroá are considered the most important species[3].

This type of exploitation in the "sequeiro" areas has not resulted in a satisfactory performance in terms of regional agricultural development. Periodical efforts have been made by the government, but results were not encouraging. In the last decade the government decided to act with a planned system, looking for long-term solutions that would stabilize agricultural performance or at least lessen the drought effects.

The agricultural producing units are cultivated mainly by small farmers who have, in general, the following characteristics: intensive exploitation of the

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[3] Carnaúba = *Copernicia brunifera*; babaçu = *Orbygnia martiana*; oiticica = *Licania rigida* Benth.; caroá = *Neoglaziovia variegata*.

land, limited fund resources, predominantly human and animal working power, use of scarcely efficient implements, lack of orientation towards risks, low cultural level and consequently strongly linked to tradition, and difficulty in obtaining credit. These are limiting factors to regional agricultural development.

3. INTERCROPPING PRACTICES

The most common intercropping systems in the Northeast are shown in Table 1.

Table 1 MOST COMMON INTERCROPPING SYSTEMS IN NORTHEAST BRAZIL

System	States
Maize + bean	Paraíba, Pernambuco, Alagoas, Sergipe, Bahia
Maize + cowpea	Ceará, Piauí, Rio Grande, Paraíba, Pernambuco
Maize + cowpea + perennial cotton	Ceará, Rio Grande, Paraíba, Pernambuco
Maize + bean + annual cotton	Pernambuco, Sergipe
Maize + cowpea + cassava	Ceará, Piauí
Cowpea + cassava	Pernambuco, Bahia
Maize + bean + cassava	Pernambuco, Bahia
Maize + rice + cassava	Maranhão
Maize + bean + castor	Bahia
Maize + cotton	Pernambuco
Maize + rice	Maranhão
Tobacco + cowpea	Alagoas

Most of the research on intercropping has been done in the last decade. A regional symposium on intercropping research was held in 1981 and data from all research organizations were compiled and discussed. Mostly, only yield has been looked at, without considering such factors as total production efficiency, competitive effects and economic analysis.

Fertilizer use is generally zero in the semi-arid Northeast. Many fertilizer response studies have been carried out on monocrops, but results have been extremely variable and inconclusive. The problems of fertilizer responses in the semi-arid Northeast are not specifically related to intercropping practices, and they occur whatever the cropping system.

3.1 Fertilizer Research in Intercropping Systems

A resumé of research in different areas is given below.

3.1.1 Sergipe

An experiment was conducted to study the response of different P levels on intercropped maize and beans (*Phaseolus vulgaris*), with the results shown in Table 2. Generally, as the phosphorus level increased, there was an increase in bean yield. The optimum P level for the bean + maize system appeared to be somewhat higher than for bean as sole crop. Fertilizer application minimized the competitive effects of maize on the beans. Both the number of cobs per plant and the cob weight were larger in the intercropped maize than in the monocropped maize.

Table 2 EFFECT OF PHOSPHATE FERTILIZER ON GRAIN YIELDS OF BEAN AND MAIZE IN MONOCROP AND INTERCROP SYSTEMS, POÇO VERDE, SERGIPE, BRAZIL 1979

Level of P_2O_5 (kg/ha)	Grain yield (kg/ha)				LER Land Equivalent Ratio		
	Bean		Maize				
	Monocrop	Intercrop	Monocrop	Intercrop	Bean	Maize	Total
0	1 193	337	1 406	808	0.28	0.57	0.85
100	2 290	963	2 199	2 006	0.42	0.91	1.33
200	2 685	1 170	2 758	2 054	0.44	0.74	1.18
300	2 583	1 236	3 051	2 163	0.48	0.71	1.19

Source: EMBRAPA, UEPAE de Aracaju, 1981.

Notes: Intercrop = one row of maize to 3 rows of beans.
50 kg N/ha was applied only to maize.

Residual effects on the second year crop were studied in 1981. Each plot was divided into four sub-plots for differential P application in the second year. The crop combinations were the same as in 1980, but the maize failed due to lack of sufficient rainfall. The bean yields are shown in Table 3. The results indicate that there was competition for phosphorus between the legume and the cereal, which could be alleviated either by the residual from the first year or by new phosphorus application in the second year.

Table 3 EFFECTS OF RESIDUAL AND APPLIED PHOSPHATE FERTILIZER ON BEAN YIELDS IN MONOCROP AND INTERCROP SYSTEMS, POÇO VERDE, SERGIPE, 1980

P_2O_5 applied first year (kg/ha)	Soil phosphorus at start of second year (ppm)	Bean yield (kg/ha) P_2O_5 applied second year kg/ha			
		0	40	80	120
		Monocrop			
0	1.9	584	817	776	921
100	3.9	737	963	949	1 088
200	8.0	962	1 030	1 071	1 121
300	10.4	931	1 269	1 081	1 184
		Intercrop			
0	2.7	269	557	634	685
100	3.9	500	732	705	710
200	6.7	674	752	722	751
300	9.6	761	674	727	807

Source: EMBRAPA, UEPAE de Aracaju, 1981.

3.1.2 Paraíba

An unreplicated experiment was conducted at Itaporanga, Paraíba, to study the effects of four soil tillage systems and two fertilizer treatments on intercropped perennial cotton + maize + cowpea. The perennial cotton was planted at a spacing of 2 x 1 m. The cowpea and maize were planted in rows between the cotton rows. All fertilizer (40-60-10) was applied to the cotton at planting (Lima and Beltrão 1978). Apparently, there was a tillage x fertilizer interaction, since the increase in cotton yield was much larger on the minimum tilled treatment. This is in agreement with results elsewhere. The fertilizer application had little effect on the maize and cowpea yields, except in the minimum tillage treatment where maize showed a substantial increase in yield due to fertilizer.

3.1.3 Rio Grande do Norte

A field trial was conducted at Seridó and Serrana to study the effect of fertilizer on perennial cotton intercropped with sorghum and cowpea (Holanda Neto and Pereira 1978). At each location, an area of 1.5 ha was divided into three plots of 0.5 ha each. Fertilizer (20-60-0) was applied to the sorghum and cowpea crops which were seeded between the cotton rows in the first year. The yields obtained are shown in Table 4. Economical analysis indicated that the 20-60-0 fertilizer treatment showed a profit of Cr$ 2.00 per each Cr$ 1.00 applied.

Table 4 EFFECTS OF FERTILIZER TREATMENT ON INTERCROPPED COTTON, SORGHUM AND COWPEA: MEAN OF TWO LOCATIONS, RIO GRANDE DO NORTE

Yield kg/ha	Without fertilizer	With castor bean cake (1.5 t/ha)	With fertilizer (20-60-0)
Sorghum	211	474	421
Cowpea	64	102	178
Cotton (1st year)	12	11	11
Cotton (2nd year)	249	350	288

Source: Holanda *et al.* 1978

3.1.4 Bahia

A randomized complete block experiment with four replications was conducted at Pindobaçu to determine the level of fertilizer required for intercropped maize + bean. The fertilizer treatments (up to 90-90-45 kg N-P_2O_5-K_2O/ha) had no statistically significant effect on the maize yield but the beans responded slightly.

3.1.5 Ceará

In the perennial cotton + maize + cowpea intercropping system, maize and cowpea are planted between the cotton rows in the first year of the 5-year cycle of the perennial cotton. After the first year the small farmer generally prunes the cotton back and plants maize and cowpea again, but the sharecropper goes on to a new area to repeat the cycle again. Research results from Quixada, Ceará, in 1975, showed that using 40-60-40 kg $N-P_2O_5-K_2O$/ha on various perennial cotton-based systems in the first year successfully offset the cotton yield reduction due to intercropping.

3.1.6 Pernambuco

The productivity of cereal (sorghum or maize) + pulse (cowpea or common bean) mixture in alternate rows was compared with pure stands of the component species in two cropping seasons (1977/78) at Itabaiana and Caruaru with and without fertilizer application (40-35-25). At both locations, there was a marked difference between the two fertility levels and between the two cropping seasons. The cereal responded to fertilizer application under both the monocrop and intercrop systems although moisture was quite inadequate at Caruaru in 1978. Generally sorghum yields increased by above 50 percent on average and a similar response to fertilizer was observed in the pure maize plots. Less response was observed in the maize + common bean system, though the common bean responded well to fertilizer application. Due to the fact that cowpea is not adapted to these locations, no general conclusion could be reached on the response of cowpea to fertilizer application.

The productivity of cassava intercropped with sorghum and/or cowpea under two levels of fertilizer treatment was investigated by BNB/IPA (1980) for three cropping seasons. The highest production was obtained from pure cassava or cassava + cowpea. The data showed that there is no justification to plant sorghum or cowpea as pure crops. In all cases, soil correction by fertilizer application produced higher gross income. The highest income was accomplished by planting either pure cassava or cassava + either sorghum or cowpea. However, long-term experiments and consideration of more factors are needed.

3.1.7 Agreste Setentrional

Farm-level new technologies were compared at 4 different farms: (i) traditional crops intercropped, i.e. cotton + maize + bean system with traditional technology; (ii) improved traditional without fertilizer, i.e. traditional crops with more substantial changes in spacing, other cultural practices and improved varieties, but no fertilizer input; (iii) improved traditional with fertilizer (Table 5). Three other technologies for the maize + bean system were compared at 2 locations in the Vale do Ipojuca (Table 6). Results of such farm-level experiments are interesting due to the accuracy of the yield data, and the responses of the component crops to fertilizer under adverse rainfall conditions. Even under adverse climatic conditions, low levels of fertilizer produced an increase in yield. One would expect that, with better rainfall conditions, there would be an even greater return to fertilizer.

4. CONCLUSIONS

The present survey of research demonstrates the variability in approach,

Table 5 PRODUCTIVITY OF COTTON + MAIZE + BEAN SYSTEM UNDER 3 TECHNOLOGIES TESTED ON FARMERS' FIELDS (KG/HA, AVERAGE OF 4 LOCATIONS) AGRESTE SETENTRIONAL, 1980/1981

Crop	Technology type 1980			Technology type 1981		
		Improved			Improved	
	Traditional	Without fertilizer	With fertilizer 50-60-30	Traditional	Without fertilizer	With fertilizer 50-60-0
Cotton	316	182	127	320	111	94
Maize	372	858	1 040	246	564	965
Bean	153	292	311	32	186	221

Table 6 PRODUCTIVITY OF MAIZE + BEAN SYSTEM UNDER 3 TECHNOLOGIES TESTED ON FARMERS' FIELDS (KG/HA, AVERAGE OF 2 LOCATIONS) VALE DO IPOJUCA, 1980/1981

Crop	Technology type 1980			Technology type 1981		
		Improved			Improved	
	Traditional	Without fertilizer	With fertilizer[1]	Traditional	Without fertilizer	With fertilizer[1]
Bean	64	320	500	20	106	116
Maize	444	964	1 340	108	559	727

[1] 70 kg P_2O_5/ha + 10 t/ha manure

type of data collected, factors considered and numbers of years and locations studied in each case. Many fertilizer response studies have already been carried out, but results have been extremely variable and inconclusive. Future research should monitor the water situation in more detail than has been done in the past. Fertilizer studies are important when combined with land and water management practices. The importance of legumes in many of the intercropping systems suggests that nitrogen fixation is a factor that would merit some study. The intercropping systems in the Northeast are much too important to leave the research as loosely structured as it is at present. There is a need to concentrate research efforts in order to produce improved alternative systems before approaching the farmer.

Paper 23 SOIL FERTILITY AND FERTILIZER USE RESEARCH IN MULTIPLE CROPPING SYSTEMS IN ZAMBIA

R.K. Rajoo[1]

1. THE EXPERIMENT

Problems arising from the use of fertilizers in relation to soil fertility at small-scale farmer's level led to the participation of Zambia in an FAO/IAEA sponsored international coordinated intercropping project. The information presented here relates to the efficiency of the use of nitrogen in a maize/groundnut intercropping system which is widely used in Zambia.

The experiment was laid out at the National Irrigation Research Station, Nanga (27°.56E, 15°.45S) on 20 December 1980. The soil of the experimental site belongs to the Mazabuka series, which are Chromic Luvisols or Eutric Nitosols (FAO–Unesco) and Typic Rhodustalfs (US SCS 1974) occurring on elevated sites under *munga* woodland Savannah of moderate rainfall (700–800 mm). They are deep well drained soils with characteristic red argillic B-horizon developed over calciumsilicate schists. Texturally they can be classified as sandy clay loam.

An area of 50 x 28 m was divided into six blocks of 28 x 7½ m, each block separated by 1 m walkways. Each block was cut into 7 plots of 7½ x 4 m, which in turn were subdivided into isotope and yield sub-plots of 1½ x 4 m and 6 x 4 m respectively. In every plot four ridges 1 m apart were made. Basal fertilizer application was 20 kg P and 40 kg K/ha as triple superphosphate and muriate of potash. Nitrogen was applied as urea at 80 kg N/ha as indicated below. The maize seed (28 kg/ha S.R. 52) was hand dibbled on the flats whereas groundnuts (80 kg/ha Makulu Red) were dibbled in the ridges. Every plot had four lines each of alternating maize and groundnuts. The maize seeds were planted 25 cm apart and the groundnuts 12.5 cm apart. The experiment was hand-weeded throughout the season four times. No irrigation was used. There was hardly any incidence of disease and pests but stagnant water for almost 10 days could not be avoided due to heavy rainfall. The randomly arranged N treatments were:

N_1 = broadcast and incorporated over entire plot at seeding
N_2 = broadcast and incorporated near the cereal row at seeding
N_3 = banded near the cereal row at seeding
N_4 = split application: one half (^{15}N labelled sub-plot) broadcast incorporated at seeding, the other half (not labelled) side-dressed to the cereal at knee high stage
N_5 = same as N_4 but side-dressing labelled
N_6 = split application: one half (^{15}N labelled sub-plot) incorporated near the cereal at seeding, the other half (not labelled) side-dressed
N_7 = same as N_6 but side-dressing labelled

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The maize was harvested on 14 May, and groundnuts on 2 June. The yield sub-plot harvesting was done from 5 x 3 m and the isotope sub-plot harvesting from 2 x 1 m of the central portion of respective sub-plots. All above-ground maize parts were harvested, dried, threshed and weighed for grain and stover separately. Representative samples were taken and dried in the oven at 70°C. Yields were adjusted for moisture loss. The same samples were ground and analysed for total N by Kjeldahl and for P by colorimetric methods respectively. The N-15 labelled samples were analysed by the IAEA Seibersdorf Laboratory.

2. RESULTS AND DISCUSSION

The results in Table 1 show that the yield of maize grain from split treatments and from single application broadcast and incorporated near the cereal row was significantly better than banding or than broadcasting over the whole plot. The poor yield from banding was probably due to leaching of the fertilizer beyond the root zone by heavy rain. Maize stover results followed the same pattern. N uptake in the maize grain and in the whole plant was also significantly higher from split application. There is hardly any similar experimentation in literature for confirmation, but the superiority of the above treatments cannot be denied even though the yield potential has not been fully exploited due to late planting. On the other hand, the groundnut intercrop remained immune to treatments because yield and N uptake did not differ significantly.

Table 1 YIELD AND N UPTAKE BY MAIZE IN MAIZE/GROUNDNUT INTERCROPPING SYSTEM

Treatment	Yield of grain (kg/ha)	N uptake in grain (kg/ha)	Yield of stover (kg/ha)	N uptake in stover (kg/ha)	Total N uptake
N_1	1 586	18.71	1 833	10.44	29.15
N_2	1 933	22.61	1 940	9.31	31.92
N_3	1 413	15.96	1 886	9.43	25.39
N_4	1 600	17.76	2 320	13.22	30.98
N_5	1 700	19.21	2 000	6.40	25.61
N_6	1 980	22.77	2 400	13.68	36.45
N_7	1 966	23.00	2 400	12.00	35.00
LSD	***	***	***	NS	*
	358	5.51	511		6.74

* Significant at 5% level
*** Significant at 1% level

The subsidiary study of P revealed mostly not significant results except uptake by maize grains which is of peripheral interest. However N and P uptakes were found to be correlated at very high significance for the 2 crops individually and together. It is therefore quite clear that, as the uptake of N increases, P uptake also increases in the same proportion thereby confirming the basic concept of balanced fertilizer application.

The data presented in Table 2 show that the percent N derived from fertilizer, fertilizer N yield and N use efficiency did not differ significantly in the maize crop. Thus the efficiency of N was the same when applied at 80 kg/ha as basal, 40 kg/ha as basal or 40 kg/ha as side-dressing at knee high stage. On the other hand, all three parameters differed highly significantly in the groundnut crop. Broadcasting N over the whole area in a single or split application performed better than banding or application near the cereal row. Soil A value analysis corroborated the trend generated by other parameters, but overall N uptake was very poor.

Table 2 NITROGEN EFFICIENCY IN MAIZE/GROUNDNUT INTERCROPPING

Treatment	Maize				Groundnut				
	Total N yield kg/ha	% N derived from fertilizer	Fertilizer N yield kg/ha	Fertilizer N use efficiency %	Total N yield kg/ha	% N derived from fertilizer	Fertilizer N yield kg/ha	Fertilizer N use efficiency %	Soil A value
N_1	28.91	17.28	4.98	6.22	39.01	5.46	2.15	2.54	964.05
N_2	32.02	14.03	4.84	6.04	42.36	0.87	0.39	0.48	1 429.36
N_3	25.98	15.31	3.78	4.73	45.08	0.30	0.13	0.16	2 122.45
N_4	31.65	12.73	3.92	9.38	39.12	4.21	1.79	4.544	511.47
N_5	25.35	8.49	2.41	6.19	40.79	1.39	0.51	1.303	1 126.27
N_6	35.99	13.63	4.93	12.32	40.88	0.77	0.31	0.78	611.51
N_7	34.82	15.53	5.45	13.67	44.25	2.35	1.06	2.68	492.89
LSD	*	NS	NS	NS	NS	***	***	***	*
	6.83	-	-	-	-	2.239	1.44	2.94	816.66

* Significant at 5% level
*** Significant at 1% level

3. CONCLUSION

From this experiment it can be concluded that N should be applied and incorporated near the cereal row in a maize/groundnut intercropping system. Split application half as basal and the other half side-dressed at knee high stage will further improve the yield and N uptake.

Paper 24 FERTILIZER USE IN MULTIPLE CROPPING IN INDONESIA

Nuryadi, T.G. Soedomo and Soegiyanto[1]

1. INTRODUCTION

Multiple cropping systems, which are a special feature of the Indonesian farm development, enable farmers to grow two or more crops a year on the same piece of land. Several systems of multiple cropping in different areas or agro--climatic zones have been developed and widely practised by the farmers.

On fully irrigated lowland, the farmers generally include two crops of rice followed by fallow or one crop of *palawija*[2], non-rice food crops such as maize, sorghum, groundnut, soybean, mungbean, sweet potato, cassava, etc., or vegetables. On partly irrigated lowland, the farmers generally grow one crop of rice, followed by one or two crops of *palawija* or vegetables; rice is planted in the wet season (December-April), followed by *palawija* and vegetables in the dry season (May-October). Most of the dry season crops are intercropped, relay planted, sequentially planted or ratooned. On rainfed lowland, the farmers generally grow one crop of rice followed by *palawija* or vegetables or fallow. On rainfed dryland, the farmers' practice of intercropping, relay planting and sequential planting includes upland rice, *palawija* and vegetables and other perennial crops as well as tree crops.

Multiple cropping systems not only increase land productivity, increase crop production and improve diet, but also provide a spread of employment for the farmer's family and help to minimize the risk of crop failure. Moreover, multiple cropping systems will make more efficient use of applied fertilizers and other inputs.

Integrated multiple cropping systems include good land preparation, suitable crop combinations, optimal plant spacing, use of high-yielding varieties, integrated pest control and soil-water management and will support fertilizer use development.

In Indonesia, monthly fertilizer use and main cropping patterns have a close relationship. Most urea is used during the wet season for rice, especially lowland rice. In the dry season, *palawija* and vegetables grown on dryland and under upland conditions receive fertilizer, but less than rice.

2. SOIL FERTILITY

There is a close relationship between inherent soil fertility and fertilizer use. The main types of soil in Indonesia are Podzolic soil, alluvial, Latosol, Grumusol, Regosol and Andosol. The physical and chemical characteristics of the same type of soil in different locations vary from one location to the other.

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[1] Department of Agriculture, Directorate General of Food Crop Agriculture.

[2] *Palawija* = secondary crops (all food crops other than rice).

Red-yellow Podzolic soils are a part of the broad category of red soils in Indonesia. These soils collectively cover much of the land area of Indonesia that is not swampy, alluvial or of recent volcanic origin. They are distinctly different from the latosols and Mediterranean soils that are also a part of the red soil group. General classifications were adequate in the past. Physical characteristics and topography were most important for planning perennial crops on large estates. There was little need for more detailed classification because the land was not considered suitable for sustained agriculture involving food crops. Shifting cultivation has been and still is a major management technique for food crop production on these soils.

For these soils fertilizer should be put as close as possible to the root zone so that the plant roots can easily and efficiently reach the nutrients. Without use of fertilizer and incorporation of crop residues (directly or as animal manure) production from continuous cropping declines rapidly. Continuous cover by cropping and mulching and terracing are management practices that must be followed to protect the soil and maintain its productivity.

3. SOIL AND CROP MANAGEMENT RESEARCH

A long-term experiment was begun in 1973 in Central Lampung by the Central Research Institute for Agriculture in a farmer's field on land that had been opened for about 20 years. The objective was to study the effects of fertilizer, lime and crop residue on production of crops grown in traditional systems of mixed cropping and in monoculture. The results have been reported by McIntosh and Surjatna (1978) (Table 1). Other long-term studies have been conducted by the Soil Research Institute and the Benchmark Soils Project of the University of Hawaii in collaboration with the Soil Research Institute. These all show the potential for crop production on these soils if properly managed.

The first two studies were basically cropping systems research involving a limited number of different cropping patterns. The management treatments were based on the premise that these were fragile soils and research was needed to evaluate management practices that would slow down or prevent the loss of soil productivity with continuous cropping. Results indicate that crop yield levels could be maintained. In the short term the data indicate that applications of inorganic sources of N, P, K and lime to replace nutrient removal would be sufficient to maintain production. On the other hand, without these applications the yields decreased yearly.

Year to year rainfall fluctuations make it difficult to detect definite trends in loss of production where fertilizers have been used. Two factors other than yield, however, give an indication of potential problems. Firstly, soil analysis data (Table 2) show that after five years of continuous cropping without fertilizer and return of residues, pH and organic carbon decreased and KCl-extractable Al increased. On the other hand, with fertilizer and return of residues these values were about the same as the uncultivated check. The return of residues is needed to maintain the level of soil organic matter and provide buffering and exchange capacity. Secondly, the direct effect on the physical properties of the soil is probably equally important. After 4 years of continuous cropping there were noticeable differences in the appearance of maize; without

Table 1 COMPARISONS OF CROP YIELDS AND NET RETURNS FOR THREE MANAGEMENT PRACTICES IN A LONG-TERM CROPPING SYSTEM STUDY, 1973-78. CROPPING SYSTEMS RESEARCH, BANJARJAYA, CENTRAL LAMPUNG

Fertilizer treatment and year	Dry grain				Cassava	Net	Food
	Maize	Upland rice	Ground-nut	Ricebean	wet root	return	calories
	t/ha				t/ha	Rp/ha	KCal/ha
No lime + no NPK + no mulch							
1973-74	0.46	0.77	0.22	0.09	14.0	91 000	22 287
74-75	0.21	0.86	0.47	0.05	6.1	-	12 391
75-76	0.22	0.65	0.23	-	6.0	21 667	10 590
76-77	0.35	0.54	-	0.07	3.7	-	5 908
77-78	0.13	0.15	0.22	-	3.9	27 137	6 520
Lime + NPK + no mulch							
1973-74	1.35	1.61	0.43	0.54	22.2	-	39 044
74-75	1.90	3.11	0.74	0.38	20.6	-	43 536
75-76	1.98	1.89	0.35	-	19.9	212 764	37 024
76-77	1.84	1.45	-	0.04	14.2	-	27 161
77-78	2.06	2.06	0.58	-	21.0	344 765	40 083
Lime + NPK + mulch							
1973-74	1.35	2.72	0.57	0.63	23.2	265 000	43 791
74-75	2.44	3.22	0.76	0.49	20.1	-	45 568
75-76	2.21	1.82	0.49	-	36.8	397 344	58 588
76-77	1.90	1.49	-	0.04	15.9	-	29 523
77-78	2.26	2.15	0.58	-	22.7	369 540	43 043

Source: Laporan Kamajuan Kenelitian, Seri Bola Bertanam (No. 4, 5 and 6), from 1974-77.

Note: 1975-76 was an exceptionally dry year. In 1976-77 the first planting of cassava failed because of bad cuttings and had to be replanted late.

Table 2 CHANGES IN SOME CHEMICAL MEASUREMENTS OF SOIL FROM PLOTS DIFFERENTLY TREATED FOR 5 YEARS, CENTRAL LAMPUNG

Treatment	pH	Extract Al.	Exchangeable base			Bray 2	Organic	
	(Kcl)	(KCl) meq/100 g	Ca	Mg	K	P	C	N
			meq/100 g			ppm	%	%
Uncultivated check (not tilled)	4.8	Nil	2.8	0.4	0.1	4.2	1.23	0.1
Without fertilizer or return of residues (continuous crop)	4.1	0.21	0.98	0.51	0.1	4.6	0.96	0.08
With fertilizer and return of residues (continuous crop)	5.5	Nil	3.8	0.3	0.1	50.0	1.15	0.09

Source: McIntosh and Effendi, 1978.

residues the soil was hard in places and there were differences in germination as well as in growth rate of the maize.

In the Benchmark Soils Project study of Typic Paleudult soils on a worldwide basis, three sites were located in Southern Sumatra. The work was designed to study the response of maize to P and N and to determine the contribution of residual P to grain yield. The remarkable aspect of this research was the 5-6 t/ha maize yield they were able to produce rather consistently on these soils with initial application rates of 80-120 kg P_2O_5 and 80 kg N/ha. They also used 50 kg K_2O, 1000 kg lime and 50 kg Mg/ha as well as applications of Zn and B. But probably their most effective management practice was the use of drip irrigation as needed. These yields are about double those obtained from other experiments on these soils with comparable management practices but where drip irrigation was not used.

The initial results from Central Lampung showed the potential for crop production. However, there were some apprehensions that the soil in the plot area was unique and that the results would not be representative of many other Red-Yellow Podzolic soils. The research was expanded to include three new sites. One was in a partially irrigated area where farmers were growing only one paddy rice crop per year even though on their adjacent land, without any irrigation, they were growing crops throughout the year. The other two were on land newly opened from secondary forest and on land previously cultivated within the last 3-4 years. These studies were designed primarily to evaluate different cropping patterns for productivity and acceptability to farmers in terms of economics, labour, markets and need for capital. Introduced patterns were compared to the farmers' existing patterns wherever possible. The results were similar to the previous work in Central Lampung and, because of the larger plot size and greater visibility, they were more convincing to farmers and extension staff.

In year-round cropping systems studies on Red-Yellow Podzolic soils in different regions of Indonesia, in which varieties, fertilizer response, pest management, etc. were studied simultaneously, the performances of Introduced Cropping Patterns compared to Farmer's Cropping Patterns were quite impressive in terms of net return and of rough rice equivalent. The variations in crop yields among the different locations indicate the need for further studies on component technology. For example, blast (*Pyricularia oryzae*) is still a major problem for upland rice. This disease problem is accentuated by the uncertain rate of N release from decomposing organic matter in newly opened land. At the same time the soils are extremely deficient in P and have low pHs.

4. CULTURAL PRACTICES AND CROP MANAGEMENT

The cropping pattern found to be appropriate for Red-Yellow Podzolic soils in most regions of Indonesia is shown in Figure 1. The management practices that follow are based on this pattern.

When the rains begin to fall, strips 2 m apart for planting maize are made by hoe. Land preparation for rice to be planted between the maize rows is made after the maize germinates. This system may provide a more even demand for

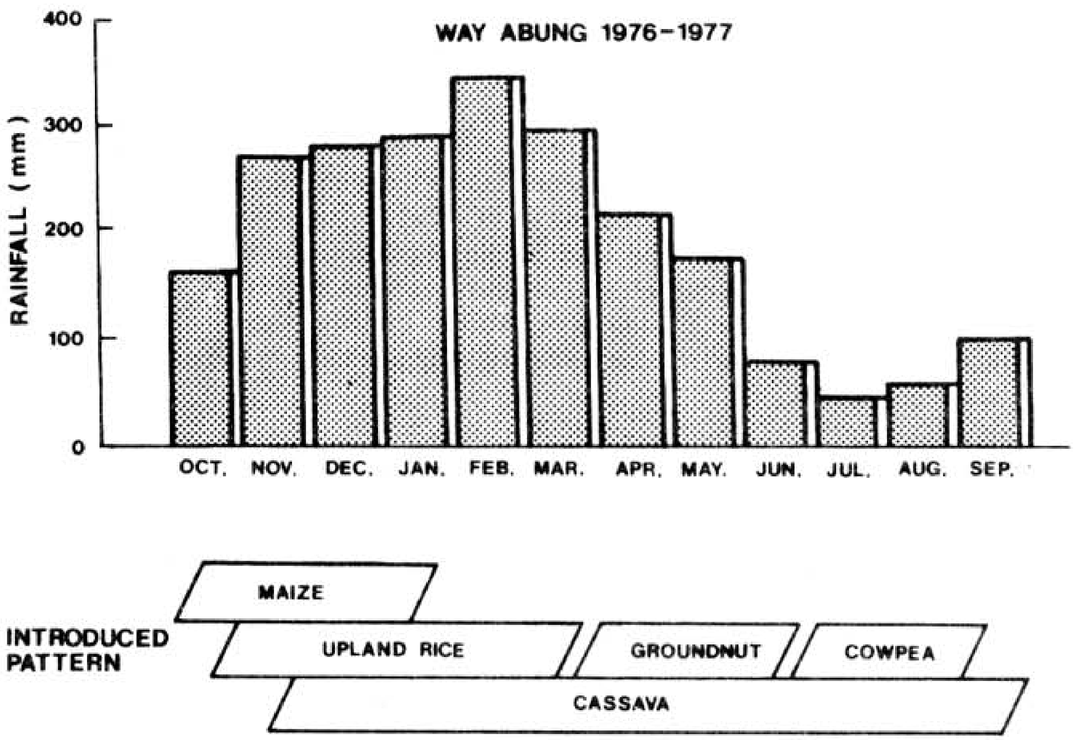

Fig. 1 Monthly rainfall distribution and year round cropping pattern commonly tested on Red-Yellow Podzolic soils

labour. However, if the farmer hires labour or uses a plough to prepare the land, then all the land is usually prepared at one time. No cultivation is necessary for the cassava. Minimum tillage is recommended for the groundnuts that are planted immediately after rice harvest. First, furrows are made along the rice stubble rows. Next, fertilizer and groundnut seeds are dibbled into the opening and covered with soil. After the groundnut harvest, one light hoeing is made to control weeds and loosen the soil for planting ricebeans or cowpeas, the last crop in the cropping sequence.

The first maize crop is sown in rows 200 cm apart, two seeds being dibbled by hand in small holes made by a wooden stick and spaced every 50 cm. This will give a population of about 20 000 plants/ha. Two weeks later, rice seed is dibbled at 10 cm spacing in rows 40 cm apart between the maize rows; we try to drop about five seeds per hill. If early maturing maize varieties (90 days) are used, the maize and rice should be sown at the same time. One and a half months after sowing the maize, cassava sticks are inserted between the hills in every other row, giving a cassava spacing of 400 x 50 cm. After harvesting the rice, the straw is cut close to the ground and pushed aside into the cassava rows. Groundnut seed is dibbled beside each hill of rice stubble (one seed/hill) at a spacing of 50 x 10 cm. The rice straw is then spread out on the field surface as mulch to suppress weed growth, conserve both soil moisture and organic matter and to prevent erosion. After the groundnut harvest, cowpea or ricebean seeds are sown at a spacing of 40 x 20 cm with two seeds/hill.

For these soils fertilizer should be put as close as possible to the root zone. For P this can be done by evenly distributing the fertilizer at the bottom of the furrows made for the plant rows of each crop. For N and K the fertilizer should be banded in a row beside and below the seed. Soils with pHs (KCl) below 4 and low levels of exchangeable Ca (1.0 meq/100 g) must be limed to sustain crop production.

This cropping pattern provides five well-distributed harvests throughout the year. One important thing to keep in mind is that all crop residues should be returned to the soil after harvest in order to conserve soil fertility. With proper management total production of food calories per hectare from maize plus upland rice intercropped with cassava and followed by groundnut and then cowpea in one year usually exceeds that from fifteen tons of padi rice.

These soils must be considered fragile compared to Latosol soils found on Java. In comparison they are poorly aggregated and shallow over impervious layers. They are susceptible to erosion and sloughing on all but level land. Continuous cover by cropping and mulching and terracing are management practices that must be followed to protect the soil and maintain its productivity. In hilly areas where erosion problems can be expected and in remote areas where marketing of food crops may be difficult, cropping systems should be designed to provide food but only enough for subsistence and should contain a high proportion of pasture crops for animal and green manure and perennial crops for stability and cash.

4.1 Irrigated Lowland

Research was conducted in Indramayu, West Java. In the wet season, all of the low-lying areas and some of the upland are planted to rice. The area gets water from the Rentang Irrigation Scheme (78 593 ha) and Jatiluhur Irrigation Scheme (23 201 ha). But, due to limited water, the irrigation service groups the area into several categories based on date of arrival and termination of irrigation water.

Four cropping patterns were tested in each irrigation category. These patterns were: farmers' cropping pattern, farmers' cropping pattern without constraints (this was intended to help understand the farmers' capabilities if all constraints that they identified were removed), and two introduced cropping patterns, designed by the research staff based on the biophysical and socio-economic conditions of the area, chosen by farmers but with material inputs and markets provided by the project. The introduced cropping patterns differed from one category to another. The most common farmers' cropping pattern consisted of a crop of lowland rice followed by Walik Jerami rice (minimum tillage).

i. Cultural practices

For the first rice crop (wet season) the land was prepared mainly by man power (using hoe). Some farmers used animals for the first tillage. The number of operations depended on soil conditions (weeds/water); usually they tilled their field at least twice. For the second rice, minimum tillage was the most common practice; this required less labour and provided for quick and timely planting since the soil remained weed-free and soft shortly after harvest of the first crop.

Pulling-up seedlings was usually done by men, and transplanting by women.

ii. Fertilizer application

Farmers in all irrigation categories used the same methods of fertilizer application. The first application (triple superphosphate and about 150 kg urea/ha) was made 15-21 days after transplanting, using hill placement. The second application (about 100 kg urea/ha) was broadcast 35-45 days after transplanting. The remainder of the fertilizer, if any, was broadcast 60 days after transplanting. Farmers in the 10-months irrigation category applied 300 kg/ha urea plus 125 kg/ha TSP for their first as well as their second rice crop. Farmers in the 7- and 5-months irrigation categories applied 250 kg/ha urea plus 50 kg/ha TSP for the first rice crop, and for the second rice crop 157 and 250 kg/ha urea respectively.

Harvesting was most commonly by *ani-ani* (a small knife) and/or sickle, with labour paid by the *bawon* system (sharing) with one-sixth by volume going to the harvester.

iii. Constraints identified

According to Herdt and Bernstein (1975), the gap between potential and actual farmers' yield could be due to biophysical as well as socio--economic constraints. The socio-economic factors would include knowledge, credit, input availability, economic behaviour, institution, tradition, risk aversion and others. In the case of rice production for the first crop in all irrigation categories, these factors did not seem to be constraints since the areas are included in the Bimas Program and their level of technology has been high.

Brown planthoppers really have been a threat to rice production, but farmers still find it hard to accept the newest varieties that are resistant to brown planthoppers because of their low yield, bad taste and the fact that farmers have almost no experience with them.

Since they still grow Pelita rice, insecticide application was considered very important, but it did not seem to increase yield, probably due to late application and low dosage.

Most farmers try to grow double crops of rice even in the 7- and 5-month irrigation areas even though lack of water supply frequently causes the second crop to fail. Their willingness to grow secondary crops after the second rice is encouraging, but this practice is almost never carried out because of lack of moisture after the second rice. Medium maturing (135 days) and some later maturing varieties of rice do not permit enough time. Other factors which hinder secondary crop production during the dry season are lack of experience and lack of labour.

Results of these cropping pattern studies confirm the first year's results; that is, growing secondary crops (legumes) after two crops of rice is feasible and makes efficient use of the remaining water and time. But the cropping pattern must be properly scheduled and arranged based on the available resources (mainly water from rain, irrigation and soil).

Growing two crops of brown planthopper-resistant rice varieties permitted more return and higher production, as well as better labour distribution, throughout the year even in the areas where irrigation water is limited and *gogo rancah*[1] is used for the first rice. But in order to grow the legumes successfully during the dry season the crop should not be planted later than June. Since gallmidge problems for rice commonly occur in January-February, the second rice should not be planted in this period unless we develop resistant varieties or find other effective methods for controlling gallmidge.

5. RECOMMENDATIONS

Recommendations for fertilizer use in multiple cropping in Indonesia are based on the results of multilocation trials all over the country.

Recommendations for fertilizer use in intercropping are given in Table 3.

General recommendations for fertilizer use and timing of N fertilizer application are shown by crop in Table 4.

6. LONG TERM RESEARCH

The overall objectives of Cropping Systems Research in Indonesia may be summarized as follows:

i. To increase food production by increasing total crop area and production per hectare by:

   a. development of viable cropping systems for new lands;

   b. more intensive use of present cropland including interplanting of food crops in estate crops such as rubber, oil palm, coconut, sugarcane, etc.;

   c. amending and maintaining soil fertility.

ii. To increase employment opportunity by increasing the opportunity for labour by:

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[1] A system in which the rice is direct seeded shortly before or at the onset of the rainy season, grown as a dryland crop in the first weeks, until water is sufficient when the field is submerged, but without puddling. The amount and depth of water depend entirely on the rainfall.

Table 3 RECOMMENDATIONS FOR PLANT SPACING AND FERTILIZER USE IN INTERCROPPING, INDONESIA

Land type	Cropping pattern	Plant spacing (cm)	Seed per hill	Fertilizer Rate (% of normal)
Irrigated lowland	Maize +	200 x 40	2	50
	Soybean	25 x 25	2	87.5
	or Sweet Potato	100 x 30	1	100
Rainfed lowland	Upland rice +	25 x 25	3-5	87.5
	Maize	200 x 40	2	50
	Upland rice +	20 x 20	3-5	60
	Maize +	200 x 40	2	50
	Groundnut	20 x 20	1	30
	Maize +	200 x 40	2	50
	Soybean	25 x 25	2	87.5
	or Groundnut	25 x 25	1	87.5
Rainfed dryland	Maize +	200 x 40	2	50
	Soybean	25 x 25	2	87.5
	or Groundnut	25 x 25	1	87.5
	Maize +	200 x 40	2	50
	Sweet Potato	100 x 30	1	100
	Maize +	100 x 30	2	100
	Cassava	100 x 60	1	100
	Upland rice +	30 x 15	3-5	90
	Maize	300 x 40	2	33.3
	Cassava +	200 x 60	1	50
	Groundnut	25 x 25	1	87.5
	Upland rice +	30 x 15	3-5	90
	Maize +	300 x 30	2	33.3
	Cassava	300 x 60	1	33.3
	Upland rice +	25 x 25	3-5	67
	Groundnut +	25 x 25	1	25
	Cassava	300 x 60	1	33.3
	Maize +	200 x 30	2	50
	Groundnut +	25 x 25	1	75
	Cassava	200 x 60	1	50
	Cassava +	300 x 75	1	45
	Maize +	75 x 30	2	100
	Groundnut	30 x 15	1	80
	Cassava +	300 x 75	1	45
	Maize +	75 x 30	2	100
	Soybean	30 x 15	2	80
	Upland rice +	25 x 25	3-5	100
	Cassava +	200 x 100	1	50
	Maize (relay sequential planting)	(150 & 50) x 100	2	22.5
	Upland rice +	25 x 25	3-5	100
	Maize	150 x 75	2	20
	Maize +	180 x 30	2	50
	Soybean	30 x 15	2	100

Table 4 GENERAL RECOMMENDATIONS FOR FERTILIZER USE PER CROP AND TIMING OF N FERTILIZER APPLICATION

Crop	N fertilizer application			Fertilizer rate (kg/ha)		
	First	Second	Third	N	P_2O_5	K_2O
Lowland rice	one third at planting	one third at 1 month after planting	one third at primordia phase	30-135	30-60	0-30
Upland rice	one half 1 month after planting	one half 2 months after planting	-	45-135	30-60	30
Maize	one quarter at planting	one quarter 3 weeks after planting	one half 5 weeks after planting	90-120	30-45	0-25
Sorghum	"	"	"	45-90	45	30
Sweet potato	all at planting	-	-	45-60	20-45	50-100
Cassava	one third at planting	two thirds 2 months after planting	-	60-90	35	50
Groundnut, Soybean	all at planting	-	-	22.5-25	25-50	0-25
Mung bean	"	-	-	22.5-25	25	25
Eggplant	one third at planting	one third 1 month after planting	one third 2 months after planting	34	100	70
Tomato, Chilli	"	"	"	22.5	100	100
Cabbage, Chinese cabbage	one third at planting	one third 3 weeks after planting	one third 7 weeks after planting	90-170	30-160	0-100
Onion	one half at planting	one half 1 month after planting	-	75-180	0-90	0-100

a. extending time for planting and harvest;

b. expansion of total area in production;

c. concomitant increase in agri-business.

iii. To improve the small farmers' bargaining position by increasing the frequency of harvests and minimizing the need to borrow.

There are no short cuts. However, time may be saved and mistakes avoided by doing some of the research in farmers' fields under farmers' conditions while developing the research methodology and staff. Specific target areas must be selected to make best use of staff and funds. Consequently, the strategy for cropping systems research and staff development has followed distinct but complementary paths:

- <u>Development of component technology</u>

  Here the primary objective is to investigate the interactions among plants in mixed cropping combinations and cropping sequences and the concomitant effects on insects, diseases, weeds, soils and crop performances. This research is best done in experimental gardens under close supervision of the scientists.

- <u>Studies in farmers' fields managed by researchers</u>

  New cropping patterns must be designed and tested in the target areas to get some idea of their agro-economic potential and likely cultural problems, under close supervision of researchers. Also, research from multiple cropping studies may be fitted to year-round cropping patterns and the system evaluated not only to determine its agronomic but also its agronomic and social acceptability.

- <u>Studies in farmers' fields under farmers' conditions and management</u>

  The final evaluation before implementation should be made through multi-locational trials conducted over the target area under farmer conditions and management but with and without removal of certain constraints such as credit, seed, fertilizer, pesticides and markets. Finally the new cropping patterns and technology must be tested for different farmers and conditions within the target area to get a measure of benefit and probability of success. This should lead to the development of production programmes and implementation. Consequently, it must be done in cooperation with the appropriate governmental agencies for production programmes at the planning and research stages along with farmers.

Paper 25 FERTILIZER USE AND NUTRITIONAL PROBLEMS IN MULTIPLE CROPPING SYSTEMS IN THAILAND

Benjavan Rerkasem[1]

1. MULTIPLE CROPPING SYSTEMS IN THAILAND

Multiple cropping is a widespread traditional farm practice in Thailand. Most of the multiple cropped areas are in the Northern and Central regions, where Cropping Intensity was 112 and 110 percent respectively in 1977. Multiple cropping is found in both irrigated and rainfed areas. Since virtually all of Thailand's irrigation projects are restricted to paddy fields, irrigated cropping systems are based on the rice crop. The most extensive of irrigated systems is probably rice-rice; the wet season rice crop (July-December) is followed by another crop of rice in the dry season (January-May).

Ninety percent of the dry season rice crop is in the Central Plain, where the Greater Chao Phya Project provides irrigation water for some 300 000 hectares of rice land in the dry months between November and April (Chao Phya Research Project 1969).

In some of the irrigated rice areas, particularly where soils are well drained or there is a problem of scarce water, upland crops such as groundnuts, soybean, tobacco and vegetables may follow the rice. In a few limited areas with reliable year-round water supply 2 or 3 crops may follow the rice in sequence. Cropping systems in these areas tend to be highly diverse, an example of such an area is the Chiang Mai Valley. The Valley covers 160 000 ha of contiguous paddy land and had a cropping intensity of 167 percent in 1978 (Gypmantasiri *et al.* 1980). Typical cropping systems in the Valley are shown in Table 1. Some of these systems are now spreading into other irrigation project areas. The total areas under all of these systems, however, is still very small in comparison to the rice-rice system.

Table 1 CROPPING SYSTEMS IN CHIANG MAI VALLEY (SEQUENTIAL)

July	December	.... July
----- Wet Season ----------/	-----Dry Season----------/	----------Wet-
Rice	Soybean	
Rice	Tobacco	
Rice	Soybean	Rice
Rice	Groundnuts	
Rice	Garlic	
Rice	Chili peppers	Vegetables
Rice	Onions*	Rice
Rice	Shallots	Shallots
Rice	Rice	

* Onion seedlings started in old rice nursery, transplanted at 40 days

[1] Multiple Cropping Project, Faculty of Agriculture, Chiang Mai University, Chiang Mai, Thailand.

Most of the country's upland crop areas are located in the upper terraces of the flood plains, i.e. above the irrigable paddy fields. Rainfed multiple cropping is even more extensive than the irrigated systems. Cropping intensity for the rainfed area for the whole country is 115 percent. In terms of actual area, 480 229 ha of the upland were double cropped in 1977, compared to 149 536 ha of the irrigated land. Most of rainfed multiple cropping systems involve maize, the most extensive is maize-mungbean, mungbean-maize. The others are black gram-maize, maize-sorghum, maize and ricebean intercropped and cotton relayed into soybean.

2. FERTILIZER USE

The level of fertilizer use in Thailand as a whole is very low. The average figure for Thailand in 1977 was 50 kg/ha (National Agricultural Census 1978). A large portion was applied to vegetables and tree crops; the average over planted areas of rice and upland crops in 1977 was 42 kg/ha. The proportion of farm land that received fertilizer and the number of farm households using fertilizer were low (Table 2).

Table 2 FERTILIZER USE IN THAILAND, 1977

	Area receiving fertilizers and/or organic manures		Rate (kg nutrients/ha) on area receiving fertilizer and/or organic manures
	thousand hectares	per cent of planted area	
Rice	4 418.3	46	101
Upland crops	524.9	14	227
Total	5 346.8	40	
	Households using fertilizers and/or organic manures		
	number using	per cent	
Mineral fertilizers only	989 557	24	
Both fertilizers and organic manures	798 279	20	
Organic manures only	469 715	12	
Total	2 257 547	56	

Source: Calculated from National Agricultural Census 1978

For the most part, multiple cropping systems in irrigated areas are well fertilized, whereas rainfed systems receive very little fertilizer. Exceptions to this general pattern are for high value crops, which are components of rainfed systems, such as cotton and tobacco to be well fertilized and soybean following rice in irrigated areas to receive no fertilizer or manure.

In irrigated systems, rice-rice is always fertilized, at least in the dry season crop. The second rice crop, in the dry season, almost entirely uses new high-yielding varieties such as RD1 and RD7 which are highly responsive to N. This is well reflected in the high yield level of the dry season rice crop, averaging 3.325 t/ha for the whole country, compared to the wet season average of 1.625 t/ha. Much of the area growing rice-rice is also under adequate water control for the wet season crop, a condition most likely to ensure the use of fertilizer. On average, the amount applied to rice at 100 kg nutrient/ha is somewhat lower than that recommended by the Rice Division, Department of Agriculture, i.e. 160-220 kg/ha of 16-20-0, 20-20-0, 18-22-0 or 16-16-8 after sowing or transplanting plus 125-250 kg/ha ammonium sulphate or choride, or half the rate as urea at panicle initiation. In irrigated systems of rice followed by upland crops or vegetables, crops such as tobacco, garlic, onions, shallots and other vegetables are always well fertilized. In most cases these high value crops receive liberal quantities of poultry and pig litter as well as mineral fertilizers. For example, tobacco and garlic grown in rice-based systems would normally receive:

Tobacco: Basal application of 12.5 t/ha farmyard manure and 312.5 kg/ha 6-18-24, also containing 3 percent Mg and 0.2 percent B, plus another 187.5 kg/ha 6-18-24-Mg-B at 30 days from transplanting.

Garlic : 12-15 t/ha of farmyard manure and 100 kg N, 62.5 P_2O_5 and 62.5 kg K_2O/ha in mineral fertilizer.

The average amount of fertilizer nutrients applied to upland rainfed crops was 227 kg/ha. However, sugarcane, a monocrop which is heavily fertilized, accounts for 80 percent of the upland crop area receiving fertilizer. Other high value crops such as cotton and tobacco make up most of the balance. Therefore, the bulk of the upland rainfed cropping systems receive virtually no fertilizer. This is correlated with the low level of yield obtained in some crops (Table 3).

Table 3 YIELD OF SOME CROP COMPONENTS OF UPLAND RAINFED SYSTEMS, 1976

Crop	Yield (kg/ha)			
	National Average[1]	Experimental		
		Yield without fertilizer	Yield with fertilizer	Fertilizer applied $N-P_2O_5-K_2O$ kg/ha
Maize[2]	2 081	1 956	4 029	112.5-112.5-0
Mungbean[3]	652	906	1 181	18.75- 75 -75
Groundnut[4]	1 244	1 397	1 688	37.5 -100 -100
Soybean[4]	1 119	1 062	1 575	37.5 -100 -100

Sources: [1] Agricultural Statistics No. 108, Office of Agricultural Economics, Ministry of Agriculture and Coopertives
[2] Tawornmas (1980)
[3] Watanaputi and Benjasil (1979a)
[4] Watanaputi and Benjasil (1979b)

3. PROBLEMS AND RESEARCH RESULTS

In Thailand, research results on fertilizer requirement and nutritional problems of existing multiple cropping systems are rare. A search through the proceedings of the National Conference on Cropping Systems, an annual event since 1977, has shown that most research concentrated on designing and testing of new "improved" systems, in which fertilizer application usually came as a part of the package. Therefore, any information available is related to these new "improved" systems; its application has either to wait for the adoption of the new systems or to be extrapolated for existing systems.

The other matter that must be borne in mind is that, in farmers' perception as well as in reality, components of each cropping system are not equally weighted. At the present price relationship and market opportunity, maize is the major crop in the rainfed cropping system; mung bean, black gram or rice bean is the by-product that farmers reap from a relatively small additional input. In the Chiang Mai Valley, the subsistence glutinous rice crop is of primary concern, although it may involve less cash input than other component crops such as garlic, tobacco, onion or the non-glutinous dry season rice crop which is sold for cash. This will change with changes in price relationship, market opportunity and farmers' income stability. The prevailing relationshop must be taken into consideration in interpreting research results on residual effects etc. of component crops in multiple cropping systems.

4. RESPONSES TO FERTILIZERS

Responses to fertilizer of crops grown in multiple cropping systems do not appear to differ greatly from those in monoculture. An experiment in the Central Plain showed no difference in response to N of rice grown in 3 crop/year and 1 crop/year systems, although yield per crop was significantly greater in the latter (Walcott *et al.* 1977). Upland rainfed crops of maize, *kenaf*, soybean and groundnut also showed similar responses to 50-100-100 to 100-100-100 kg $N-P_2O_5-K_2O$/ha either when grown as single crop or in non-legume+legume sequences (Withoon Watanaputi and Wichit Benjasil 1979b). It is interesting to note that, in contrast to the rice-rice-rice system or rice-rice system, component crops in the sequential systems of maize-groundnuts, maize-soybean, *kenaf* -groundnut, *kenaf*-soybean and maize-mungbean all yielded more as a component of these systems than when grown alone (Watanaputi and Benjasil 1979b and Tawornmas 1980).

One problem of fertilizer use in multiple cropping in Thailand is the extreme variability of research results from year to year even at the same site. Examples from two sites are shown in Table 4. Since this variation was found in irrigated as well as rainfed systems the vagaries of the weather cannot be the only explanation. Unless this situation is cleared, efforts to increase fertilizer use in multiple cropping will only add another risk factor to farmers already overburdened with the uncertainty of price and market. The weed problem is a possible cause of poor yield and low response to fertilizer in multiple cropping systems. This is one of the most common complaints in multiple cropping (Pookpakdi, Sereeprasert and Pinya 1980; Chiamkanokchai 1980; Gypmantasiri *et al.* 1980).

In addition to the yield variation many crops which are components of the common cropping systems, with the notable exception of rice and maize, respond

Table 4 VARIATION IN YIELD AND RESPONSE TO FERTILIZERS IN EXPERIMENTS WITH MULTIPLE CROPPING SYSTEMS

a. Maize and Maize-Soybean System (Watanaputi and Benjasil 1979b)

System	Maize Yield (kg/ha) 1971		1977	
	Without fertilizer	With fertilizer 37.5-100-100 kg $N-P_2O_5-K_2O$/ha	Without fertilizer	With fertilizer 37.5-100-100 kg $N-P_2O_5-K_2O$/ha
Maize	414	3 956	517	1 067
Maize-Soybean	535	4 681	569	1 217

b. Irrigated Rice-Rice-Rice (Walcott *et al.* 1977)

Season	Rice Yield (kg/ha averaged over six nitrogen levels, 0-150 kg N/ha) 1969	1970	1971 t/ha	1972	1973
Aug-Nov	4.86	4.85	3.66	5.23	4.11
Dec-Mar	3.74	4.07	5.34	3.71	5.66
Apr-July	4.39	4.16	3.73	3.94	3.27
Annual Total	12.99	13.08	12.73	12.88	13.04

only marginally to fertilizer application. Many authors have concluded that, although responses may be statistically significant, fertilizer application is not profitable (Tawornmas 1980; 1979; Watanaputi and Benjasil 1979a). For rice, the present level of fertilizer use in the rice-rice system and the relatively high national yield average for the dry season crop seem to confirm the strong response to and profitability of fertilizer use. For maize, the problem of yield and response variation probably contributed strongly to the low level of fertilizer use on this crop.

Recent work from the Field Crops Division of the Department of Agriculture has shown responses to fertilizer may be markedly influenced by cultural practices. In this case, tillage practice greatly affected yield of the component crops in a maize-cowpea system as well as their response to N fertilizer (Tawornmas 1982). As to be expected, the response to N was restricted to the maize crop. The yield response of maize to N was poorer in finely cultivated than in less vigorously tilled or no-tilled soil. It was suggested that the better water conservation characteristics of the no-tilled soil were responsible for better yields of both maize and cowpea as well as the better response of maize to N. This work has demonstrated that response to fertilizer of cropping systems can be improved, a direction of research worth further exploration.

5. RESIDUAL EFFECTS

One of the most often quoted attributes of multiple cropping is the residual effect of one crop on the succeeding crops, especially of applied fertilizers. However, little information on this is available in Thailand. At the field level farmers perceive that a component crop which is heavily fertilized, such as garlic and tobacco, can have a beneficial effect on the yield of the following rice crop. This was confirmed experimentally by Sanmaneechai and Dawson (1975) who showed that rice following maize responded significantly to the residual effect of up to 180 kg N/ha applied to the maize. The actual yield increase, however, was extremely small. For example, the residual effect of 180 kg N/ha applied to the maize was less than one fifth of the response to 60 kg N/ha directly applied to the rice. There is no similar information on residual effects of organic manures.

Wivutvongvana, Jusrigaival and Dawson (1975) and Wivutvongvana and Dawson (1975) examined the residual effects of fertilizers applied to the first crop in the sequential systems rice-soybean-sweet corn, maize-soybean-sweet corn and wheat-mung bean. They found varying degrees of residual build-up of soil P and K and of residual responses. The conclusion was that, for a nutrient that is in short supply, the response to residual effect can be marked, sometimes even stronger than in the first crop to which the fertilizer was applied. This was illustrated by responses of the two soybean crops in the soybean-soybean-sweet corn system to potassium. In the first soybean crop 80 kg K_2O/ha increased soybean yield from 1.37 t/ha to 1.68 t/ha, an increase of 0.31 t/ha; whereas in the second crop the residual effect of this same 80 kg K_2O/ha increased yield from 1.71 t/ha to 2.28 t/ha, an increase of 0.57 t/ha. In general practice, with rice-soybean or rice-soybean-rice, farmers make sure that some of the nutrients taken up by the rice are returned to the soybean by burning the rice stubble and straw. Taking the straw yield at 3000 kg/ha with 2 percent K_2O, this means a return of some 60 kg K_2O/ha as well as other nutrients.

Wivutvongvana, Jusrigaival and Dawson also found that sweet corn following two crops of soybeans gave 30 percent higher yield than in maize-soybean--sweet corn or rice-soybean-sweet corn systems. This was in spite of the fact that the double soybean system had received no N fertilizer, whereas the other systems had received 180 kg N/ha and 120 kg N/ha respectively. They suggested that accumulated effects of symbiotic N fixation by soybean may have been the reason. This is in direct contrast to the established premise that soybean is one of those legumes which leave the soil with a negative balance of nitrogen (Russell 1973). The true answer may be more complicated and may in some way be related to another aspect of residual effects discussed below.

In rice-based cropping systems, it has been reported that the rice crop may leave the soil with one unit of pH lower than at the beginning of the rice season (Gypmantasiri *et al.* 1980). This will have very little impact on the rice--rice system, since flooding would shift the pH closer to neutrality again. However, in systems with upland crops following rice the lowering of soil pH to, say, 5 might have some adverse effects. For example, at pH 5 the biological oxidation of manganous ions liberated under the flood will be retarded. Furthermore, it was found that applications of acidifying N fertilizers such as ammonium sulphate to the crop following rice resulted in a further drop of soil pH by 1.0 to 1.2 units (Gypmantasiri *et al.* 1980).

6. LONG-TERM EFFECTS

Many 5-7 years long-term experiments with multiple cropping systems have shown that, even without fertilizer application, yields are sustainable over the years, although the level of yields obtained without fertilizer may be quite low. On the other hand, most systems responsive to fertilizer application did not show any long-term declining trend either. In the Central Plain irrigated system Walcott *et al.* (1977) showed that 9 t/ha/year of paddy from rice-rice-rice was maintained over 5 years without any fertilizer, but that the system also responded well to up to 100 kg N/ha with a yield of 13.5 t/ha/year, which also showed no sign of decline after 5 years. In upland rainfed systems, year-to-year fluctuation in yields of maize, *kenaf*, groundnuts and soybean was considerable, but on average the yields of these component crops did not show any sign of a declining trend over 5-7 years, whether given up to 100 kg N, 100 kg P_2O_5, 100 kg K_2O/ha or not (Watanaputi and Benjasil 1979b; Tawornmas 1980). Most of the upland rainfed systems did not show any improvement over time, which might have indicated accumulated effects of the cropping systems or their legume components. Experiments which included green manure crops have also shown no improvement over time (Watanaputi and Benjasil 1979b; Tawornmas 1980). Indeed, Tawornmas (1980) also showed that turning in cowpea or *Crotolaria* as green manures had little effect on the organic matter content of the soil. One interesting result emerged, however. In the final year, maize covered the whole experiment which has had a history of 8 different cropping systems for four years. It was found that all the systems gave greater maize yields than the 2.40 t/ha from the plot which each year had grown single maize without fertilizer. Surprisingly the highest yield of 4.38 t/ha came from the plots which had grown single maize receiving 112.5 kg N and 112.5 kg P_2O_5/ha each year. The green manured plots gave the second highest yield of 31.2 t/ha in common with a rotational system of maize-sorghum and mungbean-mungbean.

The only report of yield decline after a long period of cropping systems came from the Multiple Cropping Project at Chiang Mai University (Gypmantasiri *et al.* 1980). In this long-term study, yields of all component crops declined drastically after intensive cropping systems with 3 crops/year and high levels of fertilizer inputs (N-P-K and lime). Early diagnosis had indicated that depletion of nutrients other than N, P, K may have been part of the problem (Rerkasem and Gypmantasiri 1981). However, the most recent indications are that accumulation of pests and diseases may have been the major problem in the rice crop. With no fertilizer input at all, 3.54 t/ha of paddy could still be obtained, and 5.59 t/ha with N alone, with careful management (Benjavan Rerkasem, unpublished). For the upland crops, evidence suggests that deterioration of soil structure causing difficulty with water management may be the major key to the problem (Prayooth SriKeaw and Benjavan Rerkasem, unpublished).

BIBLIOGRAPHY

Abeyratne E. Trop. Agric. 62:191-229.
1956

Abeyratne E. Proc. Assoc. Advmt. Sci. 18(2):58-72.
1962

Adetiloye P.O. Growth, development and yield of sole and intercropped cowpea
1980 (*Vigna unguiculata* (L) Walp) and maize (*Zea mays* L.) PhD Thesis, Univ. Nigeria, Nsukka.

Agarwala S.C. and Mehrotra N.K. J. Indian Soc. Soil Sci. 11:51-63.
1963

Agarwala S.C., Mehrotra N.K., Sharma C.P., Ahmed S. and Sharma V.K. J.
1970 Indian Soc. Soil Sci. 18:415-427.

Agboola A.A. and Fayemi A.A. Preliminary trials on the intercropping of maize
1971 with tropical legumes in Western Nigeria. J. Agric. Sci. Camb. 77: 219-225.

Agboola A.A. and Fayemi A.A. Fixation and excretion of nitrogen by tropical
1972 legumes. Agron. J. 64:409-412.

Agboola S.A. An agricultural atlas of Nigeria. Oxford University Press.
1979

Aggarwal R.K. and Ramamoorthy B. A statistical approach for recommending
1978 fertiliser doses for targetted yields and maintenance of soil fertility in a crop sequence on alluvial soils of India. Curr. Agric. 2(3-4): 1-5.

Aguiar P.A.A., Menezes E.A. and Santos M.X. Breve caracterização da região Nordeste e principais sistemas produtores da regiao semi-árida. Reuniao de Programação de Pesquisa sobre Consórcio no Nordeste, Recife-PE, 28/7 a 31/7/81. 17 p.

AICRIP Progress Report - Hyderabad 80, ICAR, New Delhi and cooperating
1980 agencies, kharif 1979, p. 2.17-2.19.

AICRIP Progress Report - Hyderabad 80, ICAR, New Delhi and cooperating
1980 agencies, kharif 1980, pp. 2.24-2.26.

Akobundu I.O. Live mulch a new approach to weed control and crop production
1980 in the tropics. Proc. British Crop Conference - Weeds, Brighton, 22-27 November.

Allison F.E. Soil aggregation: Some facts and fallacies as seen by a microbiolo-
1968 gist. Soil Sci. 106:136-143.

Alves J.F., Paulo P.H.F. de, Moreira J. de A.N. and Silva N.M. Efeitos de
1977 adubação em algodão mocó consorciado. In: Ceará, Universidade Federal. Centro de Ciências Agrárias. Estudos básicos, melhoramiento genético e experimentação com o algo doeiro mocó; Relatório de Pesquisas 1975/76. Fortaleza, CE. pp. 95-104.

Andrews D.J. Intercropping with sorghum in Nigeria. Expl. Agric. 8:139-150.
1972

Andrews D.J. and Kassam A.H. The importance of multiple cropping in increasing
1976 world food supplies. In: Multiple Cropping. Pependick <u>et al.</u> (eds). ASA Special Publ. 27, Madison, Wisconsin. pp. 1-10.

Arora R.P., Sachdev M.S., Sud Y.K., Luthra V.K. and Subbiah B.V. Fate of
1980 nitrogen in a multiple cropping system. In: Soil Nitrogen as Fertilizer or Pollutant. IAEA, Vienna. pp. 3-22.

Ayub Agricultural Research Institute, Faisalabad. Annual Reports 1978-79 and 1979-80.

Babrekar P.G. PhD Thesis. Indian Agricultural Research Institute, New Delhi.
1979

Baker E.F.I. Population, time and crop mixtures. Proc. International Workshop
1979 on Intercropping, Hyderabad. ICRISAT. pp. 52-60.

Baldock J.B. and Musgrave R.B. Effects of manure and mineral fertilizer on
1980 continuous and rotation crop sequences. Agron. J. 72:511-518.

Bansal R.K. and Thierstein G.E. Design and development of a planter-cum-ferti-
1982 lizer drill for dryland crops. To be presented at the Indian Society of Agricultural Engineering Convention, 15-17 February 1982. University of Udaipur, Udaipur, India. Available from ICRISAT, Patancheru, A.P. 502 324.

Barber S.A. The changing philosophy of soil test interpretations. In: Soil Testing
1973 and Plant Analysis. SSSA pp. 201-213.

Benites J.R. Nitrogen response and cultural practices for corn-based cropping
1981 systems in the Peruvian Amazon. PhD Thesis. North Carolina State University.

Bergmann W. and Neubert P. Pflanzendiagnose und Pflanzenanalyse. VEB Gustav
1976 Fischer Verlag, Jena.

Beri V. and Meelu O.P. Progressive Farming. p. 8
1979

Bharadwaj R.B.L. and Tandon H.L.S. Fert. News 26(9):23-32 and 44.
1981

Bhardwaj S.P. and Prasad S.N. J. Indian Soc. Soil Sci. 29:220-224.
1981

Bhumbla D.R. Indian Farming 21(8):19-21.
1972

Bhumbla D.R. and Dhingra D.R. J. Indian Soc. Soil Sci. 12:255-260.
1964

Biswas C.R., Sekhon G.S. and Singh R. J. Indian Soc. Soil Sci. 25:23-27.
1977

Biswas C.R., Singh R. and Sekhon G.S. J. Indian Soc. Soil Sci. 25:414-421.
1977

BNB/IPA. Cultura do sorgo granífero e forrageiro. Avaliação de Resultados
1980 Experimentais de Pernambuco. Convênio BNB/IPA, Acordo IPA/UFRPE, IPA/Fundação Ford. 65 p.

Bogor. Proceeding Lokakarya III Pola Tanam (Cropping Systems), Bogor. Lembaga
1977 Pusat Penelitian Pertanian Bogor.

Bogor. Proceeding Lokakarya V Pola Tanam, Cibogo, Bogor. Pusat Penelitian dan
1981 Pengembangan Tananman Pangan Bogor.

Bole J.B. Plans for initial intercropping experiment. Coordinated Research Pro-
1980 gramme on Nuclear Techniques in the Development of Fertilizer and Water Management Practices for Multiple Cropping. IAEA Vienna.

Bouldin D.R., Mughogho S., Lathwell D.J. and Scott T.W. Nitrogen fixation by
1979 legumes in the tropics. Proc. Final Inputs Review. pp. 161-182. East-West Center, Honolulu.

Bradfield R. Increasing food production in the tropics by multiple cropping.
1970 In: Research for the World Food Crisis. D.G. Aldrich (ed). Pub. No. 92. Amer. Assoc. Adv. Sci., Washington DC. pp. 229-242.

Brar M.S. and Sekhon G.S. Plant Soil 44:459-462.
1976

Brar M.S., Singh B. and Sekhon G.S. Commun. Soil Sci. Plant Anal. 11:335-346.
1980

Broeshart H. Quantitative measurement of fertilizer uptake by crops. Neth. J.
1974 Agr. Sci. 22:245-254.

Camerlynck R. and Kiekens L. Chemical aspects of trace elements on plants. In:
1981 Trace Elements in Agriculture and in the Environment. A. Cottenie (ed). State Univ., Gent.

Chapman H.D. Diagnostic criteria for plants and soils. Univ. Calif., Berkeley.
1966 Agric. Publ.

Chatterjee B.N., Bannerjee N.C., Ghosh D.C. and Devnath P.K. J. Indian Potato
1978 Assoc. 5:7-12.

Chauhan A.M. and Kumar R. Review of research and developments in seed-cum-fertilizer drills in India and areas for further work. J. Agric. Eng. 9(3):36-41.
1972

Chiamkanokchai C. Effects of cropping systems on soil fertility and rice yield. Proc. Third National Conference on Cropping Systems. Chiang Mai University.
1980

Chowdhury S.L. Fertilizer management in dryland regions for increased efficiency. Fert. News 24(9):61-66, 101.increased efficiency.
1979

Clark F.E. Soil microorganisms and plant roots. Adv. Agron. 1:241-288.
1949

Cordero A. Principles of intercropping: Effects of nitrogen fertilization and row arrangement on growth, nitrogen accumulation, and yield of corn and interplanted understorey annuals. PhD Thesis. North Carolina State Univ.
1977

Cordero A. and McCollum R.E. Yield potential of interplanted annual food crops in Southeastern U.S. Agron. J. 71:834-842.
1979

Cottenie A. Analytical techniques for determining micronutrient availability. Paper presented at India/FAO/Norway Seminar on Micronutrients in Agriculture, New Delhi, 17-21 September 1979. FAO, Rome (in press).

Cottenie A. Soil and plant testing as a basis for fertilizer recommendations. FAO Soils Bulletin 38/2. FAO, Rome.
1980

Cottenie A. and Camerlynck R. Chemische aspecten van stress bij planten. Med. Konink. Acad. Wet., Let. en Sch. Kunsten van België 41(4):3-21.
1979

Cottenie A., Dhaese A. and Camerlynck R. Quality response to uptake of polluting elements. Qual. Plant 26:293-319.
1976

Cottenie A., Verloo M. and Kiekens L. La situation des sols Belges en éléments traces. Bull. de Recherches Agron. de Gembloux. pp. 180-190.
1973

Couston J.W. Cited by Von Peter. Proc. Fertilizer Society 182:1-58.
1979

Dadarwal K.R. and Sen A.N. Varietal specificity for rhizobial serotypes in relation to nodulation and crop yield. Proc. Indian Natl. Sci. Acad. 40(B):548-553.
1974

Dadarwal K.R., Singh C.S. and Subba Rao N.S. Nodulation and serological studies of rhizobia from six species of *Arachis*. Plant and Soil 40:535-544.
1974

Dalal R.C. Effects of intercropping maize with pigeon peas on grain yield and nutrient uptake. Experimental Agriculture (UK) 10(3):219-224.
1974

Dalrymple D.G. Survey of multiple cropping in less developed nations. FEDR-12.
1971 USDA, Washington DC.

Dancette C. Niebé et valorisation des ressources pluviales dans certains systèmes
1981 agricoles Sénégalais. Proc. First OAU STRC Workshop on Agricultural Production Systems. Dakar. 12-15 January.

Daplyn M.G. Fertilizer inputs in Funtua agricultural development project. Feritt
1981 Training - Workshop, Ibadan. 2-20 November.

Das S.K. and Datta N.P. Fert. News 18(9):3-10.
1973

De Rajat. Fertilizer use in drylands-problems and prospects. Fert. News 24(12):
1979 33-37.

De Geus J.G. Fertilizer guide for tropical and subtropical farming. Centre
1967 d'Etude de l'Azote. Zurich.

Dev G. and Mann M.S. Fert. News 17:48-50.
1972

De Wit C.T. Plant Production. Misc. Papers (3). Agric. Sciences and the World
1968 Food Supply, Wageningen.

Donald C.L., Koss. Polyculture cropping systems: Review and analysis. Cornell
1978 International Agricultural Bulletin 32.

Duff N.K. and Bandyopadhyay M.N. Improving rainfed rice in India. World Crops
1966 pp. 18-26.

Eaglesham A.R.J., Ayanaba A., Ranga Rao V. and Eskew D.L. Improving the
1981 nitrogen nutrition of maize by intercropping with cowpea. Soil Biol. Bioch. 13:169-171.

EMBRAPA, UEPAE de Aracaju. Consórcio, resultados experimentais. Reunião de Programação de Pesquisa sobre Consórcio no Nordeste, Recife-PE, 28/7 a 31/7/81. 47 p.

Evans L.T. The natural history of crop yield. Amer. Scientist 68:388-397.
1980

FAO. Maximizing the efficiency of fertilizer use by grain crops. Fertilizer
1980 Bulletin No. 3. Rome.

FAI/FAO. Proc. FAI/FAO National Seminar on Optimizing Agricultural Production
1975 under Limited Availability of Fertilizers (1974). FAI, New Delhi 110 057.

FAO/Unesco. Soil Map of the World. Vol. I. Legend. Unesco, Paris. 59 p.
1974

Fasihi S.D., Malik K.B. and Bakhtiar B.A. Feasibility of increasing crop
1971 production through diversified multiple cropping. West Pak. J. Agric. Res. 9:139-143.

Fernando G.W.E., Upasena S.H. and Weerasinghe S.P.R. Proc. Rice Symposium,
1980 Dept. of Agriculture, Peradeniya, Sri Lanka.

Finck A. Z. Pflanzenernähr. Bodenk. 119:197-208.
1968

Finlay R.C. Intercropping soybeans with cereals. Soybean production, protection
1975 and utilization. INTSOY Series 6. Univ. Illinois, Urbana--Champaign. pp. 77-85.

Formoli G.N., Prasad R., Mahapatra I.C., Singh M. and Singh R. Fert. News
1977 22(4):6-8.

Freites L.E. Growth analysis of snapbeans (*Phaseolus vulgaris* (L) cv. Bluelake
1975 274) under varying plant populations and nutritional regimes. MS Thesis, North Carolina State Univ.

Fried M. Direct quantitative assessment in the field of fertilizer management
1978 practices. Trans. 11th ISSS Congress, Edmonton, Canada.

Fried M. and Broeshart H. An independent measurement of the amount of nitrogen
1975 fixed by a legume crop. Plant Soil 43:707-711.

Fried M. and Middleboe V. Measurement of amount of nitrogen fixed by a legume
1977 crop. Plant Soil 47:713-715.

Fried M., Soper R.J. and Broeshart H. ^{15}N-labelled single-treatment fertility
1975 experiments. Agron J. 67:393-396.

Furoc R.E., Magbanua R.D., Turija G.O. and Morris R.A. Paper presented at the
1979 10th Annual Meeting Crop Science Soc. of the Philippines, 23-25 April 1979.

Gajbhiye K.S. and Goswami N.N. J. Indian Soc. Soil Sci. 28:501-506.
1980

Galiba M. Amélioration du sorgho (*Sorghum bicolor* (L) Moench.). Campagne Agri-
1980 cole '79-'80. CNRA-ISRA Rapport, Bambey. 46 p.

Gaur Y.D. and Sen A.N. Cross inoculation group specificity in *Cicer-Rhizobium*
1979 symbiosis. New Phytol. 83:745-754.

Gaur Y.D., Sen A.N. and Subba Rao N.S. Promiscuity in groundnut *Rhizobium*
1974 association. Zbl. Bakt. Abt. II. Bd 129:368-372.

Gaur Y.D., Sen A.N. and Subba Rao N.S. Improved legume-*Rhizobium* symbiosis by
1980 inoculating preceding cereal crop with *Rhizobium*. Plant and Soil 54:313-316.

Ghosh A.B. Fert. News 26(9):64-70.
1981

Ghosh A.B. and Kanjaria M. V Bull. Natn. Inst. Sci., India 26:245-259.
1964

Ghosh T. Short note on jute cultivation. JARI.
1976

Gill M.S. Fifty Years of Agricultural Education and Research at the Punjab Agricultural College and Research Institute, Lyallpur, West Pakistan. Vol. II. Chapter XIV. pp. 78-79. Department of Agriculture, West Pakistan.
1960

Giri G. and De R. Effect of preceding grain legumes on dryland pearl millet in NW India. Experimental Agriculture 15:169-179.
1979

Giri G. and De R. Short-season fodder legume effects on the grain yield and nitrogen economy of barley under dryland conditions. J. Agric. Sci. Camb. 96:457-461.
1981

Godilano E.C. and Carangal V.R. Production potential of mungbean as a pre-monsoon crop under rainfed wetland environment in the Philippines. Paper presented at the 12th Annual Convention of the Crop Science Society of the Philippines. DMMMSC, Bacnotan, La Union. 22-24 April 1981.
1981

Goswami N.N., Bapat S.R., Leelavati C.R. and Singh R.N. Bull. Indian Soc. Soil Sci. 10:184-194.
1976

Goswami N.N. and Singh M. Fert. News 21(9):56-58.
1976

Grewal J.S., Randhawa N.S. and Bhumbla D.R. J. Indian Soc. Soil Sci. 17:27-32.
1969

Grewal J.S. and Sharma R.C. Fert News 26(9):33-43.
1981

Guenzi W.D., McCalla T.M. and Norstadt F.A. Presence and persistance of phytotoxic substances in wheat, oat, corn and sorghum residues. Agron. J. 59:163-165.
1967

Gupta V.K. and Dabas D.S. J. Indian Soc. Soil Sci. 28:28-30.
1980

Gypmantasiri P. *et al.* Interdisciplinary perspective of cropping systems in Chiang Mai Valley: Key questions for research. Chiang Mai University.
1980

Haldar M.P. and Mandal L.N. Plant Soil 53:203-213.
1979

Hanora J.F., Rajagopal C.K. and Krishnamoorthy K.K. Mysore J. Agric. Sci.
1979 13:159-164.

Hanway J.J. Experimental methods for correlating and calibrating soil tests.
1973 In: Soil Testing and Plant Analysis. SSSA. pp. 55-67.

Harris A.G., Muckle T.B. and Shaw J.A. Farm Machinery (2nd ed). Oxford
1974 University Press, London.

Harwood R.R. Farmer-oriented research aimed at crop intensification. In: Proc.
1975 Cropping Systems Workshop, IRRI, Los Baños, Philippines. pp. 12-32.

Hiebsch C.K. Interpretation of yields obtained in crop mixtures. Agron. Abs.
1978 Amer. Soc. Agron. p. 41.

Hiebsch C.K. Principles of intercropping: Effects of nitrogen fertilization,
1980 plant population, and crop duration on equivalency ratios in intercrop versus monoculture comparisons. PhD Thesis. North Carolina State Univ.

Holanda J.S., Menezes Neto J. and Pereira F.A.M. Adubação no consórcio sorgo/-
1978 feijão/algodão arbóreo e sem efeito residual no algodoeiro do 2 ano. EMBRAPA, UEPAE de Caicó, Rio Grande do Norte, Comunicado Técnico n 1. 13 p.

Hundall S.S. and De Datta S.K. Tillage and soil moisture effects on rainfed
1981 sorghum and mungbean grown after lowland rice. I. Root distribution, soil water extraction and crop yields. IRRI Saturday Seminar, 10 October.

IAEA. Rice fertilization. IAEA Tech. Rep. Series No. 108. Vienna.
1970

IAEA. Fertilizer management practices for maize. IAEA Tech. Rep. Series No.
1970 121. Vienna.

IAEA. Nitrogen-15 in soil-plant studies. Panel Proceedings Series, Vienna.
1971

IAEA. Isotope studies on wheat fertilization. Tech. Rep. Series No. 157. Vienna.
1974

IAEA. Root activity patterns of some tree crops. Tech. Rep. Series No. 170.
1975 Vienna.

IAEA. Isotopes in biological dinitrogen fixation. Panel Proceedings Series,
1978 Vienna.

IAEA. Isotope studies on rice fertilization. Tech. Rep. Series No. 181. Vienna.
1978

IAEA. Soil nitrogen as fertilizer or pullutant. Panel Proceedings Series, Vienna.
1980

IAEA. Nuclear techniques in the development of management practices for multiple
1980 cropping systems. TECDOC-235.

IAEA. Radiation and agriculture. IAEA Bulletin 23(3). September.
1981

IARI. Recent research on multiple cropping. Research Bull, New Series No. 8.
1972 148 p.

ICAR (Indian Council for Agricultural Research). Improved agronomic practices
1979 for dryland crops. New Delhi.

ICAR. A decade of dryland agriculture research in India 1971-80. New Delhi.
1982

ICRISAT. Annual Report 1978-79. Patancheru, AP 502 324.
1979

ICRISAT. Annual Report 1979-80. Patancheru, AP 502 324.
1980

Indonesia/FAO. Laporan Kemajuan 1978/1979-1979/1980 Program Intensifikasi
1980 Tanaman Palawija Kerjasama. Department Pertanian - FAO. Direktorat Jenderal Pertanian Tanaman Pangan. Direktorat Bina Produksi.

Indonesia/FAO. Laporan Kemajuan 1979/1980-1980/1981 Program Intensifikasi
1981 Tanaman Palawija Kerjasama, Department Pertanian - FAO. Direktorat Jenderal Pertanian Tanaman Pangan, Direktorat Bina Produksi.

Indonesia/HITI. Peningkatan Pelayanon Ilmu Tanah Kepada, Pengembangan dan
1981 Pelestarian Sumber daya lahan (buku I dan II), Kongres Nasional Ilmu Tanah III. Himpunan Ilmu Tanah Indonesia (HITI).

IRRI (International Rice Research Institute). Rice, science and man. Los Baños,
1972 Philippines.

IRRI. Annual Report for 1973. Los Baños, Philippines. pp. 15-34.
1974

Jawa Barat. Annual Report 1976/77 Cropping Systems Research Indramayu, Jawa
1977 Barat.

Jawa Madura. Peta Zone agroklimat dan Pola Pertanaman Utama pada lahan
1978 kering di Pulau Jawa Madura. Direktorat Bina Produksi Tanaman Pangan.

Jha D., Raheja S.K., Sarin R. and Mehrotra P.C. Fertilizer use in semi-arid
1981 tropical India: The case of high yielding varieties of sorghum and pearl millet. Economics Program Progress Report 22. ICRISAT, Patancheru, AP 502 324.

Jha D. and Sarin R. Fertilizer consumption and growth in semi-arid tropical
1980 India; a district level analysis. Economics Program Progress Report 10, ICRISAT, Patancheru, AP 502 324.

Kampen J. Watershed management. In: Proc. International Symposium on Devel-
1979 opment and Transfer of Technology for Rainfed Agriculture and the SAT farmers. ICRISAT Centre, Patancheru. 28 August-1 September.

Kang B.T. and Juo A.S.R. Management of low activity clay soils in tropical
1981 Africa for food crop production. Proc. Fourth Int. Soil Classification Workshop, Kigali. 2-12 June.

Kang B.T. and Wilson G.F. Effect of maize plant population and nitrogen appli-
1981 cation on maize-cassava intercrop. In: Tropical Root Crops: Research Strategies for the 1980's. E.R. Terry *et al.* (eds). IDRC, Ottawa, Ontario. pp. 129-133.

Kang B.T., Wilson G.F. and Sipkens L.E. Alley cropping maize (*Zea mays* L.) and
1981 Leucaena (*Leucaena leucocephala* Lam) in southern Nigeria. Plant and Soil 59.

Kanwar J.S. Crop characteristics in relation to fertilizer use. Indian Soc.
1970 Soil Sci. Bull. No. 8. pp. 115-119.

Kanwar J.S. (ed). In: Soil Fertility - Theory and Practice. ICAR, New Delhi.
1976

Kanwar J.S. Fertilizer of sorghum, millets and other foodcrops for optimum yield
1977 under dry farming conditions. Proc. FAI-IFDC Fertilizer Seminar, Delhi.

Kanwar J.S. Analysis of constraints to increased productivity of dryland areas.
1980 FAI Seminar on Drylands. Delhi.

Kanwar J.S., Dar M.N., Sardana M.G. and Bapat S.R. Are fertilizer applications
1973 to *jowar*, maize and *bajra* economical? Fert. News 18(7):19-28.

Kass D.C.L. Polyculture cropping systems: Review and analysis. Cornell Int.
1978 Agric. Bull. 32. Cornell University.

Kassam A.H. and Stockinger K.R. Growth and nitrogen uptake of sorghum and
1973 millet in mixed cropping. Samaru Agric. Newsletter 15:28-33.

Katyal J.C. Soil Biol. Biochem. 9:259-266.
1977

Katyal J.C. Fert. News 25(9):39-48.
1980

Katyal J.C. and Randhawa N.S. In: Proc. FAI Seminar on Fertilizers in India
1980 in the Eighties. Fertilizer Association of India, New Delhi.

Katyal J.C., Randhawa N.S. and Sharma B.D. 12th Annual Progress Report of All
1980 India Coordinated Scheme of Micronutrients in Soils and Plants for the Year 1978-79.

Katyal J.C. and Sharma B.D. Fert. News 24:33-50.
1979

Katyal J.C. and Sharma B.D. Paper presented at the 45th Convention of the
1980 Indian Society of Soil Science, Karnal. 12-15 September 1980.

Katznelson H. The 'rhizosphere effect' of mangels on certain groups of soil
1946 microorganisms. Soil Sci. 62:343-353.

Kemmler G. and Malicornet H. Fertiliser experiments - the need for long term
1976 trials. IPI Research Topics No. 1. Int. Potash Institute, Hannover.

Khetawat G.K. and Vishishtha K.S. J. Indian Soc. Soil Sci. 25:81-83.
1977

Krantz B.A., Kampen J. and Virmani S.M. Soil and water conservation and
1978 utilization for food production in the semi-arid tropics. Trans. 11th ISSS Congress, Edmonton, Canada. 22 January. pp. 1-24.

Krantz B.A., Kampen J. and Virmani S.M. Soil and water conservation and uti-
1978 lization for increased food production in the semi-arid tropics. ICRISAT Journal Article 30. ICRISAT, Patancheru, A.P. 502 324, India.

Kumbhar D.D. and Sonar K.R. Maharashtra Agricultural University 4:188-190.
1979

Kurtz T.S., Melsted S.W. and Bray R.H. The importance of nitrogen and water in
1952 reducing crop competition between intercrops and corn. Agron. J. 44:13-17.

Lal R.B., De Rajat and Singh R.K. Indian J. Agric. Sci. 48(7):419-424.
1978

Leroux M. Climat. In: Atlas du Sénégal. P. Pelissier (ed). Editions Jeune Afri-
1980 que, Paris. pp. 12-17.

Lima R.N. and Beltrão N.E.M. Efeito da adubação sob diferentes tipos de preparo
1978 do solo na cultura do algodoeiro arbóreo "Mocó" consorciado com milho e feijão. III Reunião Anual sobre Algodoeiro Arbóreo. Campina Grande, Paraíba, dezembro. pp. 62-77.

Lukman Hakim S. Pembandingan efisiensi berbagai pupuk Nitrogen pada tanaman
1981 padi sawah dan padi gogo. Soil Research Project, Bogor.

McCollum R.E. Fertilizer management practices for intercropping systems. Proc.
1979 Adv. Grp. Mtg. on Nuclear Techniques in Development of Fertilizer and Water Management Practices for Multiple Cropping Systems. 8-12 October. IAEA, Vienna.

McIntosh Jl. and Suryatna E.S. Cropping systems research and implementation.
1980 Indonesia Cropping System Staff (unpublished), CRIA, Bogor.

Madhok M.R. and Fazal-ul-Din. Relative value of different green manures. Paper
1940 read at Science Conference, January 1940. Punjab Agric. Coll. Lyallpur (Faisalabad).

Mahapatra I.C., Bapat S.R., Sardana M.G. and Bhendia M.L. Fertilizer response
1973 of wheat, gram and horsegram under rainfed conditions. Fert. News 18(4):57-63.

Mahapatra I.C., Krishnan K.S., Mahindra S. and Jain H.C. Strategy for fertilizer
1974 recommendations based on multiple cropping sequence. Fert. News. December. pp. 17-26.

Mahapatra I.C., Pillai K.G., Bharagava P.N. and Jain H.C. Fertilizer use in
1981 rice-rice systems. Fert. News 26(9):3-15.

Mandal A.K. and Doharey A.K. Fert. News 23(9):57-64.
1978

Mandal A.K., Doharey A.K. and Pal H. Jute Bull. 39:36-45.
1977

Mandal A.K., Roy A.B. and Pal H. Fert. News 26(9):45-50.
1981

Mandal S.C. Bull. Indian Soc. Soil Sci. 11:191-197.
1976

Maurya P.R. and Ghosh A.B. J. Indian Soc. Soil Sci. 20:31-43.
1972

Meelu O.P. and Rekhi R.S. Fert. News 26(9):16-22.
1981

Mehta B.V. Fert. News 19(12):27-31.
1974

Mehta N.C., Streuli H., Muller M. and Deuel H. Role of poly-saccharides in soil
1960 aggregation. J. Sci. Food Agric. 11:40-47.

Melhuish F.M., Muirhead W.A. and Higgins M.L. Current views on effects of
1976 cropping history on nutrient availability in irrigation soil. Paper presented at Australian Soil Science Society Conference, Wagga. May 1976.

Miandje N.D. Intérêts du système cultural mil-niebé dérobé dans la region de
1979 Diourbel-Bambey. MSc Thesis. Ecole National des Cadres Ruraux de Bambey, Sénégal.

Minotti P.L., Williams D.C. and Jackson W.A. Nitrate uptake and reduction as
1968 affected by calcium and potassium. Proc. Soil Sci. Soc. Amer. 32:692-698.

Mishra R.V. and Gupta R.K. (eds). Proc. FAI-Northern Region Seminar - Ferti-
1981 lizer Efficiency with Special Reference to Multiple Cropping. pp. 281.

Misra S.C. and P. Pande. J. Indian Soc. Soil Sci. 23:242-246.
1975

Mongi H.O., Chowdhury M.S. and Nyeupe C.S. Influence of intercropping methods
1980 on foliar NPK contents and yields of maize and cowpea. Second Symposium on Intercropping in Semi-arid Areas. Morogoro, Tanzania. 4-7 August.

Mongi H.O., Uriyo A.P., Sudi Y.A. and Singh B.R. An appraisal of some
1976 intercropping methods in terms of grain yield, response to applied phosphorus and monetary return from maize and cowpeas. E. African For. J. 42:66-70.

Moraghan J.T., Rego T.J. and Singh S. Aspects of nitrogen fertilization on sor-
1981 ghum production. In: Sorghum in the Eighties. ICRISAT, Patancheru, A.P. 502 324, India. November.

Morgado L.B., Silva W.S. and Albuquerque M. de. Níveis de nitrogênio, fósforo e potássio para culturas consorciadas. Petrolina, EMBRAPA/CPATSA, S.d. 3 p.

Nair K.P.P. Proc. FAI (NRC) Seminar on Fertilizer Use Efficiency through Package
1973 of Practices. pp. 115-138.

Nambiar E.K.S. Plant Soil 46:175-183.
1977

Nambiar K. The deleterious after effects of sorghum - A review. Madras Agric.
1942 J. 30:287-291.

Nayyar V.K., Randhawa N.S. and Pasricha N.S. J. Res. PAU 14:245-251.
1977

N'Diaye P. Végétation et Faune. In: Atlas du Sénégal. P. Pelissier (ed). Editions
1980 Jeune Afrique, Paris. pp. 18-19.

Norman D.H. Mixed cropping in northern Nigeria III. Mixtures of cereals. Exp.
1972 Agric. 15:41-48.

Oelsligle D.D. McCollum R.E. and Kang B.T. Soil fertility management in tropical
1976 multiple cropping. In: Multiple Cropping. Papendick *et al.* (eds). ASA Special Publication 27. Madison, Wisconsin. pp. 275-292.

Okigbo B.N. Evaluation of plant interactions and productivity in complex
1981 mixtures as a basis for improved cropping system design. Proc. Int. Workshop on Intercropping, 10-13 January 1979. ICRISAT, Hyderabad. pp. 155-179.

Okigbo B.N. and Greenland B.N. Intercropping systems in tropical Africa. In:
1976 Multiple Cropping. Papendick *et al.* (eds). ASA Special Publication 27. Madison, Wisconsin. pp. 63-101.

Olson R.A. Soil testing; its correlation, calibration and use. India/FAO/Norway Seminar on Maximizing the Efficiency of Fertilizer Use. New Delhi. 15-19 September 1980 (in press).

Pajajaran University. Laporan survey Multiple Cropping pada tanah keting/Darat
1972 dan sawah didaerah-daerah propinsi Sumatera Utara, Sumatera Barat, Lampung, Kalimantan Selatan, Sulawesi Tenggara dan Nusa Tenggara Barat. Fakultas Pertanian Universitas Pajajaran.

Palmer J.L. A list of field experiments involving crop mixtures in the northern
1971 states of Nigeria 1924-1971. Samaru Miscellaneous Paper 29.

Panabokke C.R. Soil Science, The Soils of Ceylon and Use of Fertilizers. The
1967 Ceylon Association for the Advancement of Science.

Panabokke C.R. and Nagarajah S. The fertility characteristics of the rice-grow-
1964 ing soils of Ceylon. Trop. Agric. 120:3-30.

Panabokke C.R. and Walgama A. J. Nat. Sci. Coun. Sri Lanka 1974 2(2):95-113.
1974

Patel S.P., Ghosh A.B. and Sen S. J. Indian Soc. Soil Sci. 11:225-238.
1963

Pathak A.N., Shankar H. and Mishra R.V. J. Indian Soc. Soil Sci. 16:399-404.
1968

Pathak A.N., Tiwari K.N., Hari Ram and Anil Kumar. Proc. Seminar on Use of
1978 Sedimentary Pyrites for Reclamation of Saline Sodic Soil. Lucknow. pp. 55-67.

Pelissier P. Agriculture. In: Atlas du Sénégal. P. Pelissier (ed). Editions Jeune
1980 Afrique, Paris. pp. 30-31.

Peru Min. Agric. Hoja de Balance de Alimentos. Oficina de Estadistica, Min. de
1968 Agri., Lima, Peru.

Peter A. von. Proceedings of the Fertilizer Society No. 188. pp. 1-50.
1980

Philip K., Jauhri K.S. and Subba Rao N.S. Pusa mud-pot cooling incubator for
1982 storing bacterial cultures in villages. Plant and Soil, Krishi Bhavan, New Delhi.

Pierri C. La fertilisation minérale des cultures en terres exondus. CNRA Bambey.
1972 In: Report Journées d'études sur la recherche et la vulgarisation. Rufisque. 8-13 janvier.

Pokhriyal T.C., Sachdev M.S. Grover H.L., Arora R.P. and Abrol Y.P. Nitrate
1980 assimilation in leaf blades of wheat of different age. Physio. Plant 48:477-481.

Ponnamperuma F.N. Physico-chemical properties of submerged soils in relation to
1977 fertility. IRRI Research Paper Series No. 5. Los Baños.

Pookpakdi A., Sereeprasert V. and Pinya V. Cropping systems testing in paddy
1980 fields in Central Thailand. Third National Conference on Cropping Systems. Chaing Mai University.

Prabhakara J. Soil structure in relation to relay cropping. MSc Thesis. IARI, New
1970 Delhi.

Prabhakara J. Some soil physical and biological interactions in the rhizospheres
1974 of crops under relay. PhD Thesis. IARI, New Delhi.

Prasad B., Singh A.P., Sinha H. and Prasad R.N. J. Indian Soc. Soil Sci.
1979 27:325-329.

Prasad R. and De R. Agronomic research in the service of India's chan-
1980 ging agriculture. Indian Farming 30(7):85-49.

Price C.A. Iron compounds on plant nutrition. Ann. Rev. Plant Physiol. 19:239--
1968 248.

Raheja S.K., Prasad R. and Jain H.C. Il Riso 24:303-317.
1975

Rai M.M., Pal A.R., Chinania B.P., Shitoley D.B. and Vakil P. J. Indian Soc.
1972 Soil Sci. 20:129-134.

Rajagopal C.K., Moosasheriff M., Selva Kumar G. and Madappan K. J. Indian
1974 Soc. Soil Sci. 22:347-351.

Raju S., Shivappa T.G., Sadashivaiah T. and Kulkarni K.R. Mysore J. Agric.
1978 Sci. 12:63-68.

Ramamoorthy B. Aggarwal R.K. and Singh K.D. Soil fertility management under
1971 multiple cropping. Indian Farming 21:50-52.

Ramamoorthy B., Narasimham R.L. and Dinesh R.S. Fertiliser application for
1967 specific yield targets of Sonora-64. Indian Farming 5:43-45.

Ramamoorthy B. and Pathak V.N. Soil fertility evaluation - key to targetted
1969 yields. Indian Farming 18(3):29-33.

Ramamoorthy B. and Velayutham M. Soil test crop response correlation work in
1971 India. In: World Soil Resources Report No. 41. Soil Survey and Soil Fertility Research in Asia and the Far East, Paper 14:96-105.

Ramamoorthy B. Velayutham M. and Mahajan V.K. Recent trends in making ferti-
1975 liser recommendation based on soil tests under fertilizer resource constraints in India. Proc. FAI/FAO National Seminar on Optimizing Agricultural Production under Limited Availability of Fertilizers. New Delhi 110 057. pp. 335-346.

Ramanujam S. and Baldev B. (eds). Legumes in intercropping systems. Symp.
1980 Genetics and Plant Breeding. Indian J. Genet. 40(A):1-178.

Randhawa N.S. and Arora C.L. Indian Farming 20:19.
1970

Randhawa N.S. and Venkateswarlu J. Indian experiences in the semi-arid tropics;
1980 prospect and retrospect. Proceedings of the International Symposium on Development and Transfer of Technology for Rainfed Agriculture and the SAT Farmer. 28 August - 1 September 1979. ICRISAT, Patancheru, A.P. 502 324.

Rao M.R., Reddy M.S. and Willey R.W. Improved rainfed cropping systems for
1982 Vertisols and Alfisols of semi-arid tropical India. Paper presented at the National Seminar on A Decade of Dryland Agricultural Research in India and Thrust in the Eighties, ICRISAT, Hyderabad. 18-21 January.

Rao M.R. and Willey R.W. Current status of intercropping research and some
1978 suggested experimental approaches. Paper presented at the 2nd INPUTS Review Meeting at East-West Center, Honolulu, Hawaii. May 1978.

Rovira A.D. Plant root studies. Bot. Rev. 35:35-57.
1969

Reddy R.N.S. and Prasad R. Fert. News 22(4):3-5.
1977

Reddy M.S., Rego T.J., Burford J.R. and Willey R.W. Fertilizer management in
1982 multiple cropping systems with particular reference to ICRISAT's experience. Presented at FAO Conference on Fertilizer Use under Multiple Cropping Systems, February 1982. Available from ICRISAT, Patancheru, A.P. 502 324.

Rego T.J. Nitrogen response studies of intercropped sorghum with pigeonpea.
1981 Proc.. International Workshop on Intercropping. 10-13 January 1979. ICRISAT, Patancheru, A.P. 502 324.

Rego T.J., Moraghan J.T. and Singh S. Some aspects of soil nitrogen relating to
1982 double cropping of a "deep" vertisol in the SAT. Accepted for the 12th International Soil Science Congress, 8-16 February 1982, Delhi.

Remison S.U. Neighbour effects between maize and cowpea at various levels of N
1978 and P. Exp. Agric. 14:205-212.

Rerkasem B. and Gypmantasiri P. Some aspects of key processes in nitrogen cycle
1981 of rice-based, multiple cropping systems. In: Nitrogen Cycling in South East Asian Wet Monsoonal Ecosystems. Wetelaar *et al.* (eds). The Australian Academy of Sciences.

Roy R.N. and Kanwar J.S. Fert. News 24(6):12-25.
1979

Roy R.N., Seetharaman S. and Singh R.N. Fert. News 23(11):22-31.
1978

Russell E.W. Soil Conditions and Plant Growth. Longman, London.
1973

Ruthenberg H. Farming Systems in the Tropics (3rd ed.). Clarendon Press,
1980 Oxford. pp. 41-42, 395.

Ryan J.G. and Sarin R. Economics of technology options for deep Vertisols in the
1981 relatively assured rainfall regions of the Indian semi-arid tropics. Paper presented at the Seminar on Management of Deep Black Soils, New Delhi, 21 May.

Sachdev C.B. and Khera M.S. Fert. News 25(6):6-10.
1980

Sadanandan N. and Mahapatra I.C. Studies in multiple cropping - Balance sheet
1974 of total and exchangeable potassium in soil in various cropping patterns. Indian J. Agron. 19(2):138-140.

Sadanandan N., Mahapatra I.C. *et al.* A study on the effect of multiple cropping
1976 on the Org. C. status of upland alluvial soils (India). Agro. Res. J. Kerala. pp. 33-48.

Sadikin Sumintawikarta. Program Penelitian efisiensi penggunaan pupuk untuk
1981 menunjang pembangunan Pertanian. Badab Penelitian dan Pengembangan Pertanian Jakarta.

Sagu. Pedoman Bercocok Tanam Palawija dan Sagu. Direktorat Bina Produksi Ta-
1979 naman Pangan.

Sahu B.N. Crop substitution in Orissa. Indian Council Agric. Res, New Delhi. p.
1979 32.

Sakal R. and Singh A.P. Indian Farming 28:3-5.
1979

Samui H.C. and Bhattacharya A.K. Indian Agriculturist 17(2):211-218.
1973

Sanchez P.A. Properties and management of soil in the tropics. Ch. 12: Soil Man-
1976 agement in Multiple Cropping Systems. John Wiley, New York, London, Sydney, Toronto.

Sandhu H.S., Gill G.S. and Brar S.S. Indian Farming 27(9):7-9.
1977

Sanmaneechai M. and Dawson M.D. A comparison of different N fertilizer sources,
1975 rates and methods of application on a two crop rice-corn system. Agricultural Technical Report No. 1, Multiple Cropping Project, Chiang Mai University.

Saxena M.C. and Tilak K.V.B.R. Indian J. Agron. 20(4):369-370.
1975

Sekhon G.S. Fertilizer recommendations based on multiple cropping vis-a-vis sin-
1975 gle cropping. Proc. FAI/FAO National Seminar on Optimizing Agricultural Production under Limited Availability of Fertilizers (1974). FAI, New Delhi 110 057. pp. 371-381.

Sekhon G.S., Arora C.L. and Brar M.S. Commun. Soil Sci. Plant Anal. 9:403-413.
1978

Sekhon G.S., Arora C.L. and Soni S.K. Commun. Soil Sci. Plant Anal. 6:609-618.
1975

Sen S.P., Abrol Y.P. and Singh S.K. Nitrogen assimilation and crop productivity.
1978 Proc. National Symposium Plant Biochemical Society. Associated Pub., New Delhi.

Shahi H.N., Khind C.S. and Gill P.S. Plant Soil 44:231-232.
1976

Sharma B.M. and Deb D.L. J. Indian Soc. Soil Sci. 22:145-150.
1974

Sharma K.N. and Meelu O.P. J. Indian Soc. Soil Sci. 23:76-82.
1975

Shelton H.M. and Humphreys L.R. Undersowing rice (*Oryza sativa*) with *Stylosan-*
1975 *thes guianensis*. I. Plant density. Expl. Agric. 11:89-95.

Shelton H.M. and Humphreys L.R. Undersowing rice (*Oryza sativa*) with *Stylosan-*
1975 *thes guianensis*. III. Nitrogen supply. Expl. Agric. 11:103-111.

Shrader W.D., Fuller W.A. and Cady F.B. Estimation of a common nitrogen res-
1966 ponse function for corn (*Zea mays*) in different crop rotations. Agron. J. 58:397-401.

Shrinivasan S. and Ponnayya J.H.S. Paper presented at the India/FAO/Norway
1978 Seminar on Development of Complementary Use of Mineral and Organic Materials in India, New Delhi. 14-19 September 1978. FAO, Rome.

Shukla V.C., Gupta B.L. and Singh R. J. Indian Soc. Soil Sci. 23:484-488.
1975

Shukla U.S. and Singh R. Paper presented at India/FAO/Norway Seminar on Micronutrients in Agriculture, New Delhi. 17-21 September 1979. FAO, Rome (in press).

Sillanpää M. Trace elements in soils and agriculture. FAO Soils Bulletin 17.
1972 Rome.

Singh Chockey. Fert. News 26(9):56-63.
1981

Singh C.S., Dadarwal K.R. and Subba Rao N.S. Effectiveness of groundnut rhizobia
1976 from wild species of *arachis* on the cultivated species of *A. hypogaea* and their physiological characteristics. Zbl. Bakt. Abt. II Bd. 131:72-78.

Singh D., Krishnan K.S. and Bapat S.R. Economics of fertilizer use based on ex-
1979 periments on cultivators' fields. Fert. News 21(3):8-13.

Singh H.G. and Sahu M.P. Fert. News 26(9):51-55.
1981

Singh K.C. and Singh R.P. Intercropping of annual grain legumes with sunflower.
1977 Indian J. Agric. Sci. 47(11):563-567.

Singh K.D. and Ramamoorthy B. Choice of crop rotations in sustaining the produc-
1974 tivity of crop land ecosystem of north-western Indo-Gangetic Plains. Trans. 10th Int. Congr. Soil Sci., Moscow. pp. 41-49.

Singh K.P. and Sinha H. J. Indian Soc. Soil Sci. 24:403-408.
1976

Singh P.K. Effect of *Azolla* on the yield of paddy with and without the applica-
1977 tion of N fertilizer. Curr. Sci. 46:642-644.

Singh R.P., Singh H.P., Daulay H.S. and Singh K.C. Effect of periodical applica-
1981 tion of nitrogen in organic and inorganic form on the yield of rainfed pearl millet. Indian J. Agric. Sci. 51(6):406-416.

Singh R.P., Singh H.P., Daulay H.S. and Singh K.C. Fertilisation of rainfed
1981 greengram-pearl millet sequence. Indian J. Agric. Sci. 51(7):496-503.

Singh U.S. Indian Sugar 23:755-756.
1973

Singhania R.A. and Goswami N.N. Proc. Symp. on Use of Radiations and Radioiso-
1974 topes in Studies of Plant Productivity. Department of Atomic Energy, Government of India. pp. 437-445.

Smith H.P. Farm Machinery and Equipment. McGraw-Hill, New York.
1965

Solorzano R.P. Growth analysis of grain sorghum (*Sorghum bicolor* (L) Moench)
1974 under different populations and nutritional regimes. MS Thesis, North Carolina State University.

Soundararajan M.S. and Mahapatra I.C. Indian J. Agron. 24:348-350.
1979

Spratt E.D. and Chowdhury S.L. Improved cropping systems for rainfed agricul-
1978 ture in India. Field Crop Research 1:103-126.

Srivastava O.P., Mundra M.C., Sethi B.C. and Khanna S.S. Proc. Indian National
1974 Sci. Acad. Pt.B 40(5):516-525.

Srivastava O.P. and Pathak A.N. Utilization of fertilizer phosphorus by paddy
1970 and green crops in rotation. Symp. on Fertilizer Use. Bull. No. 8 Indian Soc. Soil Sci. pp. 155-159.

Srivastava O.P. and Pathak A.N. Fert. News 21(7):31-33.
1976

Subba Rao N.S. Soil Microorganisms and Plant Growth. Oxford and IBH, New
1977 Delhi.

Subba Rao N.S. (ed). Recent Advances in Biological Nitrogen Fixation. Oxford and
1979 IBH, New Delhi.

Subba Rao N.S. Role of bacteria in crop production. Indian Farming 30(7):71-76.
1980

Subba Rao N.S. Biofertilizers in Agriculture. Oxford and IBH, New Delhi.
1982a

Subba Rao N.S. (ed). Advances in Agricultural Microbiology. Oxford and IBH,
1982b New Delhi.

Subba Rao N.S., Bidwell R.G.S. and Bailey D.L. The effect of rhizoplane fungi on
1961 the uptake of nutrients by tomato plants. Can. J. Bot. 39:1759-1764.

Subba Rao N.S., Bidwell R.G.S. and Bailey D.L. Studies of rhizosphere activity
1962 by the use of isotopically labelled carbon. Can. J. Bot. 40:1759-1764.

Sulawesi. Peta Zone agroklimat dan Pola Pertanaman. Utama pada lahan kering
1979 di Pullau Sulawesi. Direktorat Bina Produksi Tanaman Pangan.

Sumatera. Peta Zone agroklimat dan Pola Pertanaman. Utama pada lahan kering
1980 di Pullau Sumatera. Direktorat Bina Produksi Tanaman Pangan.

Swarup A. and Ghosh A.B. Bull. Indian Soc. Soil Sci. 12:334-338.
1979

Swarup A. and Ghosh A.B. J. Indian Soc. Soil Sci. 28:366-370.
1980

Syarifuddin A.K. Establishment and performance of rainfed corn (*Zea mays*) and
1979 soybean (*Glycine max*) in the dry season after puddled flooded rice. PhD Thesis, UPLB, Philippines.

Takkar P.N., Mann M.S. and Randhawa N.S. J. Indian Soc. Soil Sci. 23:91-95.
1975

Takkar P.N. and Nayyar V.K. Indian Farming 29:9-12.
1979

Takkar P.N. and Nayyar V.K. Fert. News 26(2):22-23.
1981

Takkar P.N. and Randhawa N.S. Fert. News 23(8):3-26.
1978

Tandon H.L.S. Research and development of fertilizer use in dryland agriculture.
1981 Fert. News 26(6):25-34.

Tawornmas D. Effects of different cropping systems on corn production and change
1980 in soil productivity. Proc. Third National Conference on Cropping Systems. Chaing Mai University.

Tawornmas D. A report of cropping systems research from the Field Crops Division. Fourth National Conference on Cropping Systems. Chaing Mai University (in press).

Thailand. Agricultural Statistics No. 108. Centre for Agricultural Statistics, Off-
1978 ice of Agricultural Economics, Ministry of Agriculture and Cooperatives.

Thailand. Chao Phya Research Project. Report to the Ministry of Agriculture of
1969 the Second Kingdom of Thailand, Part B Thai-Australian Chao Phya Research Project, Australian Depart, of External Affairs, Canberra.

Thailand. National Agricultural Census 1978. National Statistical Office. Office
1978 of Prime Minister.

Thierstein G.E. Possibilities for mechanizing rainfed agriculture in the semi-arid
1979 tropics. Presented at the 9th International Agricultural Engineering Congress, East Lansing, Michigan, 8-13 July 1979. Available from ICRISAT, Patancheru, A.P. 502 324, India.

Tilak K.V.B.R. and Subba Rao N.S. Carriers for legume (*Rhizobium*) inoculants.
1978 Fert. News 23:25.

Tiwari K.N. and Pathak S.P. Fert. News. 21(9):39-42.
1976

Tiwari K.N., Pathak A.N. and Tiwari S.P. Fert. News 25(3):3-20.
1980

Tomar P.S., Mathur O.P. and Oberai D.S. Indian Sugarcane J. 9:123.
1965

Tomer V.S. and Verma G.P. Indian J. Agric. Chem. 3:29-34.
1970

Torres R.O. and Morris R.A. Evaluation of selected factors that influence *Rhizo-*
1981 *bium* inoculation efficacy on soybean (*Glycine max*). Paper 12th Ann. Mtg. of Crop Sci. Soc. of the Phil. 22-24 April.

Trenbath B.R. Biomass productivity of mixtures. Advances in Agronomy 26:177-210.
1974

Trenbath B.R. Plant interactions in mixed crop communities. In: Multiple Crop-
1976 ping. ASA Special Publication No. 27. Madison, Wisconsin. pp. 129-169.

Tsuboi T. The effect of rice straw mulch on soil moisture profile and performance
1981 of mungbean after lowland rice. Report of Collaborative Research Project between The International Rice Research Institute and Japan International Cooperation Agency.

US SCS. Soil Taxonomy: a basic system of soil classification for making and in-
1974 terpreting soil surveys. Soil Survey Staff, US Soil Conservation Service, Washington DC.

Velayutham M. Fertilizer recommendation based on targetted yield concept - Prob-
1979 lems and prospects. Fert. News 24(9):12-21.

Velayutham M. and Rani Perumal. An experimental evaluation of soil testing for
1976 fertilizer recommendation under multiple cropping. Il Riso XXV(2):185--190.

Velayutham M. and Singh K.D. Fertilizer recommendations based on soil test for
1981 multiple cropping systems. FAI-NR Seminar, Lucknow. March 1981.

Velayutham M., Maruthi Sankar G.R. and Reddy K.C.K. Increasing fertilizer use efficiency - Soil test for judicious fertiliser use. India/FAO/Norway Seminar on Maximizing the Efficiency of Fertilizer Use. New Delhi. 15--19 September 1980 (in press).

Venkataraman G.S. Algal Biofertilizers and Rice Cultivation. Today and Tomor-
1972 rows Printers and Publishers, New Delhi.

Venkata Nadachary G. and Kidd D.W. Eenati Gorru-a wooden fertilizer seed drill.
1981 Indian Farming 31(4):33-35.

Venkateswarlu J. Rainfed agriculture - means of exploiting full potential. Proc.
1979 FAI Seminar. Delhi.

Venkateswarlu J. and Spratt E.D. Some suggestions for increasing fertilizer effi-
1977 ciency in dryland farming. Fert. News 22(12):39-43.

Verloo M., Kiekens L. and Cottenie A. Distribution patterns of essential and non
1980 essential trace elements in the soil-soil solution system. Pedologie 30:163-175.

Verma K.P. and Jha K.K. J. Indian Soc. Soil Sci. 18:37-40.
1970

Viets F.G. Water deficit and nutrient availability. In: Water Deficits and Plant
1972 Growth. T.T. Koslowski (ed). Academic Press, New York.

Walcott J.J. *et al.* Yields from long term rice growing systems in Central Thai-
1977 land. Expl. Agric. 13:305-315.

Watanaputi W. and Benjasil W. Multiple cropping systems and fertilizer use in
1979a northeastern Thailand. Proc. Second National Conference on Cropping Systems. Chang Mai University.

Watanaputi W. and Benjasil W. Intercropping. Proc. Second National Conference
1979b on Cropping Systems. Chang Mai University.

White W. Energy, food and fertilizers. Fertilizer greatly improves efficiency of
1978 the free energy from the sun. Fert. Progress. pp. 14-18.

Wichmann W. and Trenkel M. Establishment of fertilizer recommendations for pa-
1977 rallel multiple cropping systems. FAO/FIAC Technical Sub-Committee. Centre d'Etude de l'Azote, Zurich.

Willet I.R., Muirhead W.A. and Higgins M.L. The effect of rice growing on phos-
1977 phorus immobilization. Asut. J. of Exp. Agric. and Anim. Husb. 18:-270-275.

Willey R.W. and Osiru D.S.O. Studies on mixtures of maize and beans (*Phaseolus*
1972 *vulgaris*) with particular reference to plant population. J. Agric. Sci. Camb. 79:517-529.

Wilson G.F. and Agboola A.A. Cassava, maize based on cropping systems in the
1979 humid regions of West Africa. Proc. Annual Research Conf. on Soil and Climatic Resources and Constraints in Relation to Crop Production in West Africa. IITA, Ibadan. 15-19 October.

Wit C.T. de., Tow P.G. and Ennik G.C. Competition between legumes and grasses.
1966 Agric. Res. Rep. Wageningen No. 687. 30 p.

Wivutvongvana P. amd Dawson M.D. Influence of initially applied nitrogen, phos-
1975 phorus and potassium fertilizers on yields of wheat - mungbean cropping sequence. Agricultural Technical Report No. 1, Multiple Cropping Project. Chiang Mai University.

Wivutvongvana P., Jusrigaivul S. and Dawson M.D. I. The effects of nitrogen and
1975 phosphorus fertilizers initially applied to a field corn - soybean - sweet corn cropping sequence. II. The effect of nitrogen and phosphate fertilizers initially applied to a rice - soybean - sweet corn cropping sequence. III. The effects of phosphate and potash fertilizers initially applied to a soybean - soybean - sweet corn cropping sequence. Agricultural Technical Report No. 1, Multiple Cropping Project, Chiang Mai University.

APPENDIX I

AGENDA

Sunday, 31 January	Arrival of international participants at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad
Monday, 1 February	Field visit to ICRISAT
Tuesday, 2 February	Field visit to ICRISAT (contd.) Departure of international participants from Hyderabad and arrival at the Indian Agricultural Research Institute (IARI), New Delhi Arrival of national participants at IARI, New Delhi
Wednesday, 3 February	Registration of participants
Inaugural Session	Welcome address: Dr. H.K. Jain, Director, IARI, New Delhi Statement by the Representative of FAO to India: Dr. J. Rumeau, FAO Representative, India Inaugural address: Dr. O.P. Gautam, Director General, Indian Council of Agricultural Research (ICAR), New Delhi Vote of thanks: Dr. N.N. Goswami, Head, Division of Soil Science, Agricultural Chemistry, IARI, New Delhi
Keynote address	Fertilizer use in multiple cropping systems - an appraisal of present knowledge and future needs: Dr. N.S. Randhawa, Deputy Director-General, ICAR, New Delhi
Technical Session	Chairman: Dr. Rajat De, IARI, New Delhi Vice-Chairmen: Dr. N.N. Goswami, IARI, New Delhi Dr. R.E. McCollum, USA 1. Fertilizer use under multiple cropping systems - an overview: Dr. R.N. Roy, FAO, Rome

2. Results of the FAO/IAEA coordinated research programme for nuclear techniques in the development of fertilizer and water management practices for multiple cropping:
   Dr. F. Zapata, FAO/IAEA, Vienna

3. Fertilizer use under multiple cropping systems in South East Asia:
   Dr. Rajat De, IARI, New Delhi

4. Fertilizer use in multiple cropping systems in Nigeria, Tanzania and Senegal:
   Dr. B.T. Kang, IITA, Nigeria

5. Fertilizer management in multiple cropping systems with particular reference to ICRISAT's experience:
   Drs. M.S. Reddy, T.J. Rego, J.R. Burford and R.W. Willey, ICRISAT, India

Thursday, 4 February

Technical Session (Contd.)

6. Dynamics of soil nutrients in multiple cropping systems in relation to efficient use of fertilizers:
   Dr. R.E. McCollum, USA

7. Strategy for N fertilizer recommendations in multiple cropping systems with particular reference to its use efficiency:
   Drs. B.V. Subbiah and M.S. Sachdev, India

8. Strategy for P and K fertilizer recommendations in multiple cropping systems with particular reference to their use efficiency:
   Drs. N.N. Goswami and I.C. Mahapatra, India

9. Importance of micronutrients in multiple cropping systems:
   Dr. M. Verloo, Belgium

10. Importance of secondary and micronutrients in multiple cropping systems - Indian experience:
    Drs. J.C. Katyal and A.N. Pathak, India

11. Major rice-legume combinations and their fertilizer management:
    Dr. J.W. Pendleton, IRRI, Philippines

12. Fertilizer management in multiple cropping systems under dryland conditions:
    Dr. R.P. Singh, India

13. Transfer of soil testing techniques used for single cropping to multiple cropping and formulation of fertilizer recommendations - prospects and problems: Drs. M. Velayutham and A.B. Ghosh, India

14. Role of legumes in multiple cropping systems with reference to N fixation and soil management: Dr. N.S. Subba Rao, India

15. The need for suitable implements for fertilizer application in multiple cropping systems with special reference to small farmers: Mr. G.E. Thierstein and Dr. T.J. Rego, ICRISAT, India

Friday, 5 February

Technical Session (Contd.)

16. Constraints to increased fertilizer use in multiple cropping systems in developing countries and means to overcome them: Dr. J. de la Vega, FAO, Rome

17. Fertilizer distribution and credit strategies for multiple cropping oriented agriculture: Mr. G.K. Sohbti, India

18. Review of soil fertility and fertilizer use research in multiple cropping systems in Bangladesh: Dr. M.M. Rahman, Bangladesh

19. Review of research on multiple cropping systems to increase agricultural production and maintain a proper soil fertility status in Pakistan: Dr. S.A. Qureshi, Pakistan

20. Review of soil fertility and fertilizer use research in multiple cropping systems in Sri Lanka: Dr. W. Ratnayake, Sri Lanka

21. Green manures in multiple cropping systems in China: Dr. Chen Shiping, China

22. Soil fertility and fertilizer use research in intercropping systems in Northeast Brazil: Dr. M. de A. Lira, Brazil

23. Soil fertility and fertilizer use research in multiple cropping systems in Zambia: Dr. R.K. Rajoo, Zambia

24. Fertilizer use in multiple cropping in Indonesia: Paper of Messrs. Nuryadi *et al.*, presented by Dr. S.H.R. Lampe, FAO, Indonesia

25. Fertilizer use and nutritional problems in multiple cropping systems in Thailand: Paper of Mr. B. Rerkasem presented by Mr. W.P. Novero, FAO, Thailand

Saturday, 6 February

Technical Session (Contd.)

Formation of Working Groups on:

- Technology for immediate transfer
- Gaps in knowledge and need for further research
- Guidelines for action programmes: field trials and demonstrations

Discussion of the preliminary conclusions and recommendations of the three Working Groups

Drafting of final conclusions and recommendations

Plenary Session

Chairman: Dr. H.K. Jain, Director, IARI, New Delhi

Presentation of the conclusions and recommendations by the Technical Session Chairman, Dr. Rajat De, IARI, New Delhi

Valedictory address: Dr. H.K. Jain, Director, IARI, New Delhi

Concluding remarks by Host Institute: Dr. N.N. Goswami, IARI, New Delhi

Concluding remarks by Representative of FAO: Dr. J. de la Vega, FAO, Rome

Closing of the meeting

APPENDIX II

LIST OF PARTICIPANTS

	Name, title, address of participants
I. MEMBER NATIONS	
Bangladesh	Dr. M.M. Rahman, Member Director Bangladesh Agricultural Research Council 130/C Dhanmondi R.A., Road No. 1, Dacca-5
Belgium	Dr. M. Verloo Faculty of Agronomy Rijksuniversiteit-Gent, B-9000 Gent
Brazil	Dr. M. de Lira I.P.A. Sorghum Project Leader Empresa Pernambucana De Pesquisa Agropecuaria, Av. Gal. San Martin, 1371, Bonjii 50 000, Recife, Pernambuco
China	Dr. Chen Shiping Soil and Fertilizer Institute Liaoning Academy of Agricultural Sciences Shenyant, Liaoning Province
India	Dr. Rajat De, Head, Division of Agronomy Indian Agricultural Research Institute New Delhi-110012
	Dr. N.N. Goswami, Head Division of Soil Science and Agricultural Chemistry Indian Agricultural Research Institute New Delhi-110012
	Dr. I.C. Mahapatra, Vice-Chancellor Brisa Agricultural University P.O. Kanke, Ranchi-834001 (Bihar)
	Dr. M. Velayutham, Project Coordinator All India Coordinated Soil Test Crop Response Correlation Project 2-2-58/60 Amberpet, Hyderabad-500013 (A.P.)
	Dr. A.B. Ghosh, Sr. Soil Scientist Division of Soil Science and Agricultural Chemistry Indian Agricultural Research Institute New Delhi-110012

	Dr. N.S. Subba Rao Head, Division of Microbiology Indian Agricultural Research Institute New Delhi-110012
	Dr. B.V. Subbiah, Professor Nuclear Research Laboratory Indian Agricultural Research Institute New Delhi-110012
	Dr. J.C. Katyal Project Coordinator (Micronutrients) Department of Soil Science Punjab Agricultural University Ludhiana-141004 (Punjab)
	Dr. A.N. Pathak Head, Department of Soil Science Chandra Shekhar Azad University of Agriculture and Technology Kanpur-208002 (UP)
	Dr. R.P. Singh, ADG-cum-Project Director All India Coordinated Research Project for Dryland Agriculture 2-2-58/60 Amberpet, Hyderabad-500013 (A.P.)
	Mr. G.K. Sohbti, Director (E and S) The Fertilizer Association of India New Delhi-110067
Pakistan	Dr. S.A. Qureshi, Director General (Research) Ayub Agricultural Research Institute Faisalabad
Sri Lanka	Dr. W. Ratnayake Assistant Director of Agriculture (Extension) Anuradhapura
United States of America	Dr. R.E. McCollum, Professor Department of Soil Science North Carolina State University, Raleigh, NC 27607
Zambia	Dr. R.K. Rajoo, Senior Soil Scientist Ministry of Agriculture and Water Development Mt. Makulu Research Station, P.B. 7, Chilanga

II. INTERNATIONAL NON-GOVERNMENTAL ORGANIZATIONS

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	Dr. M.S. Reddy, Agronomist, Cropping Systems Farming Systems Research Program P.O. Patancheru 502 324 Hyderabad (A.P.), India
	Mr. G.E. Thierstein Agricultural Engineer
International Institute of Tropical Agriculture (IITA)	Dr. B.T. Kang, Soil Scientist Oyo Road, PMB 5320, Ibadan, Nigeria
International Rice Research Institute (IRRI)	Dr. J.W. Pendleton Head, Cropping Systems Programme P.O. Box 933, Manila, Philippines

III. INTERGOVERNMENTAL ORGANIZATION

German Agency for Technical Cooperation (GTZ)	Dr. K.G. Steiner P.O. Box 5180, 6236 Eschborn 1, Germany (FR)

IV. FAO/IAEA JOINT DIVISION

Dr. F. Zapata
FAO/IAEA Joint Division
International Atomic Energy Agency, Vienna

V. FAO

Dr. J. de la Vega
Manager, Fertilizer Programme/IFS
Fertilizer and Plant Nutrition Service
FAO, Rome

Dr. R.N. Roy
Technical Officer (Research and Training)
Fertilizer and Plant Nutrition Service
FAO, Rome

Dr. K. Zschernitz, Regional Leader
Fertilizer Programme in Asia and the Pacific
c/o RAPA, Maliwan Mansion
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Mr. W.P. Novero
Fertilizer Use/Plant Nutrition Expert
Project FH/THA/025, Yield Increase through the Use of Fertilizers and Related Inputs
c/o RAPA, Bangkok 2, Thailand

Mr. C. Coursier
Directeur Régional du Programme Engrais en Afrique
c/o Représentant de la FAO
B.P. 7248, Kinshasa, Zaire

Mr. D. Koole, Project Manager
Project UTF/PAK/069/PAK
National Fertilizer Development Centre
NFDC 37, Street 11, F-6/3
Islamabad, Pakistan

Dr. S.H.R. Lampe
Project GCPF/INS/053/BEL
Secondary Crop Intensification Programme
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