WORLD FOOD AND AGRICULTURE: OUTLOOK TO 2010
by
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Historical Evolution and Current Situation

In the last three decades the world as a whole made significant progress in the food and nutrition area. The world average per caput food availabilities for direct human consumption grew 19% between 1961/63 and 1993/95 to 2710 calories/day, while those of the developing countries grew 32% to 2550 calories (Figure 1). This happened while world population grew from 3.0 billion in 1960 to 5.7 billion in 1995. In parallel, the part of world population living in countries where per caput food supplies are very low (under 2200 calories) decreased considerably from 56% of world population in 1969/71 to only 10% in 92/94 (Figure 2). In the developing countries, part of the improvement depended on rising net food imports, particularly during the 1970s (Figure 10). However, progress has been very uneven and bypassed a large number of countries and population groups. There are currently still over 800 million persons undernourished, with high concentrations in Asia and sub-Saharan Africa (Figure 3).

In recent years, there has been a slowdown in the growth of world agricultural production. World cereals output stagnated and fluctuated widely in the first half of the 1990s. In per caput terms, it is now lower than in the mid-1980s (Figure 4). In parallel, production of marine capture fisheries seems to have hit a ceiling of about 80-90 m.tons and much of the increase in fish production is coming from aquaculture (Figure 5), a development likely to continue in the future. However, world average indicators have limited value for welfare analysis and the variables must be observed at a more disaggregated level. In practice, progress in food security need not manifest itself in rising world averages (i.e. with aggregate production /consumption rising faster than world population), but it is possible for progress to take place even if the world average stagnates or even falls. Thus, in the last ten years which witnessed the declines in the world averages, there has been no decline in the per caput production of cereals in the developing countries while that of all other food products (roots/tubers, pulses, bananas/plantains, livestock, sugar, oilseeds, fruit and vegetables, etc.) grew even faster than in the preceding ten years (Figure 6). The problem for the developing countries remains one of too low production and consumption per caput.

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1 Paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997. The views are the author’s, not necessarily those of FAO.
2 To understand how this is possible, consider the following example (based on approximate relative magnitudes for the developing and the developed countries): in a population of four persons, one is rich, consuming 625 kg of grain, and three are poor, each consuming 225 kg. Total consumption is 1,300 kg and the overall average is 325 kg. Thirty years later, the poor have increased to five persons (high population growth rate of the poor) but they have also increased consumption to 265 kg each. There is still only one rich person (zero population growth rate of the rich), who continues to consume 625 kg. Aggregate consumption is 1,950 kg and the average of all six persons works out to 325 kg, the same of 30 years earlier. Therefore, real progress has been made even though the average did not increase. Obviously, progress could have been made even if the world average had actually declined. Thus, if the consumption of the poor had increased to only 250 kg (rather than to 265), world aggregate consumption would have risen to 1875 kg but the world average would have fallen to 312.5 kg.
The declines in world cereals output per caput have been due, in the first place and up to quite recently, to policy reforms and supply controls coinciding with weather shocks in the main industrial exporting countries and, secondly in more recent years, to the collapse of production (as well as of consumption and net imports) in the countries of Eastern Europe and the former USSR following the drastic systemic reforms in their economies (Figure 7). Thus, the slowdown in world production in the first half of the 1990s may not be interpreted as ushering an era when the natural resource and technology constraints have become all of a sudden so much more binding to production growth (for this view, see Brown, 1996 and for discussion Alexandratos, 1996). What may prove to be a more permanent structural change in the world food system is the impact of policy reforms, in part linked to the new policy environment for international trade, mainly in the main western exporting countries, leading to the cessation of generation of quasi-permanent structural surpluses and the holding of large stocks by the public sector. This would enhance the risk over the medium term of higher variability in world market prices and reduced availabilities for food aid.

The persistence of significant undernutrition in the developing countries does not so much reflect a lack of capability of the world as a whole to produce the additional food required to eliminate undernutrition, which is a very small amount compared to current or future world food output (see FAO, 1996). It is rather due to the persistence of abject poverty, development failures (often linked to war and unsettled political conditions) and lack of appropriate social policies. In many low-income countries with high dependence on agriculture, overall development failures reflect, above all, failures of agricultural development. It follows that one of the main thrusts of national and international policies to solve the problem must be the promotion of local food production and broader rural development in these countries, so as to simultaneously increase food supplies and stimulate overall development. What are the prospects that progress may be made in the foreseeable future (to 2010)?

Prospects to 2010

We note that, in the first place, the growth rate of world population (including that of the developing countries) has been on the decline since the second half of the 1960s. However, the absolute increments in world population continue to be very high and are currently about 80 million persons p.a., over 90% of which in the developing countries). Such high annual increments may persist for another 15-20 years, but with declines in prospect for the longer term future, falling to some 40 million p.a. by 2050 (Figure 8, from the 1996 UN population projections, Medium variant). In parallel, the latest World Bank assessment indicates some improvement in the overall economic growth prospects of the developing countries for the next ten years compared with the preceding decade. Asia (both South and East) should continue to have fairly high GDP growth rates, while the prospects are for recovery in Latin America and a more modest one in Near East/North Africa.

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1 Thus, the EU-15 production of cereals fell from 191 million tons in the 3-year average 89-91 to 178 million tons in 93-95, before growing again to 207 million tons in 1996 following the high world market prices and the relaxation of supply controls. Forecasts for 1997 indicate 202 million tons, while the latest EU-Commission Study (European Commission, 1997) foresees further growth (about 6% by 2005) under present CAP policies and 17.5% land set-aside. With the GATT limits for subsidized exports and minimum import access (implying net exports of 21.4 million tons after 2000) stocks would rise again rapidly to some 80 million tons by 2005 (currently: about 27 million tons). Other studies assume that there will be further CAP reforms and that the EU will eventually be exporting part of its surplus without subsidies, e.g. USDA (1997).

2 Some of the graphs in this note compare actual outcomes to the latest year for which data are available with projections made in 1986 for the period 1982/84-2000 (published in Alexandratos, 1988) and in 1992-93 for the period 88/90-2010 (published in Alexandratos, 1995).
Prospects are also better for sub-Saharan Africa, but only compared with the dismal past record of falling per caput incomes (Figure 9). Even so, the region’s per caput income may not grow by more than 1% p.a., an outcome which does not augur well for the reduction of poverty and hence undernutrition.

These prospects indicate that further improvements may be expected in the world average indicators for the world and developing countries as a whole, but also that the food insecurity and undernutrition problems of many countries starting with very unfavourable initial conditions (mainly in sub-Saharan Africa and, to a smaller extent, in South Asia and selected countries in other regions) will persist, perhaps at slightly attenuated levels, in the medium term future and perhaps well beyond. For example, any country starting with per caput food supplies of 2000 calories/day (and some countries start with less) and a population growth rate of 3% p.a. would need a growth rate of aggregate food demand of 5-6% p.a. for 15 years if by 2010 it were to have 2700 calories/day, a level usually associated with significantly reduced undernutrition (provided inequality of distribution is not too high). Obviously, this kind of growth rates of aggregate demand for food can only occur in countries which “Asian-tiger” rates of economic growth and very low food consumption at present. Not many of the poorest countries of today face such prospects.

These overall economic and demographic prospects formed the basis for FAO’s assessment of world food and agriculture prospects to 2010, with particular reference to the developing countries, in the study “World Agriculture: Towards 2010” (Alexandratos, 1995). The main findings may be summarized as follows:

- The per caput food availabilities of the developing countries as a whole will continue to increase from the current (1993/95) 2550 calories to 2700-2800 by 2010. However, there will be only very modest gains in the currently very low average of sub-Saharan Africa, while South Asia may still be in a middling position by 2010. The other developing regions, already starting from better levels now, are expected to be near, or above, 3000 calories (Figure 1).

- The incidence of undernutrition in the developing countries may decline in relative terms (as % of the population) but, given population growth, there will be only modest declines in the numbers undernourished from the current level of over 800 million persons. High incidence of undernutrition will persist in sub-Saharan Africa, and somewhat reduced one in South Asia (Figure 3).

- Local production increases will be by far the main source of the increases in the total food supplies of the developing countries, but their net food imports from the rest of the world should continue to grow, though not at very high growth rates. Net imports of cereals may grow from the 90 million tons of the base year of the study (1988-90) and the 100-110 m.tons of more recent years to about 160 million tons by 2010 (Figure 10). It will be necessary for part of these imports to be supplied as food aid if the modest additional imports of the very poor countries are to materialize.

- The rest of the world (mainly the main exporting OECD countries) should face no major constraints in generating this additional export surplus of cereals, given that (a) their own demand grows very slowly and below the potential of their agriculture to increase output, and (b) part of the additional import requirements of the developing countries are being offset by declining ones of the region of E. Europe / ex-USSR which was a heavy net importer in the pre-reform period (some 35 million tons in 1989-91), but may be a modest net exporter by 2010. The region’s net imports had already been reduced to insignificant levels by the mid-1990s.
As in the past, and more so in the future, the mainstay of production increases will be the intensification of agriculture in the form of higher yields and more multiple cropping, particularly in the countries with appropriate agroecological environments and little or no potential to expand land in cultivation. However, the growth of yields will be slower than in the past (Figure 11) and so will expansion of irrigation. Achievement of even this slower yield growth depends on continuing high priority to the agricultural research and technology diffusion effort, as well as better policies and a more active role of the state in the areas of infrastructure, education and the creation of conditions for markets to work.

It is probable that some countries will derive part of their production increases from further land expansion. Overall, land expansion, mainly in Latin America and sub-Saharan Africa, may contribute about 20% of the increase in crop production. This increase (some 90 million ha, or 12%, in the developing countries as whole, excl. China) is a small proportion of the total unused land with rainfed crop potential (some 1.8 billion ha, Figure 12). Naturally such unused land should by no means be considered as a ‘reserve’ for agricultural expansion. Some 50% of it is under tropical forest and large tracts are environmentally fragile or suffer from other constraints, including lack of infrastructure, incidence of disease, etc.

Concerning the environmental and sustainability dimensions of the expansion and further intensification of agriculture, we note that (a) the foreseen land expansion need not be associated with the rapid rates of tropical deforestation observed in the past, though there is no guarantee that this will be so; (b) there will be further increases in the use of agrochemicals (fertilizer, pesticides) in the developing countries, though at declining rates compared with the past; (c) increased use of fertilizer is often indispensable for sustainability (to prevent soil mining); and (d) the need to accept trade-offs between production increases and the environment will continue to exist in the foreseeable future and the policy problem is how to minimize them.

This being an IFA Conference, it is worth looking at possible developments in fertilizer consumption. We first note the decline of world consumption in the last few years, which has been entirely due to the collapse of consumption in the former socialist countries (Figure 13). As noted, we expect consumption in the developing countries to continue to grow, albeit at lower rates than in the past (Figure 14). This trend towards slowdown in the growth rates is evident in the historical data. The data and methods for projecting fertilizer use as a function of economic factors and changes in volume, patterns and modalities of crop production, are in great need of improvement. We shall have an opportunity to review where we stand on this matter at the planned meeting of the Working Party on Fertilizer Demand tomorrow evening.

In conclusion, our findings leave no scope for complacency concerning the prospects that progress will be of a pace and pattern such as to eliminate, or significantly reduce, the food insecurity problems in the foreseeable future. This is a pragmatic and far from optimistic assessment, no matter that those who think that the world is going to end tomorrow will find as unduly optimistic any notion that further progress, slow and uneven as it may be can be made.

REFERENCES

FAO (1996), Assessment of Feasible Progress in Food Security, Technical Background Document No 14 for the World Food Summit, Rome
USDA (1997), International Agricultural Baseline Projections to 2005 (Summary Tables), May
Fig. 1. Per Caput Food Supplies, Developing Regions

Updated to 95.16-6-97, data in files TCAL6195

Fig. 2. World Population Living in Countries with Given Food Supplies (Kcal/Caput/Day)
Fig. 3. Incidence of Undernutrition

Million Persons

Africa, sub-Sah. 69/71
South Asia 79/81
East Asia 90/92
Near East/NAfrica 2010

(905 m.) (840 m.) (680 m.) (920 m.)

Lat.America

Fig. 4. WORLD CEREALS PRODUCTION 1961-96 (Indices)

Total Production
Population
Production per Caput

Updated Faostat data 12-6-97, File IFA-GRAP.Xls
Fig. 5. Production of Fish, Capture and Aquaculture, 1950-94

Million Tons

0 20 40 60 80 100 120
Total
Capture
Aquaculture

File: INLMAR.Xls, Upd. 10/96

Fig. 6. Developing Countries: Per Caput Prod. Cereals Vs Other Food

Index 1961=100

90 100 110 120 130 140 150 160
Cereals
Other Food Products

FSTAT data 13-6-97, File IFA-GRAF.Xls
Fig. 7. Cereals Production (with Rice in milled)

Updated 16-6-97, File FGR24MAY.xls


Fig. 8. Population, Absolute Increments and Growth Rates 1950-2050

Source, UN (1996), Medium Variant Proj., File Pop96AT.xls
**Fig. 9. Growth Rates of per Caput GDP**

-2 -1 0 1 2 3 4 5 6 7 8
Sub-Saharan Africa N.East / N.Africa Latin Amer / Carib South Asia East Asia

% p.a.

87-96 97-2006

**Fig. 10. Net Cereal Imports, Developing Countries**

0 20 40 60 80 100 120 140 160 180

Million Tons

Projection 88/90-2010*
Projection 82/4-2000**
Actual 61-97


Data for the last three years refer to trade years (July/June): 96/7 estimate, 97/8 forecast (Food Outlook, 5-6/97, Upd.12-6-97).
Fig. 11. Yield of Wheat, Rice (paddy) and Maize Developing Countries, excl. China


Fig. 12. Land with Rainfed Crop Production Potential

Near East/ North Africa
East Asia
South Asia
Sub-Saharan Africa
Latin America/Caribbean

(excl. China)

File: Tranblac/Landgrap.xls
Fig. 13 Fertilizer Consumption, 1961-94

Fig. 14. Fertilizer Consumption & Crop Production, Developing Excl. China

*Source: Alexandratos (1995): 85, 193

File:Fert-IFA.Xls, 17-6-97
RECYCLAGE DES ELEMENTS NUTRITIFS ISSUS DE DECHETS ET DE SOUS-PRODUITS EN AGRICULTURE :
PERSPECTIVES ET CONTRAINTES

par
O. Theobald
ADEME, France
Recycling of nutrients contained in refuse and agriculture by-products: outlook and constraints

Today, agriculture is recycling urban, industrial or agricultural waste containing fertilizer nutrients. Each year, nearly 1.500.000 tons of nitrogen, 890.000 tons of phophorus and 1.800.000 tons of potassium are recycled to fertilize agricultural land. Animal manure, slurries or urban waste have long been spread on land. They often replace mineral fertilizers and are an economy for farmers.

On the other hand, intensive farming, changes in methods or crop specialization, are accused of degrading water quality. Agriculture is accused of being the principal source of water or groundwater pollution. This is why sewage sludges, organic waste or slurries are being studied to understand their agronomic properties for many crop species, fertilization levels, etc. European agricultural policy, integrated agriculture, or research programs to reduce the mineral fertilization, are factors which could favour utilization of slurry, manure or waste recycled in agriculture in the future. However, we must bear in mind one fundamental concept: the final quality of the agricultural produce.

Résumé

Les effluents urbains, industriels ou agricoles contenant des éléments fertilisants majeurs (N, P et K) sont pour la plupart recyclés en agriculture. Ils peuvent remplacer les engrais minéraux dans les plans de fertilisation. Ainsi, les effluents d’élevage sont utilisés depuis toujours dans la fertilisation des terres cultivées et représentent également une économie non négligeable pour l’agriculteur.

Aujourd’hui, en raison de l’intensification, de la modification des pratiques ou de la spécialisation des cultures, l’agriculture française est souvent accusée d’être une des activités économiques à l’origine de la pollution des eaux de surface et souterraines. C’est pourquoi les effluents recyclés en agriculture, et en particulier les boues de station d’épuration des eaux usées urbaines ou les effluents d’élevage, font l’objet d’études approfondies afin de mieux connaître leurs caractéristiques chimiques et agronomiques (type de culture, techniques de travail du sol, niveaux de fertilisation, etc.). La réforme de la politique agricole commune, le développement de la notion d’agriculture intégrée, la volonté de diminuer l’utilisation des engrais de synthèse, sont autant de facteurs susceptibles d’augmenter dans l’avenir la quantité des effluents, sous-produits ou déchets recyclés en agriculture, sous réserve de respecter une notion fondamentale de l’agriculture à vocation alimentaire : la qualité.

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1 Exposé présenté à la réunion du Comité Agro-Economie de l’IFA à Tours, France, les 23 et 25 juin 1997
2 Agence de l’Environnement et de la Maîtrise de l’Energie
1. Introduction

La pollution de ces eaux par des éléments fertilisants utilisés en agriculture, constitue, en France, un problème d’une ampleur sans précédent. Agriculture intensive, productions agricoles spécialisées et concentrées dans quelques régions, sont pour partie responsables de la dégradation de la qualité des eaux de surfaces et souterraines, de l’eutrophisation des rivières, et de la prolifération des algues vertes sur les côtes.

Les pouvoirs publics avaient déjà anticipé le phénomène, en instituant une loi sur l’eau en 1964, qui a créé des Agences Financières de Bassin
devenues depuis les Agences de l’Eau. Plus récemment, des structures de concertation et de prévention comme le CORPEN
deviennent le Comité d'orientation pour la réduction de la pollution dans les eaux par les nitrates, les phosphates et les produits phytosanitaires provenant des activités agricoles. La révision de la réglementation sur les installations classées au titre de la protection de l’environnement a récemment renforcé la loi sur l’eau de 1964.

La recherche a été encouragée, au début des années 70, par le Ministère de l’Environnement, en particulier sur le problème des boues d’épuration des eaux usées urbaines. Par ailleurs, certaines dispositions réglementaires ont été prises, comme par exemple la loi n° 75-633 du 15 Juillet 1975, relative à l’élimination des déchets et à la récupération des emballages. L’ANRED
deviennent l’ADEME, en collaboration avec la profession agricole et les agences de l’Eau, a été à l’origine de la création des missions de valorisation agricole des déchets, au sein des Chambres d’Agriculture, missions chargées de promouvoir et de développer le recyclage des déchets en agriculture.

La France produit chaque année environ 500 millions de tonnes de déchets et sous-produits d’origine urbaine, industrielle ou agricole, contenant des quantités substantielles d’éléments fertilisants majeurs (N, P et K), et justifiant ainsi leur recyclage en agriculture. La part recyclée en agriculture varie selon leur provenance, et leur qualité. La valorisation des déchets et le recyclage des éléments fertilisants qu’ils contiennent, dans le respect de la qualité des produits, constitue ainsi un des défis majeurs de la politique française du XXIème siècle dans le domaine de l’environnement.

2. Méthodes

Ce document dresse le bilan, pour différentes catégories de déchets et sous-produits organiques urbains, industriels ou agricoles, de la part valorisée et de la part valorisable en agriculture, en examinant les perspectives d’évolution dans le futur.

Pour les déchets et sous-produits urbains est présenté, en premier lieu, un état de la situation actuelle du recyclage, reposant sur différentes études générales, dont celles de l’ADEME. Une hypothèse plausible d’évolution est ensuite donnée, dans un futur proche (5 à 10 années). Ce scénario repose sur les données de différentes études montrant l’évolution de la production de déchets et sous-produits, ou l’évolution de l’équipement des collectivités locales pour le traitement des déchets. Enfin, le dernier scénario présente la quantité maximale potentiellement recyclable en agriculture, dans l’hypothèse maximaliste où toute la production de déchets est épandue et valorisée sur les sols agricoles, avec des pratiques respectueuses de l’environnement.

\(^3\) devenues depuis les Agences de l’Eau
\(^4\) Comité d’orientation pour la réduction de la pollution dans les eaux par les nitrates, les phosphates et les produits phytosanitaires provenant des activités agricoles
\(^5\) Agence Nationale de Récupération et d’Elimination des Déchets
\(^6\) ADEME, 1994, Les déchets en chiffres, 146 p., Ed. Ademe

3. Les déchets et sous-produits urbains

Les déchets et sous-produits urbains représentent près de 60 millions de tonnes par an, à la fois sous forme solide, liquide ou pâteuse, se répartissant comme suit :

- 30 millions de tonnes d’ordures ménagères,
- 9 millions de tonnes de boues d’épuration urbaines,
- 3,5 millions de tonnes de déchets verts collectés (0,3 m$^3$/habitant/an),
- 10 millions de m$^3$ de matières de vidange et 4,5 millions de tonnes de déchets encombrants ou inertes, qui ne font pas l’objet d’un recyclage en agriculture.

3.1. Les ordures ménagères

La production d’ordures ménagères a considérablement augmenté entre 1960 et 1993, passant de 220 kg par habitant et par an à plus de 400 kg. L’évolution des modes de consommation, et la modification des conditionnements, font diminuer progressivement la part de la matière organique dans la poubelle des ménages. Le recyclage en agriculture des ordures ménagères concerne essentiellement les composts produits à partir de la fraction organique. A ce jour, la production de composts représente 550,000 t/an, en comptabilisant à la fois les composts produits à partir des ordures ménagères brutes non triées, et ceux provenant de la partie organique après tri "à la source". Les simulations réalisées en 1994 par Leroy$^7$ montrent que l’option "tout compostage" de la fraction organique des ordures permettrait de produire 6 Mt$^8$ par an d’un compost de qualité recyclable en agriculture. Dans un avenir proche, on peut penser que l’augmentation du tri des ordures à la source permettra la production de 700.000 tonnes par an représentant 4.200 tonnes de N, 2.800 t de P$^2$O$^5$ et 3.500 t de K$^2$O (Tableau 1).

Tableau 1 : Estimation du tonnage d’éléments fertilisants mobilisables dans les composts d’ordures ménagères recyclés en agriculture

<table>
<thead>
<tr>
<th>teneur moyenne d’un compost (kg/t)</th>
<th>N</th>
<th>P$^2$O$^5$</th>
<th>K$^2$O</th>
<th>CaO</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>situation actuelle : 550.000 t/an</td>
<td>6,0</td>
<td>4,0</td>
<td>5,0</td>
<td>39,0</td>
<td>5,0</td>
</tr>
<tr>
<td>projection à 5 ou 10 ans : 700.000 t/an</td>
<td>3.300</td>
<td>2.200</td>
<td>2.800</td>
<td>21.500</td>
<td>2.800</td>
</tr>
<tr>
<td>hypothèse maximaliste : 3,5 Mt/an</td>
<td>4.200</td>
<td>2.800</td>
<td>3.500</td>
<td>27.300</td>
<td>3.500</td>
</tr>
</tbody>
</table>

Leroy M.-G., 1994, Analyse prospective du marché français des composts issus de déchets organiques, ADEME, 57 p. et annexes, non publié

$^7$ Millions de tonnes
Ces hypothèses reposent sur la disparition, à court terme, du compostage des ordures ménagères brutes, et sur le développement du tri de la matière organique à la source. Les bilans des nombreuses opérations de tri à la source sur le territoire national attestent de la faisabilité de cette filière.

3.2. Les déchets verts

La production française mobilisables de déchets verts (tontes de gazon, résidus d’élagage, feuilles mortes, etc.) était estimée à 17 millions de m$^3$ en 1994, soit environ 3,5 millions de tonnes$^9$. En 1997, 106 plates-formes traitaient 3 millions de m$^3$ de déchets verts soit 550.000 t, et qui ont donné 232.000 t de compost. Cette filière de compostage est en nette expansion depuis 1993, où n’existait qu’une trentaine de plates-formes. Il est vraisemblable que l’expansion de la filière va se poursuivre dans les années futures. Les hypothèses maximalistes prévoient, si tout le gisement collectable est composté, une production de 3,5 millions de t de composts à partir de 7 millions de t collectées (Tableau 2).

### Tableau 2 : Estimation du tonnage d’éléments fertilisants mobilisables dans les composts de déchets verts recyclés en agriculture

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P$_2$O$_5$</th>
<th>K$_2$O</th>
<th>CaO</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>teneur moyenne d’un compost (kg/t)</td>
<td>9,0</td>
<td>3,0</td>
<td>7,0</td>
<td>50,0</td>
<td>4,0</td>
</tr>
<tr>
<td>situation actuelle : 230.000 t/an</td>
<td>2.000</td>
<td>1.800</td>
<td>3.600</td>
<td>27.000</td>
<td>1.900</td>
</tr>
<tr>
<td>projection à 5 ou 10 ans : 1 Mt/an</td>
<td>8.800</td>
<td>3.400</td>
<td>6.700</td>
<td>50.000</td>
<td>3.600</td>
</tr>
<tr>
<td>hypothèse maximaliste : 3,5 Mt/an</td>
<td>31.000</td>
<td>11.900</td>
<td>23.500</td>
<td>175.000</td>
<td>12.600</td>
</tr>
</tbody>
</table>

D’autre part, de nombreuses expériences sont tentées, afin d’utiliser la matière carbonée présente dans les déchets verts, pour le compostage de déchets en mélange, en particulier avec les boues d’épuration.

3.3. Les boues d’épuration

Actuellement, 60 % des boues produites par les 12.000 stations d’épuration des eaux usées urbaines françaises sont valorisées en agriculture, ce qui représente un tonnage de 540.000 t de matières sèches. Leur utilisation par l’agriculture nécessite une bonne conception des équipements de la station, notamment pour leur stabilisation, leur épaississement, leur stockage et leur épandage.

Leurs fortes teneurs en N et P$_2$O$_5$, et parfois en CaO pour les boues chaulées, associées à une teneur en matière organique comprise entre 50 et 70 %, en font des fertilisants particulièrement intéressants pour l’agriculture (tableau 3).

### Tableau 3 : Estimation du tonnage d’éléments fertilisants mobilisables dans les boues d’épuration valorisées en agriculture

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3.4 Les matières de vidange

Les matières de vidange, obtenues à partir des fosses septiques représentent environ 200.000 t de M.S., dont 70 % sont recyclées en agriculture. Les 30 % restants mis en décharge ou réintroduits en tête de station d’épuration, doivent trouver des débouchés, en raison de l’application de la loi de 1992\textsuperscript{10}. Les matières de vidange sont des produits très riches en eau, et en éléments fertilisants majeurs (Tableau 4).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P\textsubscript{2}O\textsubscript{5}</th>
<th>K\textsubscript{2}O</th>
<th>CaO</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>teneur moyenne d’une boue (kg/t de MS)</td>
<td>50,0</td>
<td>60,0</td>
<td>8,0</td>
<td>60,0</td>
<td>10,0</td>
</tr>
<tr>
<td>situation actuelle : 540,000 t/an</td>
<td>27,000</td>
<td>32,400</td>
<td>4,300</td>
<td>32,400</td>
<td>5,400</td>
</tr>
<tr>
<td>projection à 5 ou 10 ans : 700,000 t/an</td>
<td>35,000</td>
<td>42,000</td>
<td>5,600</td>
<td>42,000</td>
<td>7,000</td>
</tr>
<tr>
<td>hypothèse maximaliste : 1,35 Mt/an</td>
<td>67,500</td>
<td>81,000</td>
<td>10,800</td>
<td>81,000</td>
<td>13,500</td>
</tr>
</tbody>
</table>

A l’avenir, la mise en décharge des matières de vidange n’est plus envisageable. Par conséquent, les hypothèses retenues envisagent une augmentation de la part recyclée par épandage sur les sols agricoles dans un futur proche pour atteindre 90 % voire 100 %, la part restante étant dirigée vers les stations d’épuration.

Les quantités d’éléments fertilisants disponibles à partir des déchets et sous-produits urbains, en fonction des différentes hypothèses d’évolution, sont données dans le tableau ci-après (Tableau 5).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P\textsubscript{2}O\textsubscript{5}</th>
<th>K\textsubscript{2}O</th>
<th>CaO</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>situation actuelle : 140,000 t/an</td>
<td>24,500</td>
<td>7,000</td>
<td>8,400</td>
<td>8,400</td>
<td>7,000</td>
</tr>
<tr>
<td>projection à 5 ou 10 ans : 180,000 t/an</td>
<td>31,500</td>
<td>9,000</td>
<td>10,800</td>
<td>10,800</td>
<td>9,000</td>
</tr>
<tr>
<td>hypothèse maximaliste : 200,000 t/an</td>
<td>35,000</td>
<td>10,000</td>
<td>12,000</td>
<td>12,000</td>
<td>10,000</td>
</tr>
</tbody>
</table>

10 loi n° 92-646 du 13 Juillet 1992
4. Les effluents d’élevage

Les effluents d’élevage sont considérés par l’opinion publique comme un problème majeur pour l’environnement. Selon Leroy (1994), l’élevage français produit annuellement environ 270 millions de tonnes de déjections¹¹, pour la plupart valorisées sur les terres agricoles proches des exploitations. Ils se répartissent inégalement entre les déjections liquides (lisiers et fientes) pour 90 millions de tonnes et les déjections solides (fumiers et fientes) pour 180 millions de tonnes. Les tonnages corrélatifs d’éléments fertilisants disponibles pour les terres cultivées sont considérables. Depuis fort longtemps, les exploitations d’élevage ont utilisé ces "engrais de ferme" dans leur plan de fertilisation essentiellement pour les cultures céréalières ou les cultures de maïs. L’essor de l’élevage hors-sol dans l’Ouest de la France a profondément modifié ces pratiques ancestrales, et engendré des situations "d’excédents structurels" qu’il faut maintenant résorber, à l’aide de mesures spécifiques, comme l’instauration d’un code de bonnes pratiques agricoles¹², ou du programme de maîtrise des pollutions d’origine agricole (PMPOA).


| Tableau 6 : Teneurs en éléments fertilisants des déjections animales |
|--------------------------|-----------------|-----------------|-----------------|
| Type de déjections       | Teneurs moyennes exprimées en kg/t ou en kg/m³ |
|                          | N               | P₂O₅            | K₂O             |
| Fumier de bovins         | 6,0             | 3,0             | 7,0             |
| ovins                    | 7,0             | 4,0             | 11,0            |
| caprins                  | 6,0             | 5,0             | 6,0             |
| chevaux                  | 8,0             | 3,0             | 9,0             |
| volailles                | 29,0            | 29,0            | 20,0            |
| Lisiers de bovins        | 4,0             | 2,0             | 5,0             |
| porcins                  | 6,0             | 6,0             | 2,0             |
| volailles                | 7,0             | 10,0            | 6,0             |
| lapins                   | 9,0             | 13,0            | 7,0             |

Pour une utilisation agronomique de ces effluents, il est essentiel de connaître les apports réels d’éléments fertilisants, ainsi que les arrière-effets possibles. Les pollutions d’origine agricole ont souvent pour cause une mauvaise maîtrise de l’apport des effluents (période inappropriée, quantité trop importante par rapport aux besoins des plantes, etc.). Les déjections évoluent au cours du stockage avant l’épandage, et leurs teneurs en éléments majeurs sont susceptibles d’évoluer. Il est recommandé d’effectuer des analyses avant l’épandage, afin de corriger et d’adapter si besoin une fertilisation minérale en conséquence.

¹² En application de la Directive du Conseil de l’Union Européenne n°91-671 du 12/12/91 concernant la protection des eaux contre la pollution par les nitrates à partir de sources agricoles
A partir des teneurs et connaissant le nombre d’animaux présents, on obtient aisément la quantité d’éléments fertilisants mobilisable pour une valorisation en agriculture (Tableau 7).

**Tableau 7 : Quantités d’éléments fertilisants produits par les déjections animales (d’après Leroy, 1994, chiffres arrondis)**

<table>
<thead>
<tr>
<th>Type de déjections</th>
<th>Quantités d’éléments fertilisants (tonnes/an)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Fumier de bovins</td>
<td>860.000</td>
</tr>
<tr>
<td>ovins</td>
<td>100.000</td>
</tr>
<tr>
<td>caprins</td>
<td>10.000</td>
</tr>
<tr>
<td>chevaux</td>
<td>35.000</td>
</tr>
<tr>
<td>volailles</td>
<td>60.000</td>
</tr>
<tr>
<td>Lisiers de bovins</td>
<td>258.000</td>
</tr>
<tr>
<td>porcins</td>
<td>116.000</td>
</tr>
<tr>
<td>volailles</td>
<td>32.000</td>
</tr>
<tr>
<td>lapins</td>
<td>2.000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1.473.000</td>
</tr>
</tbody>
</table>

La quantité d’éléments fertilisants mobilisables pour le recyclage en agriculture est considérable, et fortement dépendante du mode de gestion des effluents. Certaines régions, où l’élevage est intensifié, ont été dans l’obligation de mettre en place a posteriori de coûteux programmes de protection des eaux de surface ou souterraines, compte tenu de la dégradation de la qualité. Dans d’autres contextes, des solutions préventives ont pu être prises. Pour l’ensemble des régions d’élevage, le code de bonnes pratiques agricoles offre la solution d’une meilleure gestion agronomique des effluents recyclés, en adaptant les épandages aux stricts besoins des cultures.

**5. Les effluents des agro-industries**

Premier secteur de l’économie par le chiffre d’affaires, les agro-industries produisent annuellement un tonnage de déchets, sous-produits ou co-produits estimé à 43 Mt\(^8\). Il s’agit de déchets contenant pour moitié de l’eau (20 Mt), des matières minérales (6 Mt) et des matières organiques (17 Mt). L’essentiel du gisement est réutilisé en agriculture, soit en alimentation animale (28 Mt), soit en usages agronomiques (4 Mt).

Cependant les déchets de ces industries ne font pas tous l’objet de statistiques fiables. De même, leurs teneurs en éléments fertilisants ne sont pas connues avec certitude, car ils peuvent être recyclés par d’autres secteurs d’activité (fabrication d’amendements organiques par exemple) ou car leur production est aléatoire, comme les retraits économiques du marché des fruits et légumes.

**6. Conclusion**

Les nombreuses études disponibles à ce jour montrent que le recyclage, par l’agriculture, des éléments nutritifs et de la matière organique contenus dans les déchets ou les sous-produits de diverses origines, constitue une solution de bon sens, et une source d’économie pour l’agriculteur. Cette solution est aujourd’hui souvent étudiée, en particulier lors de l’établissement des plans départementaux et régionaux d’élimination des déchets. Mais l’intensification croissante de l’agriculture, les mesures de la nouvelle Politique Agricole Commune, le renforcement de la législation sur les rejets des installations classées, sont autant de menaces qui pèsent sur la filière. A l’aube du XXI ème siècle il s’agit pourtant là d’un défi majeur que le monde doit relever, dans le respect de la qualité des produits agricoles et de l’environnement.
DEVELOPING SULPHUR FERTILIZERS IN EUROPE

by

P.M. Sweeney
Kemira Agro Ltd, United Kingdom
DEVELOPING SULPHUR FERTILIZERS IN EUROPE\textsuperscript{1}

by

P.M. Sweeney

Kemira Agro UK Ltd, United Kingdom

INTRODUCTION

In Europe, industrial emissions of sulphur from combustion of fossil fuels have fallen since their peak of over 20 million tonnes S in the 1970’s and the level returning to earth has also fallen over the same period. As emissions continue to fall through the continued decline in heavy industry and compliance with targets set for power plant in the Large Combustion Plant Directive, the proportion of agricultural land which receives adequate sulphur for optimal growth will also fall.

These changes are already increasing the demand for fertilisers containing sulphur and the trend will become more marked over the coming decade. The challenge to fertiliser producers is to supply agronomically effective sulphur, adapting its products and technology to cater for the anticipated demand.

BACKGROUND

In 1970, sulphur deposition, i.e. sulphur returning to earth both in rainfall (wet deposition) and via absorption in gaseous form (dry deposition), was greater than the now accepted threshold of 50 kg / ha SO\textsubscript{3} ( 20 kg / ha S) in over 80% of western Europe. Crop deficiencies were almost unheard of despite sulphur long being recognised as a major nutrient. As the level of deposition fell, so came the recognition that an increasing proportion of crops were now at risk of sulphur deficiency and research commenced.

Sulphur is principally required for the synthesis of plant proteins and is a constituent of certain amino acids. A shortage of the nutrient exhibits itself as pale growth not dissimilar to a shortage of nitrogen. Indeed, farmers observing sulphur deficiency often attribute the symptoms to a shortage of nitrogen fertiliser and make an additional application, usually exacerbating the problem.

FORECAST CONSUMPTION

Detailed forecasts by Kemira in Great Britain suggest that consumption of fertiliser sulphur will rise to in excess of 160 kte SO\textsubscript{3} (64 kte S) by 2005. At anticipated product types and concentration, this will be equivalent to over 1100 kte finished fertiliser product containing sulphur. 60% of sulphur nutrient is forecast to be contained in nitrogen and sulphur products which will account for 40% of product volume. By contrast, compound fertilisers containing all or a combination of N, P and K, in addition to sulphur will account for 60% of the volume containing 40% of the nutrient.

This points to a five-fold growth in the requirement for sulphur fertilisers over present levels, a growth which will require substantial development of manufacturing technology together with agronomic research, field development and marketing.

\textsuperscript{1} Paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997
Initial forecasts by Kemira among EU member states suggest that the growth trend within GB will generally be matched elsewhere. Total nutrient sulphur is forecast to grow to approximately 1 million tonnes $\text{SO}_3$ (400 kte S) by 2006, a figure broadly in line with that of The Sulphur Institute in Washington, USA, which estimates a figure for western Europe of 1.25 million tonnes $\text{SO}_3$ (500kte S) by 2010.

These forecasts clearly follow the weighting of crop areas, such that France and Germany are expected to dominate the demand for sulphur, followed by GB and with time the more southerly states of Spain and Italy.

The perspective of these levels of growth is focused by the overall market volumes. In Britain, 1.1 million tonnes sulphur fertilisers are likely to represent a little less than 25% of all fertilisers. In Denmark the change has been much more rapid. As market leader, Kemira has responded to a particularly strong demand for sulphur and has included the nutrient in all it’s products, so that around two thirds of all fertilisers sold in Denmark now contain sulphur. Likewise in Finland, Kemira’s home market, sulphur is featured in the majority of products.

In Europe as a whole, 5 - 7 million tonnes total S-containing product will represent between 20% and 25% of total product. But however they are viewed, sulphur fertilisers, although a tremendous growth area, are likely to represent a minority of the overall market. Likewise, excellent though the economic returns are from using sulphur fertilisers, it cannot be expected within Europe as a whole that farmers will universally adopt sulphur fertilisers, nor use them where there is no agronomic justification.

**ECONOMICS AND PRODUCTS**

In developing its sulphur fertilisers, Kemira has been very aware of the needs to demonstrate the clear economic position to farmer customers. At the same time there is a need to establish a commercial value for sulphur in products. Inclusion of an additional raw material necessarily entails costs which should be reflected in the product value.

In NPK fertilisers, including sulphur often involves a re-formulation of nutrient analysis, such that the additional cost of sulphur is not immediately obvious. Although this may be initially appealing in marketing terms, it does not particularly help in addressing the issue of establishing cost-benefit analysis that any commercially-aware farmer and adviser will naturally look for. Conversely, with straight nitrogen fertilisers, addition of sulphur will immediately alter the relative nutrient values, particularly when there is a tangible difference in price.

In aiming to establish a commercially recognised value for sulphur, development of straight nitrogen fertilisers containing sulphur have clear appeal. Not only do they address a clear need for products of this type with associated farmer-benefits of flexibility and fitting with existing practice, Kemira DoubleTop® (marketed in GB) allowed the Company to lead the market by establishing a realistic and tangible value for sulphur, in line with both raw material costs and the level of economic response a farmer could achieve.

**ELEMENTAL OR SULPHATE?**

The argument over the most suitable form of sulphur fertiliser is likely to continue for a long while. The argument broadly falls into the primary consideration of whether elemental or the oxidised form of the nutrient is most suitable in agronomic terms.
To date, Kemira has adopted sulphate as its route to providing sulphur. This has largely been driven by the consideration that crop plants require sulphur in the sulphate form for root uptake. Immediate availability is considered to be the most critical factor affecting crop response and therefore sulphate was considered the only option. To date, all Kemira sulphur-containing products have been based on inclusion of either ammonium sulphate or the anhydrite salt of calcium sulphate.

Research by both Kemira and independent organisations has clearly demonstrated that sulphate-based fertiliser materials are effective in treating sulphur deficiency and give consistent and reliable responses. Further, comparisons between soluble and insoluble sulphate salts in ammonium sulphate and gypsum demonstrate that both are equally effective in rectifying deficiency.

Elemental sulphur does, however, offer a real potential to compete effectively with sulphate products provided certain problems can be overcome, principally technical and economic. At current retail terms, sulphur in Kemira’s and competitors’ products equates to around $320 / tonne S compared to a figure around $1000 / tonne S in elemental. Compared to fob. prices for molten sulphur below $50 / tonne, consideration of fundamental costs would suggest that elemental products ought to be much closer to sulphate-based products. In addition, detailed consideration should also be given to the essential agronomic factors which govern the crop’s responsiveness to the nutrient and the farmer’s margin opportunity.

**PRODUCT REQUIREMENTS**

Within Europe, fertiliser products, rates and timings vary quite widely depending on particular requirements usually dictated by agronomic considerations or historical factors as to how the fertiliser industry has evolved. The two main types of fertiliser are straight nitrogen, mostly CAN and Ammonium Nitrate, but also Urea, and NPK’s. In the UK and France, Ammonium Nitrate is the predominant nitrogen fertiliser whilst most other countries use CAN.

Europe is perhaps unique in that the majority of phosphorus and potassium is applied in combination with nitrogen as complex NPK’s as opposed to straights or bulk blends. Given this difference, it is clear that many of these NPK products will, in future, include sulphur.

Sulphur fertilisers are needed which are both effective and, vitally, integrate well with conventional fertilisers so as to minimise the inconvenience and additional application cost associated with their use. As fertiliser products and techniques vary widely across Europe, so it is not always easy to develop products which meet all the criteria, even before consideration of manufacturing technology and safety.

For the practical farmer adopting sulphur fertilisers, convenience is a major consideration. Apart from ease-of-use there is also the consideration that an additional application could well cost more than the nutrients applied! For example, the cost of the sulphur in some commercial products, over the other nutrients may be less that £ 2 / ha, against an application cost of £ 4 - £5 / ha.

Thus, formulation not only has to deliver sulphur at a suitable range of rates, but also must complement the other nutrients required. These complications are further compounded by different fertiliser types and crops. For example, oilseed rape and winter wheat will require broadly similar levels of nitrogen, usually supplied as straight N, whereas oilseed rape will require twice the level of sulphur compared to winter wheat.

**AGRONOMIC CONSIDERATIONS**

Product formulations must take into account both local constraints of agronomy and normal fertiliser techniques as well as more exacting technical requirements. It is also clear that many soils
are undergoing a transition from adequate sulphur to deficiency. In the days of excess sulphur availability, it is likely that a certain level of mineral accumulation occurred, particularly on soils with higher base exchange capacity. Therefore, many soils will move into a vulnerable status only slowly and some not at all.

Such facts mean that it is not only difficult to define the extent of sulphur requirement but also that the optimum rate is a moving target. Add to this leaching effects and year to year carryover and it becomes easier to explain why crop effects are sometimes only transitory and not always consistent between seasons.

Continued research will help define both the extent of the problem and the remedy; it is vital that product innovations link closely with research to ensure the best practical and commercial solutions. Testing alternative formulations, application timing, rate and residual effects will lead to a constant refinement of the process. Delivering the best performing products to the farmer will give the key to commercial success.

KEMIRA’S APPROACH

Preparing for such significant changes that could easily mean over one third of Kemira’s fertiliser granulation capacity will need to include sulphur requires detailed planning and integration of all functions. Kemira is committed to a process of evaluating customer requirements in developing new products and modifying its plant and technology.

There is no merit or justification in selling sulphur fertilisers to those farmers who do not need them. Thus, considerable effort is being applied to offering farmers analytical services to assess their need, as well as researching risk-assessment techniques for the future.

A continuously changing scenario means that products will need to be adapted as greater understanding develops. Specifically, Kemira is now assessing sulphur requirements in its key markets, appropriate to local requirements.

For example, Kemira Denmark demonstrates how the close combination of independent research and the State farm advisory service have led to the opportunity to apply sulphur almost universally with inclusion in all Kemira products.

In GB a policy of developing a major branded fertiliser product for each of the five crop sectors which will account for 90% of demand has been adopted. This has seen the introduction and establishment of a small range of targeted products offering the farmer products specific to his requirement and at the same time offering the choice of sulphur-free alternatives. Likewise, in Germany, France and the Low Countries, similar development is taking place in readiness for the sustained growth in sulphur demand that is now evident.

CONCLUSIONS

Sulphur as a nutrient has come of age. Long used as an intermediate in phosphate production, sulphur is now a major fertiliser nutrient in its own right.

As the environmental controls really bite and emissions dwindle, demand for sulphur will grow dramatically over the next decade or more.

In Europe, annual reductions in emissions will see a fall of between 15 and 20 million tonnes sulphur (S) to be replaced by 400 to 500 thousand tonnes sulphur (S) in fertilisers. In Britain, annual
sulphur emissions will fall by almost 90% or over 3 million tonnes (as S), to be replaced agriculturally by a little over 50 thousand tonnes (as S) in fertiliser.

Thus, less than 3% of previously emitted polluting sulphur will be used to address the specific crop requirements in fertilisers. The fertiliser industry needs to prepare carefully how to achieve the best balance of product development, technology and customer satisfaction in meeting this need.

Kemira is working hard to satisfy these requirements and provide it’s customers with the best products and to help them derive maximum benefit from their use.
Paul Sweeney - Career History

Graduating from University of Wales in 1985, Paul Sweeney joined the State advisory service of the UK Ministry of Agriculture working as farm adviser and agronomist.

In 1989 he joined Kemira and has held positions as agronomist and product manager. He is currently responsible for new product development and field research within the UK and Ireland.

Sulphur has long been a study area for Paul Sweeney and he is well known both within Kemira and internationally for his work on developing sulphur fertilisers, market forecasting and in developing Kemira’s Sulphur Strategy.

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IFA AGRO-ECONOMICS COMMITTEE CONFERENCE
23-25 June 1997
VINCI - Centre International de Congrès, Tours, France

AMISORB NUTRIENT ABSORPTION ENHANCER IN CROP PRODUCTION
by
J.L. Sanders and L.S. Murphy
Amilar International, Inc., USA
AMISORB NUTRIENT ABSORPTION ENHANCER IN CROP PRODUCTION

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J.L. Sanders and L.S. Murphy
Amilar International, Inc., USA

INTRODUCTION

Amisorb nutrient absorption enhancer is an approximately 5,000 molecular weight polymer of aspartic acid. Chemical name: CARPRAMID.

ANIONIC POLYMER

AmiSorb (polyaspartate) is a synthetic thermal protein produced from the amino acid, aspartic acid. Characteristics of the polymer include its high cation exchange capacity arising from negative charges associated with the carboxyl groups of the amino acid molecules. The cation exchange capacity is approximately 300 milliequivalents/100 grams of the 40 percent active ingredient liquid formulation. The cation exchange capacity is much higher than most soils which range from 2-6 milliequivalents/100 grams for sand; 11-15 milliequivalents/100 grams for silt loams; 22-35 milliequivalents/100 grams for clays; 100+ milliequivalents/100 grams for organic soils.

This biodegradable polymer has been demonstrated by university research to affect growth and production of a number of crop plant species. Under controlled conditions, microscopic examination of enhanced root growth reveals greatly increased root branching and root hair development. Controlled condition studies indicate that C-14 labeled polymer is not taken up by the plant and acts externally of the root system. Plant analyses described in patents covering the product show enhanced nutrient absorption. Effects on plant root and shoot development are considered to be the result of improved nutrient uptake.

MODE OF ACTION

In liquid fertilizers or in the proximity of dissolving solid fertilizers in the soil, the polymer rapidly adsorbs cations...including the positively charged ions required for plant nutrition: potassium, K⁺, ammonium, NH₄⁺; calcium, Ca²⁺; magnesium, Mg²⁺; zinc, Zn²⁺; manganese, Mn²⁺; copper, Cu²⁺; and iron, Fe²⁺. The polymer may also hold other metals.

Anions such as phosphate (H₂PO₄⁻ and HPO₄²⁻) nitrate (NO₃⁻), chloride (Cl⁻) and sulfate (SO₄²⁻) may also be attracted to the polymer through an ionic double layer. In this situation, the negatively charged anions share some positive charges of cations such as calcium and magnesium with the polymer.

Concentrating nutrient cations and anions along the polymer creates points of high nutrient concentration when roots come into contact with the polymer molecule. That point on the root surface is also affected by the large amount of water associated with the polymer molecules. The combination of high nutrient concentrations and water enhances the movement of nutrients into the plant roots at that point. The influence of AmiSorb on increased nutrient uptake has been demonstrated in earlier work (Below, 1995).

Increased uptake of monovalent cations such as potassium and ammonium provides a positive influence on uptake of phosphate. The effects of ammonium and potassium on phosphate uptake have been understood for decades. When positively charged ions move into the root, electrical

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1 Paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997
neutrality is maintained by the roots releasing positive charges in the form of hydrogen ions. That means that the pH near the root surface tends to decline. Also, anions such as phosphate, nitrate, chloride and sulfate are taken up along with the cations as another means of maintaining electrical neutrality.

**DEGRADATION**

Since AmiSorb is an organic polymer it is subject to decomposition by soil microorganisms. Many factors can affect the rate of decomposition such as: aeration, temperature, soil moisture and carbon: nitrogen ratio. Normally AmiSorb persists through the growing season at some level but it does not carry over from the previous cropping season. Split applications with some crops, therefore, may be more advantageous due to the nature of the polymer.

**RESPONSE OF COTTON**

Field trials across the Cotton Belt in the southern United States have produced consistent yield increases. These trials have shown overall best responses when AmiSorb was banded at planting followed by additional applications at sidedressing or through irrigation with fertilizer.

Increased nutrient uptake has not only led to higher yields but also better lint quality and earlier maturity. Overall, the effects on the farmers’ return on investment (ROI) is better than 3:1.

- **Louisiana**

Replicated cotton trials in Louisiana yielded an increase in plant nutrient uptake and cotton lint yields. Table 1 shows that AmiSorb (2 qt/A) had a positive effect on N, P, K, Ca, Mg and S during early season growth. AmiSorb with starter fertilizer had a significant effect on seed and lint cotton yields. Lint yields were increased 35 percent with AmiSorb (Table 2).

<table>
<thead>
<tr>
<th>Dry Weight g/6 plants</th>
<th>N mg/6 plants</th>
<th>P</th>
<th>K mg/6 plants</th>
<th>Ca</th>
<th>Mg</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starter fertilizer below seed</td>
<td>29.7</td>
<td>1366</td>
<td>128</td>
<td>832</td>
<td>921</td>
<td>181</td>
</tr>
<tr>
<td>Starter fertilizer plus AmiSorb</td>
<td>47.3</td>
<td>2176</td>
<td>203</td>
<td>1324</td>
<td>1466</td>
<td>279</td>
</tr>
</tbody>
</table>

Plants sampled June 18, whole plants. Uptake = mg/6 plants. Cooperator: Craig Oliphant, Bonita Gin Co., Bonita, LA.
### Table 2: Effects of AmiSorb on Cotton Yields - Louisiana

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Seed cotton lb/A</th>
<th>% lint</th>
<th>Lint yield lb/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starter fertilizer only, banded below seed</td>
<td>2115</td>
<td>36.8</td>
<td>780</td>
</tr>
<tr>
<td>Starter fertilizer + 2 qt/A AmiSorb in starter</td>
<td>2796</td>
<td>36.9</td>
<td>1056</td>
</tr>
<tr>
<td>LSD&lt;sub&gt;.05&lt;/sub&gt;</td>
<td>343</td>
<td>--</td>
<td>141</td>
</tr>
</tbody>
</table>

Data calculated by University of Arkansas staff, Monticello. Cooperator: Craig Oliphant, Bonita Gin Co., Bonita, LA.

#### Mississippi

Data from Mississippi also showed dramatic increases in cotton lint yield with use of AmiSorb. At the Lexington location, yields were significantly increased at the 1 qt/A rate (Table 3). Increasing AmiSorb rates up to 2 qts/A resulted in improved micronaire and length. Increasing rates up to 3 qts/A continued to increase cotton fiber strength.

### Table 3: AmiSorb Effects on Cotton Yield and Lint Quality - Mississippi

<table>
<thead>
<tr>
<th>AmiSorb treatment</th>
<th>Yield lb/A</th>
<th>Micronarie (cents)</th>
<th>Length (inches)</th>
<th>Strength (grams/tex)</th>
<th>Lint value $/lb</th>
<th>Lint value $/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 qt/A</td>
<td>1582</td>
<td>5.02 (-2.9)</td>
<td>1.115 (+.55)</td>
<td>27 (0)</td>
<td>.7465</td>
<td>$1,180.96</td>
</tr>
<tr>
<td>2 qt/A</td>
<td>1244</td>
<td>4.83 (0)</td>
<td>1.1325 (+.60)</td>
<td>28 (0)</td>
<td>.7760</td>
<td>$965.34</td>
</tr>
<tr>
<td>3 qt/A</td>
<td>1320</td>
<td>4.73 (0)</td>
<td>1.1475 (+.60)</td>
<td>29 (0)</td>
<td>.7760</td>
<td>$1,024.32</td>
</tr>
<tr>
<td>4 qt/A</td>
<td>1378</td>
<td>4.85 (0)</td>
<td>1.1375 (+.60)</td>
<td>29 (0)</td>
<td>.7760</td>
<td>$1,059.33</td>
</tr>
<tr>
<td>6 qt/A</td>
<td>1278</td>
<td>4.65 (0)</td>
<td>1.145 (+.60)</td>
<td>29 (0)</td>
<td>.7760</td>
<td>$991.73</td>
</tr>
<tr>
<td>8 qt/A</td>
<td>1318</td>
<td>4.725 (0)</td>
<td>1.1625 (+.60)</td>
<td>29 (0)</td>
<td>.7760</td>
<td>$1,022.77</td>
</tr>
<tr>
<td>Untreated Check</td>
<td>1240</td>
<td>5.05 (-2.90)</td>
<td>1.13 (+.60)</td>
<td>27 (0)</td>
<td>.747</td>
<td>$926.28</td>
</tr>
</tbody>
</table>

Avg. of all treatments $ value/acre = $1,042.41
Untreated value/acre = 926.28
Avg. AmiSorb Advantage $/acre = $116.13
ROI (assume $15/2 qt.): = 7.73 to 1
Assumed base value of lint = $ .77/lb.
Quality Analysis: Texas Tech University
At the Oak Grove location (Table 4), yields of lint and seed cotton were both significantly increased. Lint yields at the Westfield location were also significantly increased by 226 lb/A (Table 5).

Tables 4 and 5 show the effect of AmiSorb on cotton maturity. Approximately 15 percent more cotton bolls were open at each location on September 9 with AmiSorb use. All three locations in Mississippi produced improved ROI with use of AmiSorb. ROI’s ranged from approximately 3 to 8:1.

### Table 4: AmiSorb Effects on Cotton Growth and Yield - Mississippi

<table>
<thead>
<tr>
<th>Treatment</th>
<th>% Open Bolls Sept. 9</th>
<th>Seed Cotton lb/A</th>
<th>Lint Yield lb/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>57.5</td>
<td>3750</td>
<td>1400</td>
</tr>
<tr>
<td>AmiSorb, 8 qt/A</td>
<td>72.3</td>
<td>4250</td>
<td>1630</td>
</tr>
<tr>
<td>Difference</td>
<td>14.8</td>
<td>500</td>
<td>230</td>
</tr>
<tr>
<td>LSD&lt;sub&gt;.05&lt;/sub&gt;</td>
<td>1.2</td>
<td>390</td>
<td>148</td>
</tr>
</tbody>
</table>

Oak Grove Plantation

### Table 5: AmiSorb Effects on Cotton Growth and Yield - Mississippi

<table>
<thead>
<tr>
<th>Treatment</th>
<th>% Open Bolls Sept. 9</th>
<th>Lint Yield lb/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>50.75</td>
<td>561</td>
</tr>
<tr>
<td>AmiSorb, 4 qt/A</td>
<td>68.50</td>
<td>787</td>
</tr>
<tr>
<td>Difference</td>
<td>17.75</td>
<td>220</td>
</tr>
<tr>
<td>LSD&lt;sub&gt;.05&lt;/sub&gt;</td>
<td>20.13</td>
<td>115</td>
</tr>
</tbody>
</table>

Westfield Plantation

### Texas

Six locations in Western Texas cotton growing areas were used in a study with locations serving as replications. All locations were irrigated and included grower standard practices (GSP) with 2 quarts of AmiSorb per acre compared to GSP without AmiSorb. The mean yield increase produced by AmiSorb was 365 pounds of lint cotton per acre (Table 6).

Central Texas studies were conducted with three N rates (30, 90 and 150 lb/A) along with four rates of AmiSorb (0, 2, 4 and 8 qt/A). Pix plant growth regulator was not applied to the plots during the growing season to control excessive vegetative growth of cotton. Rank growth was a problem (over 6 feet) and expression of yields was limited. No enhancement of yields was recorded at the 30 or 150 lb nitrogen rates but there was a trend toward increased yields with AmiSorb at the 90 lb/A N rate. At that nitrogen rate lint yields were increased from 635 lb/A to 690 lb/A with 8 quarts/A of AmiSorb (Table 7).
Table 6: AmiSorb Effects on Cotton Lint Yields - Texas

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Location</th>
<th>Location</th>
<th>Location</th>
<th>Location</th>
<th>Location</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0</td>
<td>901</td>
<td>1474</td>
<td>663</td>
<td>1308</td>
<td>457</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>793</td>
<td>927</td>
<td>782</td>
<td>1557</td>
<td>407</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>711</td>
<td>1025</td>
<td>841</td>
<td>1264</td>
<td>663</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>795</td>
<td>1172</td>
<td>881</td>
<td>1407</td>
<td>495</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>868</td>
<td>1258</td>
<td>822</td>
<td>1183</td>
<td>517</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>813</td>
<td>1386</td>
<td>841</td>
<td>1073</td>
<td>617</td>
</tr>
<tr>
<td>Mean</td>
<td>814</td>
<td>1207</td>
<td>805</td>
<td>1299</td>
<td>543</td>
<td>555</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>AmiSorb</th>
<th>Location</th>
<th>Location</th>
<th>Location</th>
<th>Location</th>
<th>Location</th>
<th>Location</th>
<th>Location</th>
<th>Location</th>
<th>Location</th>
<th>Location</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 qt/A</td>
<td>0</td>
<td>1302</td>
<td>1551</td>
<td>833</td>
<td>1570</td>
<td>1112</td>
<td>841</td>
<td>0</td>
<td>1286</td>
<td>1850</td>
<td>709</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1311</td>
<td>1577</td>
<td>810</td>
<td>1368</td>
<td>1007</td>
<td>941</td>
<td>2</td>
<td>1443</td>
<td>2070</td>
<td>938</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1458</td>
<td>1562</td>
<td>769</td>
<td>1874</td>
<td>1376</td>
<td>525</td>
<td>2</td>
<td>1396</td>
<td>1333</td>
<td>817</td>
</tr>
<tr>
<td>Mean</td>
<td>1366</td>
<td>1657</td>
<td>813</td>
<td>1596</td>
<td>1229</td>
<td>783</td>
<td>1241</td>
<td>365</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LSD<sub>.05</sub> for treatment means across locations

This study did not produce an economic response to AmiSorb. It should be noted that AmiSorb is a nutrient absorption enhancer which promotes growth, boll set and yields. Thus, AmiSorb should be used in conjunction with best management practices, including the use of Pix for management of late season vegetative growth.

Table 7: Cotton Response to AmiSorb in Central Texas

<table>
<thead>
<tr>
<th>AmiSorb Rate (qt/A)</th>
<th>Lint Yield (lb/A)</th>
<th>Difference (lb/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>635</td>
<td>--</td>
</tr>
<tr>
<td>2</td>
<td>640</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>640</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>690</td>
<td>55</td>
</tr>
</tbody>
</table>

Nitrogen Rate - 90 lb/A. Cothren

The effects of AmiSorb on cotton quality are shown in Table 8. The micronaire, length and strength of cotton fiber were positively influenced in 4 of 5 locations, respectively. AmiSorb (at 2 qts/A) increased the average yield of cotton significantly. Gross returns per acre were further increased by lint quality effects for an average ROI of 21:1.
Table 8: AmiSorb Effect on Texas Cotton Quality Lint

<table>
<thead>
<tr>
<th>Location</th>
<th>AmiSorb Treatment</th>
<th>Micronaire c/lb</th>
<th>Length c/lb</th>
<th>Strength c/lb</th>
<th>Value of Quality @ 77c/lb Base $/A</th>
<th>ROI</th>
<th>Gross Returns $A</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0</td>
<td>5.3</td>
<td>-4.7</td>
<td>1.02</td>
<td>-3.15</td>
<td>31.8</td>
<td>+0.25</td>
</tr>
<tr>
<td>5</td>
<td>2 qt.</td>
<td>5.0</td>
<td>-2.9</td>
<td>1.07</td>
<td>0</td>
<td>30.7</td>
<td>+0.25</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>5.0</td>
<td>-2.9</td>
<td>1.11</td>
<td>0</td>
<td>30.8</td>
<td>+0.25</td>
</tr>
<tr>
<td>6</td>
<td>2 qt.</td>
<td>3.7</td>
<td>+1</td>
<td>1.14</td>
<td>0.05</td>
<td>31.7</td>
<td>+0.25</td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>3.9</td>
<td>+1</td>
<td>1.08</td>
<td>0</td>
<td>30.3</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>2 qt.</td>
<td>3.9</td>
<td>+1</td>
<td>1.07</td>
<td>0</td>
<td>31.0</td>
<td>0</td>
</tr>
<tr>
<td>33</td>
<td>0</td>
<td>4.2</td>
<td>+1</td>
<td>1.11</td>
<td>0.55</td>
<td>30.5</td>
<td>+0.25</td>
</tr>
<tr>
<td>33</td>
<td>2 qt.</td>
<td>4.6</td>
<td>0</td>
<td>1.08</td>
<td>0</td>
<td>32.5</td>
<td>+0.25</td>
</tr>
<tr>
<td>34</td>
<td>0</td>
<td>5.5</td>
<td>-4.7</td>
<td>1.05</td>
<td>0</td>
<td>30.2</td>
<td>0</td>
</tr>
<tr>
<td>34</td>
<td>2 qt.</td>
<td>5.3</td>
<td>-4.7</td>
<td>1.05</td>
<td>0</td>
<td>31.7</td>
<td>+0.25</td>
</tr>
</tbody>
</table>

Mean

<table>
<thead>
<tr>
<th>RSS</th>
<th>2 qt.</th>
<th>581.31</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROI</td>
<td></td>
<td>892.03</td>
</tr>
<tr>
<td>Diff</td>
<td>+310.72</td>
<td>21 to 1</td>
</tr>
</tbody>
</table>

Quality data provided by Texas Tech University. Yield data provided in Table 6.

- Arkansas

Arkansas cotton trials at Marianna produced a positive response to starter AmiSorb. Only one quart of AmiSorb per acre was applied resulting in smaller yield increases compared to other trials (Table 9).

Table 9: Effects of AmiSorb on Cotton Yields - Arkansas

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Lint Yield (lb/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1104</td>
</tr>
<tr>
<td>1 qt AmiSorb</td>
<td>1140</td>
</tr>
</tbody>
</table>

Baker

The value of increased cotton lint yield from 1 qt/A of AmiSorb ($7.50/A) was $27.00 per acre. This was equivalent to an ROI of 3.6:1.

Another cotton study in Southeast Arkansas involved 40 and 115 lb/A N rates split into two applications. The lower N rate produced a 48 lint yield increase while the higher N rate produced 39 lb/A more lint (Table 10). This project did not use a growth regulator and cotton height exceeded 5 feet. Since AmiSorb is a nutrient absorption enhancer, Pix or another growth regulator should be included as a best management practice to control excessive growth. Despite the excessive vegetative growth, these plots had an ROI of 2:1.
Table 10: Nitrogen-AmiSorb Effects on Cotton Lint Yields - Arkansas

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pre-Plant N lb N/A</th>
<th>Side Dress N lb N/A</th>
<th>AmiSorb qt/A</th>
<th>Lint Yield lb/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>0</td>
<td>0</td>
<td>915</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>40</td>
<td>0</td>
<td>921</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
<td>65</td>
<td>0</td>
<td>903</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>40</td>
<td>2.0</td>
<td>969</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>65</td>
<td>2.0</td>
<td>942</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

RESPONSE OF CORN

- Illinois

A placement study at Urbana, IL provided strong evidence of corn response to AmiSorb. AmiSorb banded between the rows at 2 qt/A was more effective than comparable treatments banded over the row. Comparison of three corn hybrids indicated significant differences in response to the AmiSorb polymer. Hybrid responses ranged from 7 to 27 bu/A emphasizing the genetic differences in corn hybrid responses to plant nutrition which have been established in other studies (Table 11).

Table 11: Placement and Corn Hybrid Effects on Corn Response to AmiSorb - Illinois

<table>
<thead>
<tr>
<th>Method of AmiSorb Application 2 qt/A</th>
<th>Asgrow RX623</th>
<th>Asgrow RX699</th>
<th>Asgrow RX770</th>
<th>Mean 3 Hybrids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>135</td>
<td>140</td>
<td>128</td>
<td>134</td>
</tr>
<tr>
<td>Banded over row</td>
<td>141</td>
<td>142</td>
<td>140</td>
<td>141</td>
</tr>
<tr>
<td>Banded between rows not incorporated</td>
<td>150</td>
<td>147</td>
<td>150</td>
<td>149</td>
</tr>
<tr>
<td>Banded between rows incorporated</td>
<td>149</td>
<td>146</td>
<td>155</td>
<td>150</td>
</tr>
<tr>
<td>LSD 0.05</td>
<td>9.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

All plots received 150 lb N/A as ammonium nitrate.

- Kansas

An irrigated, ridge-tilled corn study was initiated to evaluate application of AmiSorb at 1 and 2 qt/A in starter fertilizer containing a high N: P₂O₅ ratio. The study recorded excellent responses to starter fertilizer on the high P soil of this site (Table 12). One quart of AmiSorb in the starter fertilizer placed 2 inches to the side and 2 inches below the seed at planting produced no yield increase. However, a highly significant (5 percent level) response of 13 bu/A was achieved over starter alone by the application of 2 qt/A of AmiSorb with the starter fertilizer. Plant dry matter at the 6-leaf stage was also significantly affected by AmiSorb application as was uptake of N and P.
Table 12: AmiSorb Effects on Irrigated Ridge-Tilled Corn - Kansas

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield</th>
<th>Whole Plant Dry Weight</th>
<th>N Uptake</th>
<th>P Uptake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bu/A</td>
<td>lb/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No starter</td>
<td>191</td>
<td>229</td>
<td>5.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Starter</td>
<td>213</td>
<td>366</td>
<td>10.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Starter + 1 qt. AmiSorb/A</td>
<td>213</td>
<td>358</td>
<td>10.0</td>
<td>1.3</td>
</tr>
<tr>
<td>Starter + 2 qt. AmiSorb/A</td>
<td>226</td>
<td>388</td>
<td>10.6</td>
<td>1.6</td>
</tr>
<tr>
<td>LSD (0.05)</td>
<td>12</td>
<td>21</td>
<td>0.5</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Starter: 30 lb N, 30 lb P₂O₅/A.
Constant N rate on all plots.

Maryland

AmiSorb was studied as a component of a starter fertilizer investigation with corn. AmiSorb at 1 and 2 qt/A was mixed with liquid starter fertilizer containing N, P and K and placed 2 inches to the side and 2 inches below the seed row at planting. AmiSorb inclusion in the starter produced significant yield increases (Table 13). The 1 qt/A AmiSorb rate with liquid fertilizer produced a yield increase of just over 12 bu/A, significant at the 5 percent level. The 2 qt/A rate also produced a yield increase of just under 6 bu/A. A second study (Table 14) evaluated AmiSorb in a N sidedress application. Nitrogen was applied at a rate of 120 lb N/A when corn was at the 4-6 leaf stage. All plots received a solid P-K starter application at planting. Inclusion of AmiSorb in urea-ammonium nitrate (UAN) solution at 2 qt/A broadcast with UAN produced a yield increase of approximately 5 bu/A significant at the 5 percent level.

Table 13: Corn Responses to AmiSorb in Starter Fertilizer - Maryland

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grain yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bu/A</td>
</tr>
<tr>
<td>Control, starter only</td>
<td>127.6</td>
</tr>
<tr>
<td>Starter, + 1 qt/A AmiSorb</td>
<td>140.0</td>
</tr>
<tr>
<td>Starter + 2 qt/A AmiSorb</td>
<td>133.5</td>
</tr>
<tr>
<td>LSD₀.₀₅</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Starter: 9-20-3-3 liquid, 2 x 2 placement.

Table 14: Corn Responses to AmiSorb in Sidedressed Nitrogen - Maryland

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grain yield</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bu/A</td>
</tr>
<tr>
<td>Control, P and K only</td>
<td>61.4</td>
</tr>
<tr>
<td>N Solution</td>
<td>145.9</td>
</tr>
<tr>
<td>N Solution + 2 qt/A</td>
<td>151.1</td>
</tr>
<tr>
<td>LSD₀.₀₅</td>
<td>4.1</td>
</tr>
</tbody>
</table>

120 lb N/A.

Gordon

Mulford
• Texas

This project involved a multi-location evaluation of AmiSorb on irrigated corn in northwest Texas and eastern New Mexico. Each of the field locations received AmiSorb in starter fertilizer placed to the side and below the row at planting. Individual site harvests were comprised of 6 individual plot harvests in each treated and untreated area of those individual plots and were used to compute treatment means for sites. Yield increases from 2 qt/A of AmiSorb applied with starter fertilizer were excellent ranging from 29 to 60 bu/A (Table 15). Analysis of variance showed a highly significant response to AmiSorb application with fertilizer.

Table 15: AmiSorb Effects on Irrigated Corn - Texas and New Mexico

<table>
<thead>
<tr>
<th>Location</th>
<th>Grain yield, 15.5% H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No AmiSorb</td>
</tr>
<tr>
<td></td>
<td>bu/A</td>
</tr>
<tr>
<td>TX 23</td>
<td>218</td>
</tr>
<tr>
<td>TX 24</td>
<td>196</td>
</tr>
<tr>
<td>TX 25</td>
<td>232</td>
</tr>
<tr>
<td>TX 27</td>
<td>200</td>
</tr>
<tr>
<td>NM 1</td>
<td>171</td>
</tr>
<tr>
<td>NM 2</td>
<td>192</td>
</tr>
<tr>
<td>NM 3</td>
<td>166</td>
</tr>
<tr>
<td>Mean</td>
<td>196</td>
</tr>
<tr>
<td>LSD₀.₀₅ for means</td>
<td>28</td>
</tr>
</tbody>
</table>

All locations received AmiSorb in starter fertilizer banded beside the row at planting.

RESPONSE OF GRAIN SORGHUM

• Kansas

This study was established on a Parsons silt loam soil at the Southeast Kansas Agricultural Research Center. No-till grain sorghum received AmiSorb at 2 qt/A applied with starter fertilizer, with sidedressed N and with both starter and sidedressed N. All plots received a starter fertilizer banded beside the row. AmiSorb applied with the starter resulted in a 9 bu/A increase yield in grain sorghum (Table 16). AmiSorb applied in sidedressed N was not as effective. Starter plus sidedressed N applications received a double rate of AmiSorb which resulted in smaller yield increases. AmiSorb with the starter resulted in 12 percent more kernels/head than with starter alone. Nitrogen uptake at the soft dough stage was significantly greater with AmiSorb applied with starter fertilizer which appeared to coincide with the greater number of heads/kernel and greater yield. Greater N content in the plant may have reduced seed abortion in the head, increasing yield. Phosphorus and potassium uptake were unaffected by AmiSorb.
Table 16: Effects of AmiSorb Placement on Yield and Yield Components of Grain Sorghum - Kansas

<table>
<thead>
<tr>
<th>AmiSorb Placement</th>
<th>Yield</th>
<th>Kernel Weight</th>
<th>Kernels/head</th>
<th>Heads/A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bu/A</td>
<td>g/1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control, no AmiSorb</td>
<td>65.6</td>
<td>24.5</td>
<td>1240</td>
<td>51100</td>
</tr>
<tr>
<td>Starter + 2 qt AmiSorb/A</td>
<td>74.5</td>
<td>26.3</td>
<td>1390</td>
<td>51800</td>
</tr>
<tr>
<td>Sidedress N + 2 qt AmiSorb/A</td>
<td>69.7</td>
<td>26.2</td>
<td>1320</td>
<td>51400</td>
</tr>
<tr>
<td>Starter + 2 qt AmiSorb/A</td>
<td>67.3</td>
<td>26.3</td>
<td>1310</td>
<td>49400</td>
</tr>
<tr>
<td>Sidedress N + 2 qt AmiSorb/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSD</td>
<td>5.4</td>
<td>NS</td>
<td>100</td>
<td>NS</td>
</tr>
</tbody>
</table>

All plots received starter. Mean N rate 100 lb/A, sidedressed, all plots.

RESPONSE OF SOYBEANS

• Missouri

This study of AmiSorb effects on soybeans provided statistically significant yield increases (10 bu/A) to broadcast applications of AmiSorb (Table 17). Starter applications, while promising early in the season, failed to provide as much yield increase as broadcast applications of 2 qt of AmiSorb/A. Controlled condition studies in the greenhouse demonstrated a highly significant and consistent effect of AmiSorb on increasing nodulation in soybeans. That nodulation was confined to the lateral roots and agreed with field data from a comparative study in Wisconsin.

Table 17: Soybean Responses to AmiSorb - Missouri

<table>
<thead>
<tr>
<th></th>
<th>Yield</th>
<th>Vegetative dry wt. R-6</th>
<th>Reproductive dry wt. R-6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>bu/A</td>
<td>g/plant</td>
<td>g/plant</td>
</tr>
<tr>
<td>Control</td>
<td>46</td>
<td>112</td>
<td>125</td>
</tr>
<tr>
<td>AmiSorb, 2 qt/A broadcast preplant</td>
<td>56</td>
<td>145</td>
<td>154</td>
</tr>
</tbody>
</table>

Significant differences from control at the 10 percent level.

RESPONSE OF CANOLA

Greenhouse trials in California were conducted to examine the affects of AmiSorb on canola growth and yield. AmiSorb was applied to the soil at an early growth stage which had a significant effect on number and percent of filled pods.

In Canada, canola field trials were conducted in Manitoba. The check yields were recorded at 2040 lb/A compared to 2 qts of AmiSorb yielding 2339 lb/A. This equates to a 5 bu/A yield increase, approximately 15 percent.
RESPONSE OF FORAGES

AmiSorb applications to forages in combination with fertilizer have produced increases in nutrient uptake and corresponding increases in forage yields. Trials in east Texas utilized AmiSorb at 2 qt/A in a single application with spring application of commercial fertilizer and with broiler litter. Results were affected by drought conditions which existed until late in the season.

Table 18 shows a trend for increasing uptake of N, P and K especially when AmiSorb was used with commercial fertilizer. Yields at two of five harvest were significantly increased by 51 and 26 percent in the first and second harvests using commercial fertilizer. Broiler litter plus AmiSorb showed no additional response probably due to positional unavailability during drought conditions. The value of AmiSorb in forages is positive. Earlier research by Pratt showed that split applications of AmiSorb, however, were more efficacious than a single application.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>May 31</th>
<th>June 26</th>
<th>Aug. 2</th>
<th>Sept. 10</th>
<th>Oct. 25</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>200-50-150 lb/A</td>
<td>1754</td>
<td>521</td>
<td>1859</td>
<td>1144</td>
<td>828</td>
<td>6448</td>
</tr>
<tr>
<td>200-50-150 lb/A + AmiSorb</td>
<td>2647</td>
<td>660</td>
<td>1640</td>
<td>1298</td>
<td>923</td>
<td>7167</td>
</tr>
<tr>
<td>6 tons broiler litter</td>
<td>2770</td>
<td>841</td>
<td>1959</td>
<td>1469</td>
<td>887</td>
<td>7926</td>
</tr>
<tr>
<td>6 tons broiler litter + AmiSorb</td>
<td>2618</td>
<td>739</td>
<td>2044</td>
<td>1545</td>
<td>1120</td>
<td>8066</td>
</tr>
<tr>
<td>LSD.05</td>
<td>457</td>
<td>131</td>
<td>407</td>
<td>275</td>
<td>196</td>
<td>874</td>
</tr>
</tbody>
</table>

RESPONSE OF WHEAT

This continuing series of studies was conducted in the vicinity of Hays, KS. A time of nitrogen application-AmiSorb placement study produced no consistent trend in yields from AmiSorb applications preplant, with the seed or spring topdressed. An 8-location study evaluating AmiSorb rates topdressed in the spring produced significant yield responses at the 5 percent confidence level at 3 of 8 locations. All location yields increased at the 1 qt AmiSorb/A rate and either levelled off or declined at the 3 qt/A rate. This study in combination with other investigations involving topdress AmiSorb applications indicate that this is an effective means of application for winter wheat. This study is being continued in 1996-97 at 10 locations in the Ellis County Kansas area. Treatments include at planting and topdress applications of varying AmiSorb rates (Table 19).
### Table 19: Winter Wheat Responses to Topdressed AmiSorb - Kansas

<table>
<thead>
<tr>
<th>AmiSorb rate</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>qt/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>18</td>
<td>68</td>
<td>48</td>
<td>37</td>
<td>24</td>
<td>26</td>
<td>38</td>
<td>45</td>
<td>38</td>
</tr>
<tr>
<td>1</td>
<td>23</td>
<td>73</td>
<td>50</td>
<td>38</td>
<td>26</td>
<td>29</td>
<td>41</td>
<td>48</td>
<td>41</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>71</td>
<td>49</td>
<td>38</td>
<td>26</td>
<td>27</td>
<td>40</td>
<td>47</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>66</td>
<td>48</td>
<td>37</td>
<td>26</td>
<td>25</td>
<td>39</td>
<td>46</td>
<td>39</td>
</tr>
<tr>
<td>LSD.05</td>
<td>2</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>1</td>
<td>1</td>
<td>NS</td>
<td>NS</td>
<td>1</td>
</tr>
</tbody>
</table>

40-60 lb N/A preplant

**RESPONSE OF TOMATO**

A greenhouse experiment on tomato response to AmiSorb in California indicated that the number of fruit was not influenced by AmiSorb. The fresh weight, however, was increased significantly, approximately 30 percent (Table 20).

### Table 20: Tomato Yields as Affected by AmiSorb Under Greenhouse Conditions - California

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fruit/plant</th>
<th>Fresh weight/fruit grams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>15.2a</td>
<td>61.0b</td>
</tr>
<tr>
<td>AmiSorb</td>
<td>14.5a</td>
<td>82.2a</td>
</tr>
<tr>
<td>P-value</td>
<td>NS</td>
<td>0.03</td>
</tr>
</tbody>
</table>

In California field trials, AmiSorb inclusion into growers standard practices versus a control increased market tomato yields significantly. Yields were increased on average of 3.1 tons/A (Table 21).

### Table 21: Tomato Responses to AmiSorb - California

<table>
<thead>
<tr>
<th>Crop</th>
<th>Treatment</th>
<th>Rep 1</th>
<th>Rep 2</th>
<th>Rep 3</th>
<th>Rep 4</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market tomato</td>
<td>Control</td>
<td>13.0</td>
<td>13.0</td>
<td>11.7</td>
<td>11.7</td>
<td>12.4</td>
</tr>
<tr>
<td></td>
<td>AmiSorb 2 qt/A</td>
<td>17.8</td>
<td>14.4</td>
<td>14.4</td>
<td>15.4</td>
<td>15.5</td>
</tr>
<tr>
<td></td>
<td>LSD.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.21</td>
</tr>
</tbody>
</table>

Purdy
RESPONSE OF SUGAR CANE

Four locations in Louisiana were used to evaluate effects of AmiSorb on sugarcane. At each of the four locations, AmiSorb-treated cane produced more total tons of cane per acre (Table 22). Total sugar production was also increased at each of the four locations.

Table 22: Sugarcane Responses to AmiSorb - Louisiana

<table>
<thead>
<tr>
<th>Location</th>
<th>Variety</th>
<th>Treatment</th>
<th>Cane tons/A</th>
<th>Total Sugar lb/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>321</td>
<td>Control</td>
<td>33.2</td>
<td>6499</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AmiSorb</td>
<td>36.3</td>
<td>7193</td>
</tr>
<tr>
<td>2</td>
<td>321</td>
<td>Control</td>
<td>37.6</td>
<td>8332</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AmiSorb</td>
<td>43.2</td>
<td>9101</td>
</tr>
<tr>
<td>3</td>
<td>383</td>
<td>Control</td>
<td>38.6</td>
<td>7158</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AmiSorb</td>
<td>43.6</td>
<td>7995</td>
</tr>
<tr>
<td>4</td>
<td>383</td>
<td>Control</td>
<td>30.6</td>
<td>5334</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AmiSorb</td>
<td>31.4</td>
<td>5853</td>
</tr>
</tbody>
</table>

AmiSorb: 2 qt/A with fertilizer. Lunsford
N P K S
Fertilization 130 - 40 - 120 - 8/A, knifed in.

RESPONSE OF POTATOES

In Florida, Alantic variety potatoes were used to evaluate AmiSorb response. Two quarts/A of AmiSorb were applied with liquid fertilizer at planting. AmiSorb increased the yield of potatoes 7020 lb/A over the control, a 21 percent increase (Table 23).

Table 23: Response of Alantic Potatoes to AmiSorb - Florida

<table>
<thead>
<tr>
<th>Control</th>
<th>AmiSorb 2 qt/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>34703</td>
<td>41269</td>
</tr>
<tr>
<td>33254</td>
<td>49284</td>
</tr>
<tr>
<td>32401</td>
<td>37774</td>
</tr>
<tr>
<td>31634</td>
<td>37688</td>
</tr>
<tr>
<td>28479</td>
<td>35300</td>
</tr>
<tr>
<td>38115</td>
<td>39393</td>
</tr>
<tr>
<td>Mean Difference</td>
<td>33098</td>
</tr>
<tr>
<td>7021 Significant at 5 percent level</td>
<td>40118</td>
</tr>
</tbody>
</table>

Albright
AmiSorb was applied to winter broccoli grown in the Central Valley of California. The treatments, 1 and 3 qts AmiSorb/A, were superimposed over the grower’s standard cultural practice with sidedressed urea-ammonium nitrate solution (UAN). A control with the UAN sidedressing was included. Six replications were utilized in the study.

Despite tremendous weather problems of excess moisture, soil saturation and a freeze just before the planned harvest date, the low rate of AmiSorb produced a yield increase of 14.6 percent over the control, significant at the 10 percent level. The higher rate, 3 qt/A, produced an 8.5 percent increase compared to the control (Table 24).

<table>
<thead>
<tr>
<th>Fresh Weight Broccoli (lb/plot)</th>
<th>1 qtA</th>
<th>3 qt/A</th>
<th>No Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.6</td>
<td>11.0</td>
<td>10.1</td>
<td></td>
</tr>
<tr>
<td>LSD.10</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Another study on production fresh broccoli in California also produced significant increases in yields. AmiSorb treated plants yielded 29 percent more than the control. Not only was yield increased but quality was also positively influenced by the production of larger sizes as observed in Table 25 by the grades. The combined improvement of yield and grade has significant economic impact for the farmer.

<table>
<thead>
<tr>
<th>Flower weights</th>
<th>12s</th>
<th>14s</th>
<th>18s</th>
<th>24s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>grams/plant</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>130.0</td>
<td>0</td>
<td>28</td>
<td>52</td>
</tr>
<tr>
<td>AmiSorb, 3 qt/A</td>
<td>167.6</td>
<td>16</td>
<td>52</td>
<td>32</td>
</tr>
<tr>
<td>LSD.05</td>
<td>18.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Another study was conducted on a grower’s field near Stockton, California comparing the grower’s standard fertilizer practice (GSP) with that same fertilization program plus 2 quarts of AmiSorb/A. Fertilizer plus AmiSorb was banded at planting.
AmiSorb inclusion in the fertilizer program produced more jumbo and Number 1 grade potatoes and fewer culls. Yield increases for jumbos was significantly greater at the 5 percent confidence level (Table 26). Cull decrease with AmiSorb application was significant at the 10 percent level. Overall marketable sweet potatoes yields increased but that level of significance was at the 20 percent confidence interval.

Table 26: AmiSorb Effects on Sweet Potatoes - California

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Jumbos</th>
<th>#1</th>
<th>#2 Med</th>
<th>Cull/Seed</th>
<th>Marketable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No./A</td>
<td>lb/A</td>
<td>No./A</td>
<td>lb/A</td>
<td>No./A</td>
</tr>
<tr>
<td>AmiSorb, 2 qt/A</td>
<td>3659</td>
<td>7776</td>
<td>25090</td>
<td>25744</td>
<td>18556</td>
</tr>
<tr>
<td>Control</td>
<td>1437</td>
<td>2418</td>
<td>26528</td>
<td>24404</td>
<td>21040</td>
</tr>
<tr>
<td>Difference</td>
<td>2222</td>
<td>5358</td>
<td>1438</td>
<td>1340</td>
<td>-2484</td>
</tr>
<tr>
<td>LSD</td>
<td>--</td>
<td>4696(.05)</td>
<td>--</td>
<td>NS</td>
<td>--</td>
</tr>
</tbody>
</table>

Purdy

RESPONSE OF PEPPERS

AmiSorb was evaluated on pepper production in Florida comparing growers’ standard fertilizer practice with and without AmiSorb.

AmiSorb was supplied at 2 rates with three methods of application. An application rate of 2 qt/A applied as a root soak of plants prior to transplanting was compared to 3 qt/A applied with a spike wheel at transplanting and also to 3 qt/A split between root soak and spike wheel injection.

AmiSorb produced significant yield increases over the controls for all treatments. Those differences were significant at the 5 percent confidence level and represented yield increases ranging from 27 to 32 percent (Table 27). An interesting factor in the study, reported as an observation, was advanced maturity of the peppers that received AmiSorb compared to the controls. That factor can be an important value aspect of pepper production by allowing the crop to be on the market earlier.

Table 27: Pepper Responses to AmiSorb - Florida

<table>
<thead>
<tr>
<th>AmiSorb Rate and Application Method</th>
<th>2 qt/A</th>
<th>3 qt/A</th>
<th>1.5 qt. Spike wheel</th>
<th>1.5 qt. Root soak</th>
</tr>
</thead>
<tbody>
<tr>
<td>AmiSorb Applied</td>
<td>Root Soak</td>
<td>Spike Wheel</td>
<td>1.5 qt. Root soak</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>16.4</td>
<td>16.4</td>
<td>16.4</td>
<td>16.4</td>
</tr>
<tr>
<td>AmiSorb</td>
<td>21.8</td>
<td>21.6</td>
<td>20.9</td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>5.4</td>
<td>5.2</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>LSD(0.05)</td>
<td>2.6</td>
<td>2.8</td>
<td>2.9</td>
<td></td>
</tr>
</tbody>
</table>

Spurrier
RESPONSE OF CELERY

Greenhouse studies with celery have shown an effect of AmiSorb concentration on plant growth (Table 28). Yields were increased approximately 5 percent at the 200 ppm concentration in the growth medium and 4 percent at 1000 ppm.

**Table 28: Influence of AmiSorb Concentrations on Growth of Celery Under Greenhouse Conditions - California**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Celery Fresh weight/plant (grams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>588.2 b</td>
</tr>
<tr>
<td>200 ppm AmiSorb</td>
<td>620.0 a</td>
</tr>
<tr>
<td>1000 ppm AmiSorb</td>
<td>509.5 ab</td>
</tr>
<tr>
<td>P-value</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Brown

Field trials on celery in California have also shown significant improvement in yields when AmiSorb was used at a 3 qt/A rate. Yields were increased approximately 25 percent (Table 29). Quality was also improved as indicated by the larger percent of yield in the 2.0 and 2.5 stalk grade class.

**Table 29: Celery Responses to AmiSorb - California**

<table>
<thead>
<tr>
<th></th>
<th>Stalk weight grams</th>
<th>Petioles/Stalk</th>
<th>Stalk grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td>Control</td>
<td>802</td>
<td>10.7</td>
<td>8</td>
</tr>
<tr>
<td>AmiSorb, 3 qt/A</td>
<td>1000</td>
<td>12.5</td>
<td>28</td>
</tr>
<tr>
<td>LSD.05</td>
<td>82</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

AmiSorb “nutrient absorption enhancer” has proven beneficial on a large number of crops across North America. One crop that has not responded is rice but research is being continued in an effort to understand polymer management on that crop.

The mode of action of AmiSorb has been shown to be its effect on increasing nutrient absorption and nutrient use efficiency. This has been demonstrated in both the laboratory, greenhouse and in the field.

For centuries scientists have known that increasing nutrient uptake in a balanced manner improves the potential for increased crop yields. AmiSorb applied with proper amounts of plant nutrients enhances the plants’ ability to reach their genetic yield potential and increases fertilizer use efficiency.
The effect of increasing nutrient use efficiency with AmiSorb has been recorded in plant growth and yield response. AmiSorb has demonstrated positive effects on crop maturity especially in cotton and vegetables. Positive effects on crop quality have also been demonstrated on potatoes, vegetables and cotton. But the most dramatic effect of AmiSorb has been on increasing crop yields.

Simply increasing crop yields is not enough. Considerations must be directed to the economics of utilizing AmiSorb in a farm situation. AmiSorb effects on maturity, quality and yields impact net returns.

In the North Central U.S.A., where wheat and doublecrop soybeans can be a problematic rotation due to extended ripening periods, the impact of AmiSorb on earlier maturity is a significant factor. In the southern cotton growing areas, data have shown that lint can be harvested earlier, reducing the chances of inclement fall weather lowering yields and quality. Earlier maturity has also been demonstrated in corn and other grains through lower moisture at harvest. AmiSorb use in vegetable production has also shown dramatic effects on advancing crop maturity. The inclusion of AmiSorb in a fertilizer program and its significant impact on crop maturity can substantially increase farmers’ ROI and is sufficient in many cases to pay for the product.

Crop quality is often difficult to assess. In cotton, however, lint quality is a typical measurement and is used to determine dockage at the gin. Use of AmiSorb has shown improvement in lint quality that can more than pay for the product cost. Vegetables (i.e., lettuce, broccoli and celery) and potatoes have all shown improvement in crop quality and grade that have led to significant improvements in ROI.

Crop yields are naturally the largest driving force behind farm profits. A multitude of crops across a variety of soils and climates have shown economic yield responses to AmiSorb. It should be noted that AmiSorb is not a “cure-all” but when used with other best management practices can have a significant impact on farm economies by potentially improving maturity, crop quality and yields.

**SELECTED REFERENCES**


SYSTEMES DE CULTURE ET NUTRITION DES PLANTES DANS
LES ZONES DE SAVANES D'AFRIQUE DE L'OUEST
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1. INTRODUCTION

Dans la période actuelle, en Afrique de l'Ouest, les rendements des cultures restent plafonnés à des niveaux relativement faibles par rapport aux potentiels des espèces et variétés cultivées. La consommation d'engrais va plutôt en diminuant. Pourtant, les études prospectives (Alexandratos, 1995) montrent que la demande en produits alimentaires va aller en augmentant dans les prochaines années, du fait de l'accroissement démographique et de l'urbanisation. La question est donc de savoir si l'agriculture de la région va pouvoir faire face à la demande et dans quelles conditions ? La question est d'autant plus d'actualité que le problème se situe à l'échelle de l'ensemble des pays en développement, que la première "révolution verte" marque le pas et que des efforts nouveaux, sous la forme d'une "révolution doublement verte" (Griffon, 1996) sont à entreprendre pour le résoudre.

Cela conduit à s'interroger sur :

- les potentiels de production des milieux dans la zone concernée,
- puis les perspectives offertes par les connaissances disponibles sur la nutrition des plantes et la fertilisation dans ces régions,
- enfin, le contexte de la production agricole, pour comprendre les raisons pour lesquelles les producteurs utilisent peu les engrais dans le contexte actuel et quelles sont les perspectives.

2. LES POTENTIELS DE PRODUCTION

En zone de savane, les potentiels de rendement sont souvent limités par des facteurs autres que la nutrition minérale (Piéri, 1989; Ganry et Campbell, 1995). Certains sont identifiables et contribuent à fixer un potentiel de rendement, sur lequel l'agriculteur peut s'appuyer pour raisonner les problèmes de fertilisation. D'autres sont aléatoires et rendent l'efficacité des engrais incertaine.

La pluviosité, souvent réduite, en particulier depuis le début des années 70, et mal répartie, constitue le facteur limitant le plus important de ces régions.

En culture irriguée, les facteurs limitants majeurs autres que l'alimentation en eau sont le rayonnement incident, dans la mesure où, en Afrique de l'Ouest, le ciel est fréquemment voilé, même en saison sèche, et les fortes températures qui perturbent certaines fonctions physiologiques comme la floraison.

Le niveau d'intensification permis par l'irrigation amène les agriculteurs à utiliser des intrants pour limiter les effets d'autres contraintes, en particulier les déficiences minérales (§ 4) et les maladies et ravageurs.

En culture sans irrigation, malgré l'abondance possible des pluies en saison humide, d'autres facteurs limitants interviennent également pour limiter le potentiel de production et rendre l'utilisation des engrais peu intéressante :

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1 Exposé présenté à la réunion du Comité Agro-Economie de l'IFA à Tours, France, les 23 et 25 juin 1997
• maladies et prédateurs (le coton est l'une des cultures de la région les plus sensibles aux insectes prédateurs).
• mauvaises herbes. La compétition des mauvaises herbes constitue l'une des raisons les plus fréquentes d'abandon des parcelles cultivées dans les systèmes de culture traditionnels, sans intrants mais avec alternance culture - jachère.
• l'érosion très fréquente dans les sols en pente, peu importante en culture traditionnelle avec alternance culture - jachère, beaucoup plus importante lorsqu'on passe en culture continue.
• la texture du sol, ses propriétés physiques.

3. CONNAISSANCES ACTUELLES EN MATIERE DE NUTRITION DES PLANTES

3.1. Nature des mécanismes impliqués dans la nutrition des plantes

En matière de nutrition des plantes cultivées, les problèmes se posent à peu près dans les mêmes termes dans toutes les régions du monde. Grâce aux travaux conduits en station expérimentale et/ou en milieu contrôlé, la nature des principaux mécanismes susceptibles d'intervenir est connue, aussi bien au niveau des sols qu'à celui des cultures et pour une très large gamme de systèmes de culture, des plus extensifs aux plus intensifs, aussi complexes soient-ils.

Cette connaissance recouvre, par exemple (Piéri, 1989; Van Reuler et Prins, 1993; Gigou, 1995; Bump et Baanante, 1996):

• la nature des éléments indispensables à la croissance et au développement des cultures. Les carences ou les risques de toxicité ont été identifiés pour un grand nombre d'espèces cultivées et d'éléments minéraux.
• la dynamique de ces éléments minéraux dans le sol, leur biodisponibilté.
• les cycles des éléments dans des associations complexes, qu'il s'agisse d'associations végétales dans les systèmes agro-forestiers, ou d'associations plantes - microorganismes, comme dans le cas de la fixation symbiotique ou non symbiotique de l'azote.
• la nature des engrais et amendements, minéraux et organiques susceptibles d'être utilisés.

Il reste cependant de nombreux points à approfondir, en particulier :

• pour le compartiment sol, la dynamique de la matière organique des sols et celle de l'azote, qui lui est très liée (Feller, 1994 ; Feller, 1995; Ganry, 1990; Sanogo, 1997).
• au niveau de la plante, la croissance et le fonctionnement du système racinaire (Picard, 1992).

C'est à partir de ces données qu'on peut être établis les conseils en fertilisation des principales cultures de la zone, sous forme de normes. A titre d'exemple, sur le coton au Mali, les apports conseillés ont longtemps été les suivants : 200 Kg d'"engrais coton" (apportant 14 N, 22 P et 12 K) au semis et 50 kg d'urée 30 à 45 jours après (Crétetenet et al., 1994).
3.2. La quantification des flux et des bilans

Ce type de conseil normalisé, qui ne prend pas en compte la diversité des systèmes de culture et la variabilité des rendements des cultures, n'est pas satisfaisant. Désormais, les problèmes sont à aborder dans les mêmes termes qu'en zone tempérée : comment ajuster aussi précisément que possible les apports (doses, modalités d'apports) aux besoins. En culture intensive, en zone tempérée, la question procède prioritairement du souci de préserver l'environnement. En zone tropicale, elle est très sensible du fait du coût des engrais et des difficultés d'approvisionnement. Les problèmes environnementaux commencent à se poser dans les systèmes les plus intensifiés.

Cela implique de pouvoir évaluer des flux et les éléments de bilans (Crétenet et al., 1994). Malheureusement, dès qu'il s'agit de quantifier, les problèmes deviennent beaucoup plus ardus et les résultats sont rares (Ruiz et al, 1995). L'identification précise des besoins en éléments minéraux des cultures pour un objectif de rendement donné, celle des fournitures par le sol, l'ajustement de la fertilisation à ces besoins, posent des problèmes beaucoup moins bien résolus dans les pays tropicaux que dans les pays tempérés.

En Afrique de l'Ouest, en particulier, l'élaboration d'une stratégie de fertilisation aux échelles de la parcelle, de l'exploitation agricole, d'un pays, se heurte à de nombreux problèmes. Face à la diversité des situations, ces problèmes concernent : l'existence et l'accessibilité des méthodes, celle des outils à mettre en œuvre, les connaissances disponibles pour interpréter les résultats analytiques. Ils sont d'ailleurs liés : si les méthodes et/ou les outils sont peu accessibles, il existe peu de données pour interpréter les observations et mesures.

Les méthodes les plus classiquement employées pour évaluer les besoins nutritifs des plantes et leur taux de couverture font appel à plusieurs types de déterminations (Piéri, 1989 ; Janssen et al. 1990, pour le maïs ; Martin-Prével et al, 1984) :

- celle des éléments minéraux disponibles dans les sols,
- celle de la fraction de ces éléments qui est facilement échangeable, facilement assimilable pour une culture donnée,
- celle du niveau d'alimentation d'une plante en un ou plusieurs éléments (diagnostic foliaire ; courbes de dilution ; tests de composition de sève),
- enfin, l'analyse de la composition des amendements et engrais disponibles, leurs coefficients d'utilisation.

Pour leur mise en œuvre, il faut distinguer, en première approximation, le cas des systèmes de culture traditionnels, faisant peu appel aux intrants, ceux en voie d'intensification, enfin, les systèmes de production intensifs, avec ou sans recours à l'irrigation.

3.3. Interactions avec les types de systèmes de culture

Dans des systèmes de culture traditionnels, les objectifs de rendement sont en général faibles. Le recours aux méthodes classiques de calcul de la fertilisation est peu envisageable. En effet, ces systèmes sont le plus souvent complexes (par exemple, les cultures associées sont le cas le plus fréquent, la fixation biologique de l'azote, par voies symbiotique et non symbiotique, joue un rôle important ; les parcelles de culture se déplacent). L'utilisation des engrais minéraux est limitée celle des amendements organiques plus fréquente, mais leur nature et leur composition sont très variables. Les parcelles elles-mêmes sont petites et très hétérogènes, notamment du fait des pratiques des agriculteurs (défrichement qui bouleverse la couche superficielle du sol, brûlis en tas
par exemple). De ce fait, il est très difficile et coûteux de mettre en oeuvre des analyses de sol et/ou d'établir un diagnostic de l'état nutritif des plantes du peuplement.

Là encore, les données qui sont disponibles concernent surtout des essais en stations expérimentales sur des modèles simplifiés de systèmes traditionnels, souvent très difficiles à vulgariser en l'état (un bon exemple est celui des systèmes de culture "en couloir", Ganry et Dommergues, 1995). Elles concernent également la composition des amendements disponibles (par exemple, Berger, 1996²).

Ainsi, les grandes lignes du fonctionnement des systèmes de culture traditionnels sont connues, mais les méthodes de suivi de la nutrition des cultures sont le plus souvent hors de portée des producteurs, à quelques exceptions près (lorsqu'un projet de recherche - développement se met en place et que les coûts analytiques sont pris en charge par ce projet). Peu d'analyses ont été faites dans les parcelles cultivées des agriculteurs, il y a donc peu de références pour interpréter convenablement les observations et mesures. Les travaux de Clermont-Dauphin (1995), bien que situés dans une zone géographique différente (Haïti), illustrent bien le type de difficulté rencontré, les réponses que l'on peut apporter.

Les systèmes en voie d'intensification posent des problèmes similaires. Ils sont cependant moins complexes à aborder, dans la mesure où les cultures sont en général en peuplements purs et où la mécanisation des techniques culturales conduit à un parcellaire plus simple (de formes plus géométriques), plus homogène. Au fur et à mesure que le parcellaire se stabilise, que les tailles de parcelles augmentent, que les rendements croisent, le recours aux méthodes pratiquées dans les pays tempérés devient possible. Cependant, ces méthodes restent inaccessibles à la plupart des agriculteurs, pour des raisons de coût. De ce fait, peu de résultats sont disponibles (Cattan, 1996; Legrand, 1995). Cela repose le problème de méthodes utilisant des techniques de diagnostic simples et peu onéreuses, antérieurement utilisées dans les pays tempérés, qui sont en train de se perdre, ne sont plus disponibles pour les pays tropicaux.

Par ailleurs, le faible nombre des formulations en engrais, simples ou complets, disponibles, est en soi une limitation à leur utilisation.

Dans le cas des systèmes intensifiés, les travaux récents de l'IRRI⁴ (résumés dans une note récente de Doberman et Cassman, 1996), ceux de Jamin (1996) à l'Office du Niger au Mali, sur le riz irrigué, illustrent bien certaines des difficultés. Dans les pays du sud-est asiatique, l'augmentation progressive du potentiel des variétés s'est traduit par des besoins croissants en éléments minéraux, en particulier en azote. Cependant, l'absence de réponse aux doses croissantes apportées a attiré l'attention sur les bilans des autres éléments majeurs, ce qui a permis de montrer que, souvent, ceux en potassium étaient largement déficitaires. L'extension des observations à des réseaux de parcelles d'agriculteurs a montré que l'on manquait d'indicateurs pertinents pour évaluer de façon suffisamment précise la fourniture d'éléments minéraux par le milieu (sol, eaux d'irrigation). Au Mali, ce n'est que récemment que sont apparues les conditions d'une intensification, en particulier du développement de la double culture annuelle, entraînant de besoins croissants en engrais. Les observations de l'IRRI, si elles ne sont pas directement transposables, devraient néanmoins attirer l'attention des agronomes sur la nature des problèmes à venir.

² Beaucoup de données sont dans des rapports malheureusement peu accessibles.
⁴ IRRI : International Rice Research Institute
4. LE CONTEXTE DE LA PRODUCTION AGRICOLE

Plus encore que les connaissances sur la nutrition minérale de plantes cultivées, il semble que ce qui limite l'utilisation des engrais en Afrique de l'Ouest soit l'organisation des filières de production, à l'amont et à l'aval de la production proprement dite.

Cette organisation évolue rapidement sous l'effet de nombreux facteurs, aux effets contradictoires.

C'est ce qui ressort notamment de l'étude "Perspectives à long terme en Afrique de l'Ouest" (1995) réalisée à la demande du Club du Sahel et plus particulièrement des travaux de B. Ninin. En effet, l'étude met en évidence une forte corrélation entre la densité de population rurale et la productivité agricole d'une part, la proximité des marchés urbains d'autre part. Les villes exercent une influence croissante sur la production de leur hinterland rural, quel que soit leur localisation sur le continent : cela est vrai aussi bien des grandes villes du Nigeria en zone de savane que des capitales localisées sur la côte atlantique. L'existence de marchés, en particulier pour les produits vivriers, incite les agriculteurs à intensifier leurs cultures le long des axes routiers, par conséquent à recourir de façon croissante aux engrais et aux autres intrants.

Cette voie d'intensification des systèmes de culture est confirmée par une étude fine réalisée en Côte d'Ivoire par Chaléard (1996) qui montre comment ceux-ci évoluent dans plusieurs petites régions en fonction du développement des marchés urbains, en entraînant notamment une réduction des superficies en cultures d'exportation et une augmentation des cultures vivrières.

L'intensification obtenue par le développement des marchés urbains, par augmentation rapide de la population urbaine, apparaît comme un moteur d'intensification de la production agricole au moment où, par ailleurs, pour de multiples raisons, les États se désengagent des structures d'encadrement des agriculteurs et d'approvisionnement en intrants des cultures, soit qu'ils les suppriment, soit qu'ils les privatisent. En l'absence de marché porteur, comme dans le cas de l'arachide au Sénégal, ou du coton au Burkina Faso ces dernières années, la désorganisation des circuits d'approvisionnement conduit à une baisse significative de la consommation en intrants et des rendements.

Un autre exemple intéressant est celui du riz irrigué, suite à la dévaluation du Franc CFA. Au Sénégal, où la production reste largement tributaire d'intrants importés (irrigation par pompage, culture motorisée) et est fortement concurrencée par les importations, la dévaluation n'a pas permis la relance de la production dans des conditions économiquement rentables. Au Mali, par contre, une moindre dépendance vis à vis des intrants importés (irrigation essentiellement par gravité, culture manuelle ou utilisant la traction animale) s'est traduite par un développement important de la production, elle même accompagnée par une politique de réhabilitation des équipements et de prise en charge de la vulgarisation par les organisations professionnelles agricoles (Jamin, 1996).

Des programmes de recherche ont été mis en place récemment pour tenter de résoudre ces problèmes globaux aussi bien que ceux plus sectoriels concernant la nutrition minérale des plantes. Ainsi, l'un d'entre eux ("Pôle sur les systèmes irrigués en Afrique de l'Ouest", ou PSI) (CIRAD,1996) a pour objet d'aborder à différentes échelles (la parcelle, le périmètre d'irrigation, la petite région) les problèmes posés par l'intensification et la diversification des cultures dans les zones irrigables le long des fleuves Sénégal et Niger. Un autre ("Pôle régional de recherche appliquée au développement des savanes d'Afrique centrale", ou PRASAC) (CIRAD,1996) concerne les régions de savanes d'Afrique centrale où la culture du coton occupe une place importante. Il s'agit de programmes régionaux, associant des équipes de recherche multidisciplinaires de plusieurs organisations de recherche aux organismes de développement et aux
agriculteurs, dont les objectifs sont d'apporter des réponses aux principaux problèmes posés par la mise en valeur de ces régions, y compris ceux liés à l'intensification par l'utilisation des engrais.

5. CONCLUSION

Les connaissances sur la nutrition minérale des plantes cultivées montrent l'intérêt de l'utilisation des engrais dans les zones de savane d'Afrique de l'Ouest, sous réserve de bien évaluer les potentiels de rendement, notamment dans les régions où le risque de déficit hydrique est important.

Cependant, les conditions de production actuelles se traduisent par une faible utilisation des engrais. Dans le très court terme, la consommation des engrais devrait peu augmenter.

L'amélioration de la nutrition minérale des plantes dans un contexte d'intensification des productions est une nécessité dans le moyen et le long terme, compte tenu des prévisions en matière d'évolution démographique des zones urbaines et rurales.

L'intensification des productions devrait se faire par le développement des marchés, en particulier pour les cultures vivrières.

L'utilisation rationnelle des engrais dans ce contexte demandera un développement des recherches sur les méthodes de quantification des flux, celles des bilans, pour apprécier convenablement les besoins des cultures, les apports nécessaires, en particulier dans le cas d'utilisation des engrais organiques sous toutes leurs formes.

CONCLUSION

Available knowledge concerning the mineral nutrition of crops demonstrates the advantage of applying fertilizers in the savanna zones of West Africa, with the reservation that the yield potentials must be assessed, especially in regions where the water deficit is substantial.

However, under present production conditions, fertilizers use is low. In the very short term the consumption of fertilizers is not likely to increase much.

The improvement of the mineral nutrition of crops, in the context of the intensification of production, is necessary in the medium and long term, in view of the anticipated increases of population in urban and rural areas.

The intensification of production should result from the development of markets, in particular for food crops.

The rational use of fertilizers in this context will require research into methods of quantifying flows, balances, assessments of crop needs and application requirements, especially where different forms of organic fertilizers are used.

Bibliographie


LIFE CYCLE ANALYSIS: AN UPDATE OF THE INDUSTRY'S EFFORTS
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Note: The figures are not included.

INTRODUCTION

In Norsk Hydro's last environmental report, we made a simple sketch to illustrate the life cycle aspects of our fertilizer business (Figure 1). Having the life cycle perspective implies an evaluation of the environmental impact from raw material extraction through fertilizer production, packaging, transport, fertilizer application, harvesting and use of harvest, ultimate disposal of wastes, and recycling of nutrients.

You may have heard some life cycle phrases:

- **Life cycle approach**, a way of thinking, to have the life-cycle perspective.
  In my opinion, the life cycle approach is a part of a philosophy, in the US also known as industrial ecology.
- **Life-cycle analysis**, or assessment, which refers more to specific tools and methods used for transforming the philosophy into practical, workable quantities. The European work has to a great extent been on methods.
- **Life-cycle inventory**, which is a way of collecting and systemizing all input and output data related to emissions, waste and other categories chosen.

Before going more deeply into these different concepts, we should ask: Is the life-cycle idea something quite new? My answer is yes - and no. In the 1970s, much work was done, especially on the energy side, on material and mass flows. General interest in the concept then partly vanished until the mid 80s when life cycle thinking gathered new momentum, by adding an environmental and product perspective to the analysis. The new approach was so ground-breaking that one started to mention a paradigm change.

My presentation will deal with industry's progress on three issues:

- the fundamental and strategic thinking inherent in the life cycle concept
- the systematic way of performing the analysis
- the practical use of the available tools and methods

THE LIFE CYCLE PERSPECTIVE IN A STRATEGIC CONTEXT

To place life cycle thinking into an industrial perspective on environmental care, I will use our experience with environmental work in Norsk Hydro as an example. In order to simplify, we can divide Hydro's environmental efforts into three fairly distinctive phases (Figure 2):

- The first phase involved local clean-up actions to remedy environmental sins from the past, and the introduction of end-of-pipe treatment facilities to reduce emissions and discharges from existing plants. The most common environmental tool used to gain an understanding of the actions necessary, was and still is, simple environmental impact assessments.

- The second phase involved the development and introduction of "cleaner technology", i.e. the integration into the plants of measures to avoid creating pollution problems in the first place. Another crucial factor is a stronger emphasis on operational excellence in all our production facilities. Technical assessments are a key tool to learn how to reduce waste and emissions and save energy.

- The third phase, which today is the most demanding one, focuses on applying all our experience and expertise to the life-cycle aspect of our products. To complete the circle, receive the public's "license to

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operate" and move towards sustainability, we have to evaluate the products not merely "from cradle to grave" but "from cradle to cradle". We are thus making environmental care in its widest sense an important strategic business issue. Our key tool in this phase is life cycle analysis.

If we structure the environmental protection context in another way (Figure 3), we have a time-dependent phase description on the stage of implementation of measures, dependent on factors such as abatement measure, decision level, and other key driving factors.

The life cycle concept is of lesser importance in a stable and reactive phase, in which environmental care can be handled as an operational problem. When focus goes beyond a firm's production process, and is concentrated instead on analyzing and improving the life cycle of the products and sustainability of the business at the strategic level, then the life cycle analysis is the most important tool industry has to promote both environmental care and business development. Our chief motivators and partners in this work are our customers and the community surrounding us. The insight we thus gain provides us with an opportunity to apply the most advanced knowledge in offering solutions to increasingly more environmentally oriented and demanding customers.

Many industries are today prime drivers in the use of tools as life cycle analysis. An example from Norsk Hydro: In 1993, we issued a set of environmental principles (Figure 4) which now govern the behaviour and strategies of the company. The first, and a main point, is to promote the life-cycle perspective of our products.

If we look for an example outside the fertilizer industry, the automotive manufacturers show a very strong commitment to the life cycle approach. An example of a customer relationship, where environmental concerns are an important driving force, is the collaboration of the light metal business with the automotive industry to increase the use of aluminium and magnesium in cars.

Viewed through the eyes of a business, the work of analysing the environmental qualities of the product throughout its life cycle will reveal business opportunities arising from the fact that the product and the market are in focus. Anyone who can develop a product that offers a sound, holistic environmental solution will have a competitive advantage. The leading companies will find opportunities for business development by implementing a "cradle to cradle" perspective in their product development.

THE SYSTEMATIC WAY OF PERFORMING LIFE CYCLE ANALYSIS

In the recent standardization developments, the term normally used is life cycle assessment, and not life cycle analysis.

Definitions

- Life cycle assessment (LCA) is a systematic method used to describe and evaluate a product's total environmental impact throughout its entire life cycle.
- LCA is a compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system throughout its life cycle (ISO/DIS14040).
- LCA is a technique for assessing the environmental aspects and potential impacts associated with a product.

LCA methodology

Pioneering work on LCA was done by the Society of Environmental Toxicology and Chemistry, and has later been followed up through work by the International Organization for Standardization (ISO), aiming for specific ISO standards for the different parts of LCA's. In addition, much work in some European countries, especially in the Nordic countries, has contributed to standardizing the way of performing the analysis.
The LCA methodology consists of four main stages (Figure 5):

1. Goals and scope
2. Inventory analysis
3. Environmental impact assessment
4. Interpretation of results

The steps can be divided into two groups: Steps 1 and 2 quantify the environmental aspects, steps 3 and 4 are evaluations of the first two steps. A closer look at each of the steps related to the fertilizer business will give us some idea of the stage of maturity of the development of methodology.

Step 1. Goal, scope

The main steps in a systematic approach are to define the functional unit and to set up the analysis model.

a) Functional unit

Function as the basis for comparison is one of the strict requirements imposed on an LCA. Using current LCA methods, it is seldom possible to compare two products fairly. Most LCAs therefore do not compare different products, but different alternative ways of fulfilling a particular function or providing some specific benefit. An example: We compare the environmental impact of applying different production schemes and different fertilizers to produce one tonne of grain - which is the function we want to fulfil. Functions as the basis for the comparison is one of the strict, original requirements imposed on an LCA.

b) All activities

In theory, all activities, from cradle to grave, required to fulfil the function must be included. LCA is a simplified model of reality. To include every aspect would be prohibitive and very time-consuming.

c) The depth of the analysis

An LCA is a simplified model of a real-life phenomenon that is usually highly complex, and it is a matter balancing clarity and thoroughness. The degree of detail of the analysis will therefore vary from study to study.

Step 2. Inventory analysis (Figure 6)

The inventory analysis of material and energy flows in the system studied are summarized, e.g. raw materials, products, waste and emissions to air and water.

Step 3. Environmental impact assessment (Figure 7)

The impact assessment includes resource use, and is divided into three subsidiary stages:

- classification of resources and emissions into impact categories. For agricultural production, typical impact categories would be global warming, eutrophication, acidification, winter and summer smog, and heavy metals. Corresponding emission parameters are given in Figure 8.

- characterization, either quantitative or qualitative, of contributions to each category. The goal is to model categories in terms of indicators and to provide a basis for the aggregation of the inventory input and output data within each category.

- valuation of the contributions from various categories, which are weighted using different methods to get an estimate of total environmental impact
The methodological and scientific framework for impact assessment is still being developed. There are no generally accepted methodologies for consistently and accurately associating inventory data with specific potential environmental impacts, but several systems have been proposed. Some examples: Environmental priority setting systems which weight various forms of environmental impact and resource use and result in a single figure has been developed in Sweden and in the Netherlands. In Denmark another method is used, where no attempts are made to weight different kinds of environmental impact to get a single figure or indicator.

Step 4. Interpretation of results

The interpretation of results relates the outcome from the previous stages to the objectives of the study. The findings may take the form of conclusions and recommendations.

Evaluation of the methodology

In my opinion, the LCA methodology has advanced significantly in the past few years. The four steps of a life cycle assessment include many complex questions, and much further development work is needed. A personal attempt to make a rough evaluation of the present status is given in Figure 9. The goal and scope of study, the inventory analysis and the two first stages of the impact assessment are regarded as having many scientifically based elements. Subjective elements are to a strong degree included in the valuation. Value judgements normally include political attitudes, scientific, emotional and ethical considerations.

PRACTICAL USE OF THE TOOLS AND METHODS

According to the definitions, an analysis must include both classification and characterization to be an LCA. The studies which only include the inventory analysis, are called "Life-cycle inventory" (LCI). Many of the studies performed are inventory studies only.

As a practical example, I will show some of the output from the inventory part of a life cycle study. To go through a whole study would require more clarification and explanations than time would allow.

The system model consists of the three main elements: the fertilizer production plant, transportation, and the agricultural part (Figure 10), with one tonne of winter wheat as the functional unit. The outputs given as specific emissions for two types of fertilizer are for the fertilizer production (Figure 11), the transportation (Figure 12), the agricultural application (Figure 13), and these are summed up as a total in Figure 14.

One main advantage of the inventory studies is that they help to compare and identify the phases in a product's life cycle responsible for the major environmental impacts. They also supply information to product developers, and they provide data for customers who need upstream data to do their own LCA's. Due to increased efforts in industry, more and more reliable data are now available for use in LCA's.

R&D efforts are ongoing to further improve the practical usefulness of the life cycle assessments. Main efforts are related to step 3 - to bring the complex issue of emissions and energy use into a system where some few indicators concentrate the most significant information in a reliable way.

Conclusion

LCA is one of our fundamental tools to evaluate progress towards sustainable development, and the fertilizer industry has made good progress in its LCA work. It is a methodology under continual development to enhance our life cycle work. In future it will be even more important.
Literature


PLANT NUTRITION MANAGEMENT FOR SUSTAINABLE AGRICULTURE IN 2000
by
Nisar Ahmad and Abdul Jalil
National Fertilizer Development Centre (NFDC), Pakistan
PLANT NUTRITION MANAGEMENT FOR SUSTAINABLE AGRICULTURE IN 2000

by

Nisar Ahmad and Abdul Jalil
National Fertilizer Development Centre (NFDC), Pakistan

1. INTRODUCTION

Pakistan is situated between latitudes of 24° and 27° North and longitudes of 61° to 75° East. The geographical area of the country is 79.6 million hectares which consists of mountainous and sub-mountainous areas in the north, alluvial plains in the centre, deserts in the south and riverian delta in the south-west. The climate is sub-tropical arid and semi-arid. Therefore, agriculture depends upon irrigation. Out of 22.0 million ha of cropped area about 75 per cent is irrigated by both surface and ground water sources.

The population of Pakistan in 1996 is around 135.0 million and is growing at rate of about 2.9 per cent per annum. The performance of agriculture sector in Pakistan, despite many constraints has been satisfactory growing above the population rate. The introduction of high yielding dwarf varieties of wheat and IRRI rice during late 1960’s along with expansion in irrigation sources and use of mineral fertilizers created a great optimism for agricultural growth. However, since mid 1980’s agricultural growth is not keeping its momentum. The past increase in production have been both horizontal due to area expansion as well vertical through increased use of fertilizers. Due to limited scope in area expansion in future, agricultural production will depend on high productivity per unit of land. Thus, appropriate strategies in fertilizer use and plant nutrition management will pave the way to match food requirements of the growing population as well as economic development. This paper reviews fertilizer use and its impact on crop production in Pakistan and suggests measures to achieve envisaged crop production targets in year 2000 and after appropriate plant nutrition management.

2. CROPS GROWN AND THEIR PRODUCTIVITY

There are two cropping seasons in Pakistan. The winter season called Rabi extends from October to March and the summer known as Kharif, covers period April to September. Wheat is the major Rabi crop. Kharif crops consist of cotton, rice, sugarcane and maize. Relay and intercropping is also practiced. The national yield levels are very low against existing economic yield potential (Table 1) which takes into account variations in soil fertility, cropping system and management conflicts among farmers.

<table>
<thead>
<tr>
<th>Crop</th>
<th>National average yield¹/</th>
<th>Economic Potential²/</th>
<th>Yield gap %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat (irrigated)</td>
<td>2,275</td>
<td>3,500</td>
<td>35</td>
</tr>
<tr>
<td>Wheat (rainfed)</td>
<td>1,129</td>
<td>2,500</td>
<td>65</td>
</tr>
<tr>
<td>Seed Cotton</td>
<td>1,740</td>
<td>3,000</td>
<td>43</td>
</tr>
<tr>
<td>Sugarcane</td>
<td>46,700</td>
<td>80,000</td>
<td>42</td>
</tr>
<tr>
<td>Paddy (IRRI)</td>
<td>2,960</td>
<td>5,000</td>
<td>41</td>
</tr>
<tr>
<td>Basmati</td>
<td>1,564</td>
<td>2,500</td>
<td>38</td>
</tr>
<tr>
<td>Maize</td>
<td>1,481</td>
<td>5,000</td>
<td>70</td>
</tr>
</tbody>
</table>

¹/ Agricultural Statistics of Pakistan, 1994-95.

¹ Poster paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997.
3. FERTILIZER AND THEIR USE IN PAKISTAN

Fertilizer use in Pakistan began in 1952-53, but picked momentum after introduction of high yielding, semi-dwarf, fertilizer responsive varieties in mid 1960’s. The fertilizer consumption maintained a growth rate of about 5.0 per cent during past 30 years. The current consumption is about 2.5 million nutrient tonnes. Of this N consists of 79%, P₂O₅ 19.6% and K₂O 1.4%. The fertilizer consumption is highly imbalanced and skewed in favour of nitrogen. This use pattern has not only resulted in inefficient use of nitrogen but is also one of the main reasons of yield stagnation.

4. FERTILIZER USE AND TRENDS IN CROP YIELDS

Wheat

Wheat is a main Rabi crop grown over 8 million hectares. The fertilizer consumption share on wheat had varied between 42 to 50%. The recent estimates are that wheat consumes about 42 per cent of total fertilizer annually. Figure 1 shows overall national wheat yield since 1975-76 together with estimated nutrient consumption. An increasing yield trend up to 1985-86 is visible followed by stagnation to 1993-94. Slight improvement took place in past two years. Though during this period NPK use (mostly N) increased substantially, the yield level of about 2000 kg/ha against estimated fertilizer use over 125 kg/ha does not reflect the efficient use of applied fertilizers. The per capita production of wheat declined over period.

Rice

Figure 2 shows the national trend of rice yield from 1975-76 to 1996-97. The mean rice yield comprise those of IRRI and Basmati rice. Rice consumes about 11% of total fertilizer consumption. It is evident from the Figure 2 that during period from 1975-76 national average rice yield was totally stagnant except in the last two years when an upsurge was observed. Rice is an important major export commodity, thus this stagnation is extremely serious. In addition to poor crop husbandry imbalanced use of nutrients coupled with faulty nutrition management practices at farm level are among the major reasons leading to low yield levels. The fertilizer use efficiency in rice particularly of nitrogen is reported only 30%.
Cotton

Figure 3 shows that fertilizer use trend on cotton commensurates with yield progress by 1992-93. Share of fertilizer use on cotton (20 per cent) is highest after wheat crop. In addition to imbalanced nutrition management practices in cotton other very important factors which affected the yield after 1992-93 were “cotton leaf curl virus” and ineffective pest control. The virus problems in cotton coupled by severe white fly attack restricted yield growth momentum after 1991-92. Thus cotton yield in relation to fertilization of cotton have followed a different pattern from those of wheat and rice. In the case of cotton, fertilizer use has been reflected in improving productivity with other yield promoting practices. However, high use of nitrogen in relation to phosphates and negligible use of potash and micronutrients (Boron) are among some causes of poor cotton response to applied nutrients.
Sugarcane

Figure 4 shows the average national yield of sugarcane since 1975-76 together with estimated NPK fertilizer use. It may be seen that up to year 1985-86 the yield was stagnating but from that year onward there has been a modest rise. However, this slight improvement in recent years does not reflect the heavy use of inputs (water, fertilizer, pesticide, energy) required to grow this crop.

Sugarcane is a second major cash crop of Pakistani farmers and is grown for different purposes such as fodder for livestock in addition to produce sugar. Sugarcane is planted either in spring or in autumn which affects the growth period of harvest and the yield especially of millable cane. Thus due to cropping systems for sugarcane the yield levels can not be expected very high but present yield is very low in relation to genetic potential and use of inputs like fertilizer and water. Moreover, national recovery of sugarcane around 8.7 per cent is also very low. Major fertilizer use on sugarcane is again nitrogen (urea) and negligible quantities of potash. Thus in addition to the other agronomic factors such as crop variety and poor crop husbandry practices the imbalance, inadequate use of fertilizer coupled with poor nutrition management are other reasons of yield stagnation.

Maize

Grain yield trend in maize at national level combining both irrigated and barani maize also show a long static period with slight improvement in the recent years. However, average yield is still very low compared to high potential this crop contains.

The above five major crops consume about 85 per cent of total fertilizer offtake in Pakistan. All crops show stagnation in yields, low fertilizer use efficiency and crop growth is not keeping pace with use of nutrients and demand of increasing population.
5. CROP RESPONSE TO FERTILIZERS

The physical relationship between fertilizer application and additional yield obtained is termed as response ratios or productivity index (P1) i.e. units of crop produced by one unit of plant nutrient. The provincial soils fertility organizations conduct a number of fertilizer trials, following technique of ‘dispersed trials in farmers’ fields’. These trials are conducted under varied soil-climatic conditions and management practices.

National Fertilizer Development Centre (NFDC) retrieved, compiled and analyzed some of the data of major crops at national as well as provincial level. The crop response functions were established for three periods between 1975-76 to 1993-84, 1984-85 to 1991-92 and 1992-93 to 1995-96. The yield equations obtained for irrigated wheat crop were as follows:

(i) 1975-76 to 1983-84

\[ Y = 1483 + 13.49 N - 0.024 N^2 + 11.18 P_{2O_5} - 0.042 P_{2O_5}^2 
+ 0.0182 NP \]

(ii) 1984-85 to 1991-92

\[ Y = 1460 + 10.22 N - 0.02 N^2 + 7.93 P_{2O_5} - 0.02 P_{2O_5}^2 
+ 0.01 NP \]

(iii) 1992-93 to 1995-96

\[ Y = 1417 + 14.07 N - 0.0405 N^2 + 9.23 P_{2O_5} - 0.0288 P_{2O_5}^2 
+ 0.036 NP \]

The response curves derived from these equations of different periods at variable N and constant P$_{2O_5}$ levels are shown in Figure 5. It may be seen that response of wheat to applied fertilizers inter alia efficiency of fertilizers declined over period. Slight improvement in the period 1992-96 can be attributed to three good years due to favourable weather. However, after 1994-85 declining trend in wheat response to fertilizers is sustaining which calls for review of plant nutrition practices at farm level in order to improve its efficiency.
6. BALANCED FERTILIZATION TO IMPROVE CROP YIELDS

The fertilizer use in Pakistan comprise about 1991 thousand tonnes of N, 494 thousand tonnes of P₂O₅ and 30 thousand tonnes of K₂O. Despite this nutrient budget of Pakistan soils is negative in respect of all nutrients and soil is being mined not only of NPK but micronutrients as well. The current NP ratio of 4.1:1 is far wide compared to agronomic standard of 2:1, for the alluvial soils of Pakistan.

It has been found that through balanced use of N and P₂O₅, wheat yield increases by about 35 per cent when all other factors remained constant (Figure 6). Wheat response to potash is erratic but its overall role in improving yield and quality of other crops like potatoes, sugarcane, rice, maize, cotton, tobacco, vegetables and fruits can not be under estimated. In addition secondary nutrients like sulphur and micronutrients (Zn, B, Fe) have also been found deficient in some soils and their application resulted in yield increase.

7. PLANT NUTRITION IN 2000 - FOR ACHIEVING CROP PRODUCTION TARGETS

A survey conducted by NFDC showed that 34 per cent of farmers who obtain wheat yield in irrigated areas of 3.0 to 5.9 tonnes per hectare were mostly those who applied 90 to 180 kg/ha of N and 57 to 60 kg P₂O₅. In rainfed wheat yields of best farmers ranged from 2.0 to 4.5 tonnes per hectare after use of 80-100 kg N, 28 to 56 P₂O₅ kg/ha.

This conclusive evidence from farmers own yield results show that crop yields can be considerably increased above present levels to achieve the potential through improved crop nutrition. Along with alleviation of other constraints. The main nutritional improvements includes in steps:

- improve N:P₂O₅ balance,
- introduction and use of micronutrients and potash,
- proper integration of farm yard manure/biological practices with fertilizers,
- proper method and time of application,
- improved techniques like foliar fertilization and fertigation.

Balanced fertilization needs special attention. However, the first step is better balance between N and P₂O₅ coupled with means of increasing the efficiency of each through better methods and application techniques at right time in a cropping sequence and not in a single crop.

The research findings have revealed the need of introduction and use of micronutrients particularly
zinc (rice, wheat) boron (cotton) and iron (orchards). The use of potash has been limited due to its erratic responses or none at all in situations where benefit would accrue partly due to potash in irrigation water. Nevertheless, there are several situations in Pakistan where K should be used know.

Multinutrient fertilizers should be introduced with high priority, suitable to a particular soil-crop combinations. Multi-nutrient fertilizers can be complexes or blends. Foliar spraying of fertilizers and fertigation are at nascent state. This technology has not moved from research and demonstration plots to the farmers fields even in orchards and vegetables where this technology can be easily adopted.

The supplementary role of organic and bio-sources should be integrated in plant nutrition system. These sources will help to improve the efficiency of fertilizers and supplement partly some nutrients. It may be pointed out that under Pakistan conditions organic farming/or substitution of mineral fertilizers with organic sources have little potential.

SELECTED REFERENCES


INTTEGRATED PLANT NUTRITION -
AN ESSENTIAL PART OF INTEGRATED CROP PRODUCTION

by
H. Nieder
FIP, Germany
INTRODUCTION

Many definitions, many interpretations

In the early 1950's a group of entomologists at the University of California at Berkeley began to formalize the concept of what was to become Integrated Pest Management (IPM). The original intention of these entomologists was to combine the use of pesticides and natural enemies like predators and parasites to manage insect pests.

Today this initial concept, which has also been started in European countries has changed to a complex mixture of practices and technologies, specific to given crops, to control pests.

In the 1980's the IPM-concept developed into the Integrated Crop Management-System. In Germany we set up an Association for Integrated Crop Management (Fördergemeinschaft Integrierter Pflanzenbau). Starting in 1990 nowadays we are acting and developing it further into an "integrated farming system", because plant and animal husbandry are part of the whole integrated farm system. In 1993 we founded the European Initiative for Integrated Farming which up to now is a working party of six national associations: FIP (Fördergemeinschaft Integrierter Pflanzenbau in Germany), LEAF (Linking Environment and Farming in Great Britain), FARRE (Forum de L'Agriculture Raisonnée Respectueuse de L'Environnement in France), Odling i Balans (Radet för integrated Växtodling in Sweden), AGROFUTURO (Gestion Integrada de Cultivos in Spain), FILL (Fördergemeinschaft Integrierte Landbewirtschaftung in Luxembourg).

Regarding the concept of sustainable development, defined at the United Nations World Summit on the Environment in Rio de Janeiro 1992 it is clear that, to survive, all nations should no longer treat their economics, their social developments and environment as separate fields of activities.

The concept adopts an economic strategy, in which the use of energy and other finite resources is to be drastically reduced. Biodiversity, protection of water bodies, climate and soils are also advocated as essential elements of sustainability. These targets have important implications for agriculture. The emphasis of farming, whether arable or livestock-based, has to be put more strongly towards sustainable farm management practices.

Integrated farming as well as integrated crop management is a whole farm policy which aims to provide the basis for efficient and profitable production which is economically viable and environmentally responsible. It integrates beneficial natural processes into modern farming practices and aims to minimize farming inputs, while conserving, enhancing and recreating what ever is of environmental importance. This is achieved by combining crop rotation with the targeted use of crop protection chemicals as well as fertilizers, cultivation practices, variety selection and improved energy efficiency together with a positive management plan for landscape and wildlife features.

1 Paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997
ICM or IF does not lay down a set of specific prescriptions. It has, however, a set of principles and procedures which have to be applied, and they have to take account of the specific circumstances of a farm and its surroundings.

Integrated Crop Management

**The basic principles of ICM are:**

- to minimize the reliance on inputs such as fertilizers and crop protection chemicals, by considering alternatives;
- the maintenance and site-appropriate management of soil and its fertility;
- the efficient and responsible use of organic farm manures and crop residues in order to ensure that they are no threat to the health of soil, water, wildlife, humans and animals;
- to minimize pollution of water, air and soil;
- the overall reduction of fossil fuel use with the aim of improving the on-farm energy balance; the maintenance and improvement of site-appropriate ecological diversity and wildlife habitats;
- the maintenance and improvement of landscape and farm buildings together with the amenity value of the countryside.

**Procedures:**

*A key factor in the successful application of these principles is the adoption of planned rotational cropping so as:*

- to suit the farming system to the site (i.e. climate, location, soil and natural resources);
- to maintain or improve soil fertility on cropped land;
- to achieve agricultural bio-diversity by avoiding large areas of land laid down to one arable crop and/or variety;
- to identify and safeguard areas of environmental importance and sensitivity.

*In taking cropping and crop management decisions, it is also important to:*

- vary the choice of crops and varieties as to minimize pest and disease incidences;
- manage the crop environment in ways which are sympathetic to wildlife and landscape;
- ensure timely and appropriate operations with equipment best suited to the task, after making full use of available meteorological information;
- consider cultural and biological as well as chemical solutions to pest and disease problems;
- make full use of the available range of diagnostic and predictive techniques to ensure that only essential crop protection, fertilizers and other inputs are used;
- ensure accurate calibration of machinery used for applying pesticides or fertilizers;
- select and apply crop protection products (chemical or biological) in ways which ensure operator and consumer safety and seek to avoid environmental damage, such as to non-target species;
- ensure that applications of organic as well as inorganic fertilizers are matched to crop needs;
- ensure careful management and utilization of crop residues and use cover and cash crops, where appropriate, to avoid long periods of bare ground.

*Three crucial areas which also require close attention are:*

- efficient energy use;
- waste disposal and the minimization of pollution risks;
- safeguarding and, where possible, enhancing the ecological and landscape value of uncropped areas.
The successful application of the above principles and procedures requires careful planning, effective management and clear communication with all farm staff as well as contractors. It is also vital to keep abreast of new knowledge, technologies and practices and to be able to develop and adapt farming systems to respond to changing circumstances, knowledge and opportunities.

Politicians like FRANZ FISCHLER, member of the European Commission and responsible for agriculture, underlined:

"Both aspects of integrated farming, the economic rational and the environmental, reflect perfectly the thinking which has also entered into political decision making, geared towards sustainable agriculture. The idea of integration becomes more and more important in this context".

This must be seen with respect to the fact that the concept of sustainable development figures among the main objectives of the European Community policies in article 2 of the European Treaty and is given even more emphasis by the stipulation under article 130 r of this treaty to integrate the requirements of the environment into other Community policies.

WHY INTEGRATED FARMING OR INTEGRATED CROP MANAGEMENT?

Surveys of the public opinion in European Countries demonstrate that impacts resulting from agricultural production activities are seen as the most pressing within environmental problems. Air pollution ranks first, very closely followed by water pollution problems and drinking water quality. The ozone layer, deforestation, pollution of the oceans and pesticide residues in water and the foodchain are also most significant issues. It cannot be overlooked that the public holds widely varying opinions of agriculture. Many people, particularly those having little or no contact to farmers believe that they use the environment indifferently and do not treat it with the care it deserves. The image of farmers and agriculture is poor, regarding environmental problems. This is shown in Figures 2.1 and 2.2.

Environmental protection groups and organic farmers are seen and ranked as taking care and showing sufficient concern for the environment. "Normal farmers" however are rated on a median but very low level, nearly equal to national governments. Chemical industry received the lowest rating along with local governments.

This public opinion causes pressure, political activities and at least environmental legislation which farmers have to follow. The German fertilizer and fertilizing legislation and its very detailed regulations are a good example. (Figure 3)
Figure 2.1: To what extent do you agree or not with the following statements

all countries (in %)

- Generally people don’t think enough about the environment: 81% don’t agree, 11% agree, 8% don’t know.
- Most farmers keep in mind the environment when using pesticides: 69% agree, 16% disagree, 15% don’t know.
- Nowadays agriculture without the use of pesticides and fertilizers is impossible: 41% agree, 42% disagree, 17% don’t know.
- Without using fertilizers and pesticides growing world population could not be nourished sufficiently: 40% agree, 41% disagree, 19% don’t know.
- In agriculture the use of fertilizers and pesticides is higher than necessary: 56% agree, 24% disagree, 20% don’t know.

Figure 2.2

Which of the following groups shows sufficient concern for environmental problems

- ENVIRONMENTAL PROTECTION GROUPS
- ORGANIC FARMERS
- CONSUMERS
- LOCAL GOVERNMENT
- NATIONAL GOVERNMENT
- FARMERS
- NONE OF THESE GROUPS
- DO NOT KNOW, NO ANSWER
- CHEMICAL INDUSTRIE
- KEY LOCAL POLITICIANS
- KEY NATIONAL POLITICIANS

All countries %
The main problem arising from legislation is its generalizing impact. It allows no individual acting and organizing of production systems based on the special conditions of single sites possible. So innovations and new methods could be stopped or limited due to legal validity. There is an other point, however, which we have to take into account. It is the European extensification policy. While the main objective of the 1992 CAP-reform was to achieve an equilibrium of agricultural markets, the reform process became an additional important opportunity to integrate environmental requirements into the core of the CAP. Accordingly politicians argue that extensification is absolutely necessary because it serve environmental objectives as well as achieve market equilibrium. This false opinion has become quite common after environmental pressure groups picked it up and promoted extensive organic farming without any use of synthetic fertilizers and pesticides as the ecologically top ranking farming systems. Intensive farming with high yields of biomass and corresponding inputs of plant nutrients and plant protection products, however, is regarded as ecologically unfriendly by the general public. Residues of pesticides, leaching and run off of plant nutrients, soil erosion, changing of the site-specific biodiversity are discussed as general results from intensive farming. Especially the "water and nitrate" discussion is one of the main topics throughout Europe. Many people have developed a dangerous sense of complacency about the environment and agricultural situation. There is some confusion about the pathways of nitrogen inputs resulting from applications of mineral fertilizers and organic materials. The idea to charge taxes from mineral nitrogen fertilizers and to spend this money for investigations on a more efficient use of manure and other organic waste seems to be ridiculous. But like this, in environmental policies, not all opinions, decisions and actions are logical. The following figures give a short overview about the factual nitrogen balance in some German regions. The results are very clear: nitrogen imbalances and consequently nitrate problems are rising mainly from those areas with intensive animal husbandry. (Figures 4.1 and 4.2)

Explanation: By fragmentary balances, based on the inputs of manure and other organic farm fertilizers and symbiotic nitrogen fixing minus nutrient export by yields, the additional fertilizer need besides the nutrient input resulting from animal husbandry can be calculated. The nitrogen input by animal husbandry is limited to 70% of the total amount resulting from farm animals as 30% are calculated for gaseous losses.

The figures show results of North-Rhine-Westphalia. On a local basis, mainly by arable farming there is only a slight surplus of nitrogen while in areas with high intensities of pig and cattle husbandry the nitrogen input and output are totally imbalanced.

Consequently the total balances which include the input by mineral fertilizers and/ or other compounds are also extremely unequal. The nitrogen surplus ranges from approximately 50 kg/ha in areas with mostly arable farmers up to 200 kg/ha in those with intensive animal husbandry.

THE KEY ROLE OF INTEGRATED PLANT NUTRITION

Integrated plant nutrition has become a very important part of the overall system of integrated farming: Reasons are firstly the high improving effect of fertilizing on biomass production and yields and secondly on the impact of plant nutrients on environment compartments like soil, waterbodies flora and fauna (biodiversity) atmosphere etc.
In European countries these impacts are very intensively discussed, particularly with respect to nitrogen and phosphorus as water eutrophication agents. However, nitrogen is the key nutrient for soil fertility, plant growth and also animal husbandry, and the discussion of efficient and profitable farming is increasingly geared to the environmental impacts. It seems that nitrate for instance nowadays is mostly regarded as a poison rather than an absolutely necessary and important natural substance essential for life on earth.

As a consequence of high inputs of plant nutrients we have reached high levels of soil fertility. And this fertility is the main source for outputs into other ecological systems, particularly into water bodies. The European Drinking Water Directive and national legislation based thereon have raised a Europe-wide discussion on strategies to avoid increasing inputs and to minimize outputs. Plant nutrition management has become a mainly nitrate and in some cases also a phosphate defending strategy. The nitrate limit in drinking water was set up mathematically, calculating the daily human intake from average food consumption and then working out the amount a person of 70 kg weight could be permitted to consume with a daily intake of two litres of drinking water. The "permitted" intake is valued at 257 mg per day.

It should be underlined that up to now there are no scientific studies which confirm the hypothesis that nitrate could be a source of nitrosamines and therefore a cancerous agent. Also, the discussion about nitrate uptake and methemoglobinemia is still a hypothesis: "it could be". However for the past 30 years in Germany no report in medical reviews can be found reporting that nitrate intake from drinking water has caused this illness. Nevertheless we have to keep the limit of 50 mg nitrate per litre of drinking water. In all European countries this is fixed by water legislation. This leads to the utterly absurd situation, whereby drinking water containing 49 mg of nitrate per litre is considered safe to drink but a content of 51 mg per litre is deemed to be poisoned and undrinkable.

With respect to these politically but not toxicologically "set" values it may be asked how farmers can follow them and ensure that percolation of nitrate through the soil profile is kept below the limit?

Minimizing contaminations of aquifers represents a permanent task for farmers. The use of combinations of different measures in accordance with the strategy of integrated crop management allows farmers to optimize production methods and, simultaneously take account of ground water protection requirements. However, it is impossible to reduce the leaching of nitrogen from farm land to the level found in natural or near natural ecosystems. The aim has to be rather to adjust the supply of nitrogen to the level of its removal by crop products and to optimize nitrogen utilization with the aid of appropriate crop protection measures. This seems to be simple. But in reality it needs considerable knowledge and ingenuity of the farmers.

The natural leaching process is fed by three sources: the organic matter in soil and soil organisms, organic and mineral fertilizers and inputs from the air pathway. Ruling out losses of nutrients is impossible. The only chance is to minimize them. This does not simply depend on a strict input-output balancing. The real unknown nitrate quantity comes from the organic matter in the soil. High soil fertility depending on a high content of organic matter extremely complicates the strategies against nitrate leaching.

<table>
<thead>
<tr>
<th>Possibilities for minimizing nitrate contaminations from agriculture are:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. minimizing of periods without a growing, nutrient-consuming plant cover,</td>
</tr>
<tr>
<td>2. use of catch crops and undersowing,</td>
</tr>
<tr>
<td>3. use of varieties appropriate to the site,</td>
</tr>
</tbody>
</table>

7
• appropriate crop rotation,
• direct or mulch sowing,
• possible avoidance of certain crops,
• postponements of tillage for spring sowing until just before the crop is sown,
• calculation of nitrogen fertilizer requirements with due regard to the level in, and subsequent take-up from, the soil,
• consideration of the quantities of nutrients in the farm's own manure (content analyses),
• reduction of the nutrient level of farmyard manure by alteration of feeding strategies (phased feeding),
• use of the appropriate form of fertilizer, application technique, and nitrification inhibitors,
• maintenance of crop health via protection measures to improve the uptake of nitrogen.

INTEGRATED CROPPING, A GOOD WATER PROTECTING PRACTICE

For some years in the federal land North-Rhine-Westphalia of Germany, which has a high population density of about 17 million inhabitants, co-operations between farmers and water authorities have been established aiming for profitable farming as well as water protection on the same level of importance. After a working practice of about seven to eight years (in some areas more than ten) it has to be concluded: this strategy of co-operation works and pays, as long as the special regional and natural conditions are strictly taken into account. High efficiency in both farming and water protection can only be expected if they are consequently orientated to the site.

The following figure shows the course of the nitrate level in groundwater in a cooperation zone since 1986.

Integrated cropping and water protection are also economically efficient. This may be concluded from the fact, that the regional government of North-Rhine-Westphalia dispensed special regulations based on water protecting legislation because the results are quite satisfactory and the financial costs low.

A second example for the positive economic effect of integrated cropping can be drawn from the following results which have been collected from an advisory working party. Members included up to 40 farmers who were guided and advised by agronomical specialists. The following tables demonstrate the efficiency of nitrogen fertilizing in those groups.
Table 1: Efficiency of nitrogen fertilizing in wheat cropping

Yields and Nitrogen Fertilization in arable Farms 1980-1990
Winter-Wheat

<table>
<thead>
<tr>
<th>Group of results</th>
<th>(-) 25%</th>
<th>medium</th>
<th>(+) 25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium yield 1988-1990</td>
<td>82,50</td>
<td>73,60</td>
<td>84,50</td>
</tr>
<tr>
<td>100 kg/ha</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium N-fertilizing kg/ha</td>
<td>211,60</td>
<td>201,70</td>
<td>191,60</td>
</tr>
<tr>
<td>kg of N per 100 kg relative</td>
<td>3,4</td>
<td>2,7</td>
<td>2,3</td>
</tr>
<tr>
<td>mean soil quality</td>
<td>51,0</td>
<td>61,0</td>
<td>66,70</td>
</tr>
</tbody>
</table>

(JANINHOFF 1997)

Table 2: Efficiency of nitrogen fertilizing in barley cropping

Yields and Nitrogen Fertilizing in arable Farms 1980-1990
Winter Barley

<table>
<thead>
<tr>
<th>Group results</th>
<th>(-) 25%</th>
<th>medium</th>
<th>(+) 25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium yield 1988-1990</td>
<td>59,40</td>
<td>70,0</td>
<td>78,60</td>
</tr>
<tr>
<td>100 kg/ha</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium N-fertilizing kg/ha</td>
<td>160,90</td>
<td>165,0</td>
<td>160,80</td>
</tr>
<tr>
<td>kg of N per 100 kg relative</td>
<td>2,70</td>
<td>2,4</td>
<td>2,1</td>
</tr>
<tr>
<td>mean soil quality</td>
<td>53,00</td>
<td>60,30</td>
<td>67,60</td>
</tr>
</tbody>
</table>

(JANINHOFF 1997)
Table 3: Efficiency of nitrogen fertilizing in sugar beet cropping

Yields and Nitrogen Fertilization in arable Farms 1980-1990
Sugar beet

<table>
<thead>
<tr>
<th>Group results</th>
<th>(-) 25%</th>
<th>medium</th>
<th>(+) 25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium yield 1988-1990 100 kg/ha</td>
<td>425,70</td>
<td>523,20</td>
<td>636,90</td>
</tr>
<tr>
<td>Medium N-fertilizing kg/ha</td>
<td>167,40</td>
<td>164,90</td>
<td>160,20</td>
</tr>
<tr>
<td>kg of N per t relative</td>
<td>3,90</td>
<td>3,10</td>
<td>2,50</td>
</tr>
<tr>
<td></td>
<td>127,00</td>
<td>100,00</td>
<td>81,50</td>
</tr>
<tr>
<td>mean soil quality</td>
<td>57,50</td>
<td>64,40</td>
<td>70,30</td>
</tr>
</tbody>
</table>

(JANINHOFF 1997)

Table 4: Efficiency of nitrogen fertilizing in rape cropping

Yields and Nitrogen Fertilization in arable Farms 1980-1990
Winter rape

<table>
<thead>
<tr>
<th>Group results</th>
<th>(-) 25%</th>
<th>medium</th>
<th>(+) 25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium yield 1988-1990 100 kg/ha</td>
<td>26,00</td>
<td>31,60</td>
<td>37,60</td>
</tr>
<tr>
<td>Medium N-fertilizing kg/ha</td>
<td>214,20</td>
<td>205,20</td>
<td>187,40</td>
</tr>
<tr>
<td>kg of N per t relative</td>
<td>8,20</td>
<td>6,50</td>
<td>5,0</td>
</tr>
<tr>
<td></td>
<td>127,00</td>
<td>100,00</td>
<td>76,70</td>
</tr>
<tr>
<td>mean soil quality</td>
<td>52,30</td>
<td>54,30</td>
<td>57,00</td>
</tr>
</tbody>
</table>

(JANINHOFF 1997)

Successful farmers use up to 40% less fertilizer than those who are not so efficient and about 20 % less than their colleagues in a medium range. The "turnover rates" of nitrogen per 100 kg wheat or barley, resp. per t. of sugar beet or rape show high differences between the three groups "most", "medium" and "less" successful.
INTEGRATED FARMING AND WORLD POPULATION

Considerable disagreement prevails on the magnitude and nature of the world’s food and environmental problems. Many people in industrialized countries believe that future food needs will be met through technological innovations which will happen without any special effort to increase food production. They also believe that the dangers of resource losses have been exaggerated and that the global food surplus is a sufficient guarantee for world food security, even for low income countries and their people. Others counter that the limits of production are being reached, that new technologies will not be able to raise agricultural productivity sufficiently to meet growing needs and that natural resources are being depleted at an alarming rate. Some of these believe, world food needs could be met, concerning the daily food energy uptake, by world wide organic farming. An impressive answer to this opinion can be shown with the following figure which illustrates data about the additional need of agricultural land to meet the food demand.

Figure 6

The "2020 Vision for Food, Agriculture and Environment", published in 1995 by the International Food Policy Research Institute pointed out the most important topics, giving nine different key challenges which must be overcome in order to eradicate poverty and hunger, and bring food security and sufficient nutrition for all the people of the world. Sustainable and highly productive techniques which do not harm the natural resources are essential to secure this. Integrated plant nutrition and fertilizing systems and integrated pest management have to be developed and adapted to specific regional and natural conditions. That needs a substantial increase in research, consultation and use of fertilizers primarily in developing countries.
Fertilizers play also a key role in enhancing the natural resource base. For example: the depletion of soil nutrients is a critical constraint on food production. In most developing countries the problem is not an excessive but insufficient fertilizer use. In the past 40 to 50 years nearly 2 billion hectares of a total of 8.7 billion hectares (arable land, permanent pastures, forest and woodland) have been degraded. 750 million hectares of middle degraded land could be restored through good agricultural practices, including sufficient fertilizing. 900 million hectares of moderately degraded land need to be restored by significant on-farm investments and an immediate compensation of depleted nutrients.

SUMMARY AND CONCLUSION

- The soil is a fundamental natural resource.
- Careful management is paramount, because without it many of the other inputs to an Integrated Crop Management will be negated.
- The aim of a planned soil management and crop nutrition policy is:
  - to maintain and enhance soil structure and stability (resistance to erosion),
  - to protect natural fertility, soil fauna and flora,
  - to optimize crop growth and health.

Soil management and crop nutrition are linked very tightly.
Therefore a farm soil map, is essential.
It should include details of
- soil type (textures),
- pH,
- organic matter levels,
- depth of top soil,
- pans,
- impermeable layers,
- areas with special requirements.
These information details are essential for:
- planning,
- cultivation practices and mechanisms,
- soil water management,
- crop nutrient management.

How to improve water management and crop nutrition management?
- Soil erosion can occur through wind and water.
- Risks have to be identified and minimized by:
  - cover cropping, permanent grass, erosion breaks,
  - avoiding excessive cultivation,
  - cultivation along contours,
  - using uncultivated grass buffers alongside water courses,
  - drainage maintenance,
  - autumn crops,
  - management of organic manures particularly with high proportions of water.
The aim of crop nutrition is to optimize and make best use of natural fertility and to supplement it where necessary:

- adopting a cropping and soil care strategy that avoids nutrient losses
  - green cover out of season,
  - minimum tillage,
  - rapid crop establishment after ploughing.
- determination of nutrient levels every 3 to 5 years (P, K, Mg, pH status),
- conducting mineral nitrogen analysis and leaf tissue analyses,
- analyzing nutrient contents of organic manures,
- calculating detailed fertilizer requirements,
- adopting a strategy to minimize nitrate leaching,
- using professional advice,
- ensuring that operators are trained and familiar with the fertilizers to be used and the fertilizer applicator,
- determining precisely nitrogen requirements and time of spreading,
- taking care of nitrate sensitive and vulnerable zones,
- taking into account: each kg of plant nutrient which is spread unnecessarily contributes to minimize benefits and profit and may have negative impacts on the environment.
UNE INITIATIVE FRANÇAISE EN VUE DE MODIFIER
LES PRATIQUES AGRICOLES POUR LIMITER LA POLLUTION
DES EAUX PAR LES NITRATES : L’OPERATION FERTI-MIEUX

par
A. Mouchart
Ferti-Mieux-ANDA, France
SUMMARY

Limiting the risk of water pollution from nitrates of agricultural origin is a concern which is shared by all the countries of the European Union.

Ferti-Mieux is not the only operation in France with this objective. There are other programmes in the context of the application of the European Nitrate Directive 91/676/EEC, and also agro-environmental measures for the reduction of inputs. However, Ferti-Mieux can claim to be the first in this field.

Ferti-Mieux is based on two observations:
• The information required to give correct advice is generally already available.
• It is necessary to operate on the basis of a catchment area.

The principles followed are that:
• Participation is voluntary.
• There is a consensus.

There must be consensus on a national basis, between the Ministry of Agriculture, the farmers' associations, the fertilizer associations, other Ministries etc., and at the local level, between farmers, advisors, consumers, water agencies etc.

Ferti-Mieux has defined the steps to be taken in order to obtain, in a given area, a progressive change in agricultural practices which could risk polluting water:
• Identification of the practices which increase the risk of nitrate pollution.
• Assessment of the impact of changes in farmers' practices.

This is to be achieved by;
• Classifying farms, using input-output analyses for average farms.
• Ranking the risks related to particular cropping systems
• Quantifying the risks in terms of probable nitrate flows.

An approved Ferti-Mieux operation, which respects the guidelines, is recognized by a label, which is attributed, for one or two years, by three different national bodies. The label provides a guarantee, for farmers, advisors, financial bodies and the general public.

To date there have been 54 approved Ferti-Mieux operations. There are different initiators, but generally the initiator is a farmers' association. The operations concern 1300 communes in 46 Departments, covering 1.5 million ha and 26 000 farmers. Most of the Ferti-Mieux operations are located in "vulnerable zones" as defined by the EU Nitrate directive.

La limitation des risques de pollution des eaux par les nitrates d'origine agricole est une préoccupation largement partagée par les pays de l’Union Européenne.

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1 Exposé présenté à la réunion du Comité Agro-Economie de l'IFA à Tours, France, les 23 et 25 juin 1997

Mai ce n’est pas dans le calendrier qu’il faut rechercher l’originalité de l’opération Ferti-Mieux. Cette originalité tient, en fait, à la démarche proposée à partir de deux constats et aux principes d’action qui la soutiennent.

**Deux constats**

1 - Dans la plupart des cas, des références techniques, scientifiques et méthodologiques sont disponibles dès le démarrage de l’action pour mieux raisonner la fertilisation et agir sur l’ensemble des pratiques agricoles en fonction du cycle de l’eau et de l’azote … Mais elles sont dispersées chez les partenaires et elles sont parfois enfouies au fond de tiroirs ou de placards.

Il est donc généralement possible de donner des conseils pertinents aux agriculteurs dès le démarrage d’une action locale de conseil.

2 - L’eau circule. Sous terre, elle alimente des nappes de dimension bien supérieure à la parcelle. À la surface du sol, il est bien connu que les petits ruisseaux font les grandes rivières.

La protection efficace d’une ressource en eau amène donc à agir dans la mesure du possible sur l’ensemble de son bassin d’alimentation, avec la participation de tous les partenaires concernés, en particulier celle de l’ensemble des agriculteurs et de leurs conseillers techniques.

**Des principes**

Le cahier des charges de l’opération Ferti-Mieux basé sur un certain nombre de principes qui lui confèrent son originalité.

**Des actions basées sur le volontariat**

Ferti-Mieux s’adresse aux agriculteurs et aux organismes de conseil sur la base du volontariat et de la responsabilisation.

Dans les régions, la mise en place d’actions FERTI-MIEUX est le fruit d’initiatives locales. S’il est exigé la mise en place de comités locaux pour accompagner l’action, leur organisation et leur mode de fonctionnement sont gérés par les partenaires locaux.

Il revient également à ces instances de définir la stratégie de l’élaboration et de la diffusion du conseil et de la promotion de l’opération tant auprès des agriculteurs pour obtenir leur adhésion à la démarche, que du grand public pour faire connaître les actions engagées.

**Des actions basées sur le consensus**

*Consensus au niveau national*

En 1991, le ministère de l’Agriculture confie la mise en place et la gestion de l’opération Ferti-Mieux à l’Association Nationale pour le Développement Agricole (ANDA), organisme géré paritairement par les organisations professionnelles agricoles et les pouvoirs publics dont la mission est de favoriser la cohérence des programmes de développement et stimuler les initiatives.

*Consensus au niveau local*

Localement, pour se donner les meilleures chances de réussite, chaque action doit mobiliser le plus grand nombre possible d’acteurs concernés par la qualité de l’eau, qu’il s’agisse des agriculteurs, des agents du conseil aux agriculteurs mais aussi de ceux qui ont la charge de la distribution de l’eau et du contrôle de la qualité de cette eau, ou, encore des collectivités territoriales, des associations de consommateurs, …

C'est le rôle du Comité de Pilotage qui, sous la responsabilité de son Président, définit la stratégie générale de l'opération et assure à l'animateur de l'opération la collaboration des compétences nécessaires.

Chaque action se dote également d’un Comité Technique pour la mise au point des conseils et de la communication. Lieu d’échange d’expériences et de références techniques, ce comité est notamment chargé de rechercher une harmonisation des messages diffusés par les différents prescripteurs intervenant sur la zone, auprès des agriculteurs.

*Enfin, concernant le volontariat et le consensus, ajoutons :*

--> qu’ils constituent deux atouts pour limiter durablement les pertes de nitrates dans les eaux
--> que l’accent mis sur ces deux aspects confère aux actions Ferti-Mieux une dimension d’expérimentation sociale.

*Des opérations visant à modifier les pratiques « à risque »*

*Une obligation de moyens*

L’évaluation de l’efficacité des actions de type Ferti-Mieux par le seul suivi de la qualité de l’eau est délicate.

En effet, même s'il existe une unité hydrogéologique qui peut permettre à terme une évaluation sur la qualité des eaux, les connaissances hydrogéologiques sont encore souvent insuffisantes pour évaluer le temps qu’il s’écoulera entre la modification des pratiques et celle de la qualité de l’eau.

Aussi, sauf situations exceptionnelles comme, par exemple, la protection d'une nappe très peu profonde et bien délimitée ou celle d'un ruisseau alimenté par ruissellement superficiel ou hypodermique rapide, il est très difficile de prévoir si la modification des pratiques agricoles se traduira sur la qualité de l'eau dans 3, 10 voire 50 ans. De plus, lorsqu'une évolution positive sera observée, encore faudra-t-il s'assurer qu'elle soit durable et non simplement liée aux conditions climatiques saisonnières.

C'est pourquoi, Ferti-Mieux s’est fixé une **obligation de moyens**, c'est à dire d'obtenir sur la zone d'action une modification progressive des pratiques agricoles susceptibles de polluer la ressource en eau à protéger.

*L’identification des situations à risque pour définir les priorités*

Pour modifier les pratiques à risque, il faut bien sûr les identifier. Cela nécessite de faire un diagnostic qui intègre les connaissances acquises sur l'hydrogéologie, la pédologie et climat de la
zone concernée ainsi que toutes les informations disponibles sur les systèmes de production, les systèmes de cultures et sur les pratiques des agriculteurs et de leurs conseillers.

Les investigations dans ces différents domaines permettent de construire une grille de risque telle que proposée par M. SEBILLOTTE et J.M. MEYNARD. Cette grille permet de hiérarchiser les situations définies par les systèmes de culture et le milieu en fonction :
- des risques de lixiviation de l’azote hors de portée des racines durant les cycles culturaux,
- de la variabilité interannuelle des potentialités agricoles qui rend plus ou moins difficile la prévision des niveaux de productions.

Elle constitue un outil de décision très précieux pour définir les situations sur lesquelles doivent porter prioritairement les actions et établir un calendrier de travail en fonction de l'ampleur de la tâche et des moyens financiers disponibles.

L'évaluation des modifications des pratiques des agriculteurs

Ferti-Mieux s'est fixé comme objectif de modifier les pratiques pour limiter les risques de pollution de l'eau. Il est donc logique que l'accent ait été mis sur l'évaluation des modifications des pratiques des agriculteurs, lors de l'évaluation des actions Ferti-Mieux,

Il est en effet nécessaire de prouver que les modifications des pratiques vont dans le sens d'une réduction des risques de rejets de nitrates dans le milieu. Un guide méthodologique est en cours d'édition.

La démarche proposée comporte 3 étapes progressives qui aboutissent :

- Etape 1 : au classement des types d'exploitations identifiés lors du diagnostic, la hiérarchisation des risques étant organisée selon les valeurs du solde "entrée - sorties " diffusé par le CORPEN, établi pour une exploitation moyenne,
- Etape 2 : à la hiérarchisation des risques liés aux situations culturales par groupes de parcelles ou parcelles moyennes, en utilisant la grille de risque déjà évoquée à propos du diagnostic. Cette étape fournit une idée précise de l'extension des risques et de leur localisation,
- Etape 3 : à la construction d'un tableau de bord quantitatif de l'impact des pratiques, exprimé en flux de pertes probables de nitrates.

Des opérations reconnues par un label

S’ils disposent de beaucoup de latitude dans l’organisation de l’action au plan local, les responsables des opérations se doivent de respecter le cahier des charges dont les principes viennent d’être évoqués.

Il est également essentiel que les conseils diffusés répondent à des critères scientifiques et techniques et, surtout, contribuent à réduire les risques aussi loin que possible.

Enfin, les actions Ferti-Mieux ont tout intérêt à être reconnues officiellement pour témoigner des efforts des agriculteurs en faveur de l'environnement.

C'est le rôle des instances nationales : 

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2 M. SEBILLOTTE, Professeur d'Agronomie et Directeur Scientifique à l'Institut National de Recherche Agronomique
J.M. MEYNARD, Directeur de recherche à l'Inra et Directeur de l'unité agronomique de l'Inra - INAPG
- le Comité National de Pilotage, présidé par Jean SALMON agriculteur dans les Côtes d'Armor, qui regroupe les différents partenaires de la qualité de l'eau. Il délivre un pré-label puis un label, aux actions locales qui répondent au cahier des charges de l'opération.

- le Comité Scientifique et Technique présidé par Michel SEBILLOTTE, qui juge la conformité des actions locales au cahier des charges. Il réunit des chercheurs de différentes disciplines scientifiques et des experts de terrain (25 environ).

- le Secrétariat Technique qui assure le lien entre les instances nationales et les actions locales. Il suit les actions, instruit les dossier de candidature et réalise des travaux en liaison avec le Comité Scientifique et Technique.

Attribué pour un à deux ans et renouvelable, le label garantit ainsi :

- aux agriculteurs, un appui technique efficace et la reconnaissance de leurs efforts,
- aux prescripteurs, la cohérence et la qualité de leurs interventions,
- aux partenaires financiers, le bon emploi de leurs contributions,
- au grand public, que les agriculteurs se mobilisent et adaptent leurs pratiques pour préserver la qualité de l'eau.

54 actions locales de conseil sur le terrain

Réparties sur l'ensemble du territoire, les 54 actions labellisées (12 pré-labellisées et 42 labellisées) témoignent du succès de la méthode et de l'intérêt de l'avoir conçue avec une pédagogie de responsabilité progressive.

Les initiateurs de ces actions sont multiples, mais la profession agricole en est le plus souvent à l'origine. L'initiative qui peut être spontanée, répond souvent à une demande forte des acteurs de l'eau et des élus, préoccupés par l'alimentation en eau de zones rurales ou urbaines (par exemple, Paris, Rennes, Perpignan) et par la protection de ressources en eau représentant un enjeu touristique fort. L'animation des opérations est généralement assurée par des ingénieurs et techniciens des Chambres d'Agriculture départementales.

Ces actions concernent actuellement 1300 communes réparties dans 46 départements et couvrent environ 1,5 million d'hectares où vivent 26 000 agriculteurs. Leur diversité reflète des enjeux multiples, économiques ou sociaux, des tailles de zone d'action variables, de 1000 à 100 000 ha (en moyenne de 25 000 ha), des systèmes de production différents, grande culture, élevage dont hors-sol, cultures spécialisées dont maraîchage, viticulture, arboriculture, etc…, des nombres plus ou moins importants d'agriculteurs sur la zone. Cette diversité illustre bien la priorité donnée à l'initiative locale.

Une opération reconnue

La plupart des zones concernées par les actions Ferti-Mieux se situent en zone vulnérable définie dans le cadre de la Directive européenne déjà évoquée.

La question s’est donc posée de savoir comment pouvaient se positionner les actions Ferti-Mieux par rapport à la mise en œuvre des programmes d’action, notamment lorsque l'action Ferti-Mieux ne couvre qu'une partie de la zone vulnérable.

Sans entrer dans les détails, il convient de souligner que les actions locales Ferti-Mieux ont la possibilité de poursuivre leur travail selon leur propre dynamique en adoptant un statut spécifique.
Cette possibilité d'adoption d'un statut spécifique ne dispense pas du respect de certaines dispositions prévues dans le code des bonnes pratiques agricoles et de la fourniture des informations nécessaires à l’évaluation des programmes d’action à l’échelle départementale et locale.

Mais, elle constitue une reconnaissance de l’intérêt et du sérieux de l’opération Ferti-Mieux.

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RESPONSE OF WHEAT TO N-FERTILIZER UNDER THE CROPPING SYSTEMS OF NEWLY RECLAIMED DESERT LAND AND OLD IRRIGATED LAND IN EGYPT

by

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M. Sherief
Soil, Water and Environment Research Institute, Agricultural Research Center (ARC), Giza, Egypt
RESPONSE OF WHEAT TO N-FERTILIZER UNDER THE CROPPING SYSTEMS OF NEWLY RECLAIMED DESERT LAND AND OLD IRRIGATED LAND IN EGYPT

by

M. Abdel Monem, H. Khalifa, A. Eissa and M. Sherief

(Note: Certain figures are not included)

Abstract

Extending agriculture to desert land is one of the major components of the national agricultural strategy to increase agricultural production in Egypt. As most of the newly reclaimed soils are sandy and calcareous, with poor organic matter and macro- and micronutrient content, application of fertilizers is important for crop production in these soils. Fertilizer management practices for the cropping systems in the newly reclaimed desert land are different from those in the old irrigated land of the Nile Valley. In this study a field trial was conducted in two locations, representing the sandy soil of the newly reclaimed land and the clay irrigated land of the Nile Valley, to compare nitrogen and water use efficiency of two wheat varieties as affected by N rate and irrigation regime. Nitrogen fertilizer was applied at four rates as ammonium sulfate applied in two split applications in the clay soil, and in five split applications for the sandy soil. Two irrigation treatments were used. Surface irrigation was used for the clay soil, and sprinkler irrigation was practiced in the sandy soil. Biological yield of wheat as well as N-recovery varied according to soil texture, rate of fertilizer and wheat variety. Average nitrogen recovery was 45% and 25% for wheat grown in the clay and sandy soils respectively. Values of N recovered by Sakha 69 are higher than that of Sids 6 in both sites. However, values of N recovery by both cultivars are always higher in case of the clay soil than the sandy soil. Water consumptive use values WUE \( (m^3/ha) \) for the two wheat cultivars is affected by irrigation treatments and locations. Data indicated that average CU values for both cultivars at the sandy soil were about 23% higher than the values at the clay soil. Also Sids 6 consume more water than Sakha 69. As water use efficiency is estimated, it was found that it is higher for Sakha 69 (1.11) than that of Sids 6 (0.77). Average WUE value at the clay soil (1.26) was higher than that at the sandy soil (0.62). Results suggests that Sakha 69 wheat is more efficient in using nitrogen and water.

Introduction

Egypt occupies a total area of about one million square kilometers, or 238 million feddans (one feddan = 0.42 hectare) of which only a small portion (about 3.5%) is agriculturally productive, while desert occupies 96% of Egypt's territory. The old irrigated land with an area of 5.4 million feddans laying within the Nile Valley and Delta. It represents the most fertile soils in Egypt, which is alluvial, level, deep, dark brown and medium to heavy in texture. According to USDA soil taxonomy, the order Vertisiol dominates the major part of the old land. Agriculture in Egypt is almost entirely dependent on irrigation; the country has no effective rain except in a narrow band along the northern coastal areas (about 150 mm/yr). Egypt has only one main source of water, the River Nile. Intensive land reclamation projects in Egypt started early in the fifties and continued until now to develop and utilize new lands and to intensify and diversify agricultural and livestock production to meet the growing national demand for food. Most of the newly reclaimed soils are sandy and calcareous (about 84% is sandy). The newly reclaimed areas depend on irrigation water either from canals coming from the Nile or underground water. Usually modern irrigation systems (sprinkler and drip) are used. Wheat is the staple food crop in Egypt where the national consumption reaches about 10 million

1 Poster paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997
2 Nile Valley and Red Sea Regional Program, the International Center for Agricultural Research in the Dry Areas (ICARDA), Cairo, Egypt
3 Field Crops Research Institute, Agricultural Research Center (ARC), Giza, Egypt
4 Soil, Water and Environment Research Institute, Agricultural Research Center (ARC), Giza, Egypt
tons, while the production reached 5.7 million ton in 1996. Contribution of the newly reclaimed land for the wheat production increased from 112 thousand tons in 1990 to more than half million tons in 1996. The potential of increasing area and productivity is high, wheat became appealing to farmers as the price increases after agricultural market liberalization policies were initiated.

Producing the massive quantities of food materials needed in Egypt, would have been impossible today without using fertilizers. Results of a soil fertility survey study carried out by the Soils and Water Research Institute (ARC 1994), where 5670 soil samples representing eleven governorate were collected, indicated that the tested samples contain an adequate concentration of potassium, 36% were poor in phosphorus and 75% were poor in nitrogen. Total fertilizer consumption in Egypt was increased about 69%, while the increase in nitrogen fertilizer consumption was 77% in 1994 as compared with 1980 (IFDC 1993). The intensive agricultural farming system, where the crop rotation consists of 2 or 3 crops per year, adding new cultivated areas, and the gradual increase in the recommended fertilizer rate for various crops are the main reasons for the high consumption of fertilizers in Egypt (Hamissa and El Mouwelhi 1989). Several studies show that, efficient use of the applied N fertilizers by the various crops in Egypt is poor.

The objectives of these field trials were to 1) Compare productivity of the newly introduced cultivar (Sids 6) and the tradition one (Sakha 69) under the newly reclaimed sandy soil and the old irrigated land of the Nile Valley, 2) Assess the response of the two wheat cultivars to N fertilizer rates and irrigation regimes, 3) Determine the actual water consumptive use and water use efficiency for the wheat cultivars, 4) Estimate the nitrogen use efficiency for the added fertilizer for each cultivar under both soil conditions.

**Material and Methods**

1- **Giza site:** The site represents the old irrigated clay soil. Chemical and physical properties of the soil are presented in Table 1. The experiment plot was planted in 1995/1996 growing season on 17 November 1995. A split-split plot design was used where two irrigation treatments represented the main plots, two wheat cultivars represented the sub-plot and four N-fertilizer levels represented the sub sub-plots with three replicates. The experimental unit used in the trial was 20 m². The two irrigation treatments were I1 (required level, irrigating to replenish the difference in water content at field capacity and water content before the next irrigation) and I2 (75% of the amount of irrigation water applied in I1). Two wheat cultivars namely Sakha 69 (traditional cultivar) and Sids 6 (newly released long-spine cultivar) were compared. The N-fertilizer levels were 0, 70, 140 and 210 kg N/ha. Phosphorus fertilizer was applied at one rate of 150 kg P₂O₅ /ha, while nitrogen fertilizer was applied as ammonium sulfate in two splits. The first (1/3 N-rate) was applied after 21 days from planting, while the second (2/3 N-rate) was applied at the growing stage of Z-31. Grain and straw yields from each plot were recorded to determine the effect of the tested variables on wheat yield, water consumptive use and water use efficiency. Surface irrigation system was used and the amount of water consumption was determined by collecting soil samples at sowing, before and after each irrigation and at harvest time. The depth of water applied at each irrigation was calculated according to the formula suggested by Israelson and Hansen (1962). The data were subjected to the proper analysis using the CoHort (1986) statistical package. Average values from the three replicates of each treatment were interpreted using the analysis of variance (ANOVA). Also, the Student-Newman-Keuls Test was used for comparisons between means.
Table 1: Chemical and physical properties of the soil at Giza.

<table>
<thead>
<tr>
<th>Organic Matter</th>
<th>pH</th>
<th>CEC meq/100g soil</th>
<th>EC dS/m</th>
<th>Clay %</th>
<th>Silt %</th>
<th>Sand %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.80</td>
<td>8.4</td>
<td>50</td>
<td>0.7</td>
<td>53</td>
<td>31</td>
<td>16</td>
</tr>
</tbody>
</table>

2-Ismailia site: The site represents the newly reclaimed sandy soils. Chemical and physical properties of the soil are presented in Table 2. The experiment was planted in 1995/1996 growing season on 23 November 1995. The same experimental design, tested variables and statistical analysis techniques were used as in Giza site. The experimental unit was 42 m². N fertilizer levels used in this site were 70, 140, 210 and 280 kg N/ha applied in five splits. Sprinkler irrigation system was used for applying the irrigation water. The irrigation treatments were performed by varying the distances between sprinklers and between laterals such that the number of sprinklers for the I2 treatment were three fourth those of the I1 irrigation treatment. The depth of applied water for each irrigation was determined by collecting gravimetric soil samples.

Table 2: Chemical and physical properties of the soil at Ismailia.

<table>
<thead>
<tr>
<th>Organic Matter</th>
<th>pH</th>
<th>CEC meq/100g soil</th>
<th>CaCO₃</th>
<th>Clay %</th>
<th>Silt %</th>
<th>Sand %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25</td>
<td>8.1</td>
<td>11</td>
<td>2.0</td>
<td>9</td>
<td>4</td>
<td>87</td>
</tr>
</tbody>
</table>

Results and Discussions:

1 -Wheat response to fertilizer and N recovery:

Data presented in Table 3 show that, as an average for all N treatments, grain and straw yield of Sakha 69 is significantly higher than Sids 6 (36.6% and 47.9% higher in grain and straw yield respectively). The newly released cultivar Sids 6 has long spikes, however its yield is lower than Sakha 69 this due to its lower tillering. Data of table 3 also revealed that, application of N fertilizer resulted in significant increase in grain and straw yield of the both cultivars tested. However, percentage of increase for the cultivar Sakha 69 was higher than that of cultivar Sids 6. While percentage of grain yield increase for Sakha 69 was 33, 41 and 78 for the application of 70, 140, and 210 kg N/ha, those percentages were 19, 34, and 50 for Sids 6.

Compared to the average yield at Giza, grain and straw yield at Ismailia under the sandy soil conditions (Table 4) is lower. Grain yield obtained from the control plot where N= 0 kg N/ha at Giza (3.676 Mg/ha) is higher than yield obtained from the first rate applied at Ismailia where N= 70 kg N/ha (2.306 Mg/ha), reflecting the poor chemical and physical properties of that sandy soil (Table 2). Similar to its performance in the clay soil, yield of Sakha 69 is significantly higher (33.5% and 25.5% in grain and straw yield respectively) than Sids 6. Mitkess et al. (1992) reported that Sakha 69 responded significantly to N fertilizer under different environmental conditions.
Table 3: Average grain yield of two wheat cultivars (Mg/ha) as affected by irrigation treatments and nitrogen rates at Giza:

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>N-Level</th>
<th>Grain Yield (ton/ha)</th>
<th>Straw Yield (ton/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sakha 69</td>
<td>N000</td>
<td>3.676</td>
<td>7.598</td>
</tr>
<tr>
<td></td>
<td>N070</td>
<td>4.876</td>
<td>11.382</td>
</tr>
<tr>
<td></td>
<td>N140</td>
<td>5.181</td>
<td>13.174</td>
</tr>
<tr>
<td></td>
<td>N210</td>
<td>6.555</td>
<td>14.860</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>5.072</td>
<td>11.753</td>
</tr>
<tr>
<td>Sids 6</td>
<td>N000</td>
<td>2.953</td>
<td>6.304</td>
</tr>
<tr>
<td></td>
<td>N070</td>
<td>3.505</td>
<td>7.282</td>
</tr>
<tr>
<td></td>
<td>N140</td>
<td>3.950</td>
<td>8.286</td>
</tr>
<tr>
<td></td>
<td>N210</td>
<td>4.436</td>
<td>9.926</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>3.711</td>
<td>7.949</td>
</tr>
</tbody>
</table>

LSD (0.05) values for:
- diff. N-level & same cultivar
- same N-level & diff. cultivar

<table>
<thead>
<tr>
<th>N</th>
<th>ANOVA effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>*** (0.263)</td>
</tr>
<tr>
<td>Cultivar</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>*** (0.558)</td>
</tr>
<tr>
<td>N X I</td>
<td>NS</td>
</tr>
<tr>
<td>N X C</td>
<td>***</td>
</tr>
<tr>
<td>C X I</td>
<td>NS</td>
</tr>
<tr>
<td>N X C X I</td>
<td>NS</td>
</tr>
</tbody>
</table>

Values between practices represent the LSD at 0.05 significant levels for the averages.
***, *** Significant at the 0.1, 0.01 and 0.001 probability levels, respectively.

Table 4: Average grain yield of two wheat cultivars (Mg/ha) as affected by irrigation treatments and nitrogen rates at Ismailia

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>N-Level</th>
<th>Grain Yield (ton/ha)</th>
<th>Straw Yield (ton/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sakha 69</td>
<td>N070</td>
<td>2.306</td>
<td>3.880</td>
</tr>
<tr>
<td></td>
<td>N140</td>
<td>3.313</td>
<td>4.937</td>
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<tr>
<td></td>
<td>N210</td>
<td>3.484</td>
<td>6.016</td>
</tr>
<tr>
<td></td>
<td>N280</td>
<td>3.635</td>
<td>5.865</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>3.184</td>
<td>5.174</td>
</tr>
<tr>
<td>Sids 6</td>
<td>N070</td>
<td>1.751</td>
<td>3.328</td>
</tr>
<tr>
<td></td>
<td>N140</td>
<td>2.431</td>
<td>3.986</td>
</tr>
<tr>
<td></td>
<td>N210</td>
<td>2.587</td>
<td>4.287</td>
</tr>
<tr>
<td></td>
<td>N280</td>
<td>2.773</td>
<td>4.893</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>2.385</td>
<td>4.123</td>
</tr>
</tbody>
</table>

LSD (0.05) values for:
- diff. N-level & same cultivar
- same N-level & diff. cultivar

<table>
<thead>
<tr>
<th>N</th>
<th>ANOVA effect</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>*** (0.376)</td>
</tr>
<tr>
<td>Cultivar</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>*** (0.339)</td>
</tr>
<tr>
<td>N X I</td>
<td>NS</td>
</tr>
<tr>
<td>N X C</td>
<td>NS</td>
</tr>
<tr>
<td>C X I</td>
<td>NS</td>
</tr>
<tr>
<td>N X C X I</td>
<td>NS</td>
</tr>
</tbody>
</table>

Values between practices represent the LSD at 0.05 significant levels for the averages.
*, **, *** Significant at the 0.1, 0.01 and 0.001 probability levels, respectively.
Data presented in Figure 1 illustrate that the values of N recovered by Sakha 69 are higher than that of Sids 6, indicating higher N use efficiency by Sakha 69 in both sites. However, values of N recovery by both cultivars are always higher in case of the clay soil than the sandy soil. In different study conducted in heavy clay soil of the Nile Valley, Abdel Monem (1996) found that percentage of N recovery by the wheat cultivar Sakha 69 as estimated by $^{15}$N method averaged 46%. High percentage of the unrecovered N by plant is lost in sandy soil as estimated to be as high as 49% (Soliman et al 1993).

II- Water Consumptive Use (CU) and Water Use Efficiency (WUE):

Water consumptive use values (m$^3$/ha) for the two wheat cultivars as affected by irrigation treatments and locations are presented in Figure 2. Data indicated that average CU values for both cultivars at Ismailia (sandy soil) were about 23% higher than the values at Giza (clay soil). The average water consumptive use values for Sids 6 were 7% and 4% higher than the average CU values for Sakha 69 at Giza and Ismailia sites, respectively. Average CU values for I2 irrigation treatment were about 2 cm less than those of I1. Serry et al. (1980) reported that average CU values for wheat were 38.3, 47.5 and 52.3 cm for Lower, Middle and Upper Egypt, respectively. While the CU values for wheat crop grown in the newly land under sprinkler irrigation system ranged between 52.4 and 57.1 cm (Ministry of Agriculture, 1989).

Figure 3 illustrate the effect of wheat cultivars and irrigation treatments at the experimental sites on water use efficiency. The results showed that average WUE (kg grain/m$^3$ water consumed) value for Sakha 69 wheat cultivar (1.11) was higher than that of Sids 6 wheat cultivar (0.77). Average WUE value at Giza site (1.26) was higher than that at Ismailia site (0.62). Results indicated also that average water consumptive use value for the I2 irrigation treatment was 0.97 while for I1 irrigation treatment the average value was 0.91. These results suggests that for more efficient water use we can grow Sakha 69 wheat cultivar using 75% of the required amount of water per irrigation. Several studies indicated that increasing soil moisture deficit resulted in increasing WUE values (Metwaly et al., 1984; Abdel Maksoud et al., 1988 and Yousef and Eid, 1994). In the old irrigated, average WUE values ranged between 0.9 (Ibrahim et al., 1987) to 1.46 (El Refaie et al., 1988) while the average value in the sandy soil was 0.56 (Ministry of Agriculture, 1989).

Conclusion:

Selection of varieties according to its better efficient use of fertilizer and water, became an economic and environmental need, for rational use of the limited natural resources. Cultivating the sandy soil of the desert in Egypt is important, however considering the limited water resource and low fertility of the soil has to be taken into consideration while managing this new land. In this respect, according to the results obtained from this field trial, Sakha 69 wheat cultivar uses the applied N fertilizer and the irrigation water more efficiently in both the clay and sandy soil than Sids 6.


3- Agriculture Research Center report 1994. Soil survey report. ARC. Giza, Egypt

4- CoHort Software. 1986. Costat 3.03, P.O. Box 1149, Berkeley, CA 94701, USA.


INTEGRATED PLANT NUTRITION -
RESULTS OF RECENT TRIALS

by
A.R. Leake
CWS Agriculture, United Kingdom
INTEGRATED PLANT NUTRITION - RESULTS OF RECENT TRIALS

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Summary

This paper has examined, from a practical farmers point of view, how all sources and plant nutrients can be utilised within a farming system. The objective in the future will be to more efficiently exploit the nutrient within the system and increase the precision of use of that applied to the system. Such an approach appears likely to maintain high yields, but reduce the reliance on external inputs to the system by exploiting interactions between factors resulting in an improved economic and environmental performance.

Introduction

The need and importance of providing sufficient nutrient to sustain a crop has long been understood. In Roman Europe this was achieved by crop rotation which included a fallow period and applications of animal manure. Around 1730 in Eastern England Townsend introduced his famous four course rotation, and over a century later Sir John Lawes began trials at Rothamsted Experimental Farm to measure the impact of individual nutrients applied at varying rates on plant growth and crop yields. The use of such nutrients in the form of blends or applied as straights to specific crop requirements has formed the basis of plant nutrition in the UK for the past 40 years. The availability of crop protection products in the form of fungicides, insecticides and herbicides along with these fertilisers has enabled farmers to abandon crop rotations in favour of more simplistic cropping patterns in recent years.

A very small number of farmers, however, shunned the use of artificial fertilisers preferring to continue with the traditional approach to plant nutrition of crop rotation, fertility building crops and livestock manures. This so called organic farming has been increasing in Europe in the past decade fuelled by consumer demand and financial incentives offered by national governments. The extent to which organic methods are sustainable, both economically and environmentally, is the topic of continued debate. The proponents state that conventional agriculture is resource hungry, polluting, over exploitive and environmentally damaging, reducing species numbers and biodiversity. The opponents state that conventional agriculture is the only system which delivers the high yields needed to feed a growing world population, that can deliver high quality food reliably and affordably and any reduction in yield would have to be made up by bringing fresh land into production, thereby reducing habitat and species which inhabit therein. Furthermore, there is a belief that the extent of environmental damage is overstated, but measuring population trends among all the species found on European farm land would be a daunting and time consuming task.

In order to generate data on a farm scale basis, CWS Agriculture who farm 20,000 hectares at 14 locations in the UK converted 110 hectares to organic methods in 1989. The objective was to find out if organic farming could be a profitable way of producing crops (the ultimate measure of sustainability for all farmers), the extent to which crops could be protected from the ravishes of pest, diseases and weeds by cultural, biological and mechanical means only and to attempt to measure some of the environmental effects of the system.

The first seven years are now complete and the data collected. During this period there have been notable successes and failures. Yields are, on average, only 40% of conventional levels, but the

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1 Paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997
availability of price premiums from a public who view organic farming as environmentally desirable and organic food as healthy and tasting better has sustained profitability. However, to agriculturists of greatest interest is how the system manages nutrients and controls antagonists. The success of failure of the system in my view hinges on these factors and results to date show that weeds in particular can cause significant crop losses and that nitrate leaching can be high at certain stages of the rotation. These losses could be avoided if targeted intervention were permitted.

In 1993 the trial was extended by a further 60 hectares in an attempt to use the experiences gained through organic farming, but integrating crop protection products and fertilisers. The objective was to use all methods, old and new, to ensure that profitability and productivity were maintained while minimising environmental impact. The concept is known as Integrated Farm Management (IFM) and is being supported financially and technically by Hydro Agri UK and Profarma. The trials are now in the fourth year and producing some useful results for the future of farming. Most importantly, IFM recognises that holistic approach needs to be taken to whole farm operation. Factors are not viewed in isolation, but as interactive components and while this makes the system more complex it reduces the chances of a specific action creating another problem that has to be dealt with subsequently.

**Materials & Methods**

In order to develop the system 7 fields were put into an integrated rotation. These fields were split in half, half farmed to conventional wisdom and operated by the commercial arable manager, the other half farmed to the principles of IFM and operated by the project manager.

The objective within the integrated system is to recycle wherever possible potassium and phosphate across the rotation topping up to index 1 to 2 where depletion occurs. The approach to nitrogen is more complex because of its relative instability within the soil, but essentially consists of 3 components:

1. Enhancing mineral Nitrogen through crop rotation.
2. Conserving this nitrogen so that the maximum available is taken up by the crop.
3. Precisely applying fertiliser to increase yield to the maximum economic potential.

Various techniques are used to achieve these components.

1. **Enhancement of Fertility**

The rotation is designed to add fertility at some points and then to release this supplying nutrient to other cash crops in the rotation. The objective is to enhance fertility by natural means and then try to release and recapture this fertility in the growing crop. To achieve this the following rotation is used.

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>Grass/ Clover</td>
<td>Grass/ Clover</td>
<td>Wheat</td>
<td>SAS</td>
<td>Wheat</td>
<td>Beans</td>
<td>Wheat</td>
</tr>
</tbody>
</table>

The grass is cut and ensiled which reduces the weed burden at this point of the rotation and the soil structure and fertility are improved for the subsequent wheat crop.
During the set-aside period farmyard manure is applied to the natural regeneration of the stubble. The manure is used to replenish potassium and phosphate which is depleted by removal at the other points in the rotation. This green cover is then destroyed to release nutrient for the subsequent wheat crop. This is followed by a leguminous crop, usually field beans which again raise the nitrogen level by biological fixation. The residues of the bean crop are incorporated and the release of nitrate contributes to the final wheat crop in the rotation.

Additional nitrate enters the system through atmospheric deposition which is being measured and through in-crop weed control operations which mineralise organic matter.

2. Conservation of Nutrient

Generating fertility through natural means is resource efficient, but retaining that nutrient, especially nitrate, in a form which is available to the growing crop is a considerable challenge. The release of nitrate from organic matter created through the enhancement process is dependent upon cultivation activities and biological activities which, in turn, are dependant upon temperature and soil moisture. Nitrate loss is most likely to occur where leafy crops are incorporated early in the autumn with multiple cultivations prior to winter rainfall and the subsequent return of the soil to field capacity and drain flow. Options to limit this loss at this site have been trialled and include the following:

a) use of stale seed beds
b) use of minimal tillage and direct drilling
c) cover crops
d) early drilling

a) Stale Seed Beds

Stale seed beds are used in an integrated system to reduce weed pressure in the cropping period. Stubbles are heavy disced and pressed immediately post harvest in order to incorporate residues and trash and to stimulate weed and volunteer germination. The incorporation of the straw locks up nitrogen as decomposition occurs and as the green cover develops so further nitrate is taken up. Where these are sprayed with a low dose contact herbicide prior to drilling the subsequent crop the death of the weed is slow and full decomposition does not usually occur until spring when the crop is more able to benefit from the release of nitrate.

b) Use of Minimal Tillage and Direct Drilling

Where stale seed bed techniques are used it is generally undesirable to disturb the soil again prior to drilling since this may encourage a further flush of weeds. It is also known that the greater the upheaval of soil the more nitrate is likely to be mineralised. As cultivations generally occur in the autumn prior to crop establishment and the return of the soil to field capacity the nitrate released at this stage is more likely to be leached. Minimal tillage and direct drilling reduce or remove this soil disturbance and measurements taken from porous pots on the site have shown lower levels of nitrate in soil water solution, compared to the conventional plough based system.
The measurements were taken over the winter period when no fertiliser was applied to either system so only naturally derived mineral N is being measured.

Additional environmental benefits have also been observed. The direct drilled fields retain the stubble which provides valuable habitat for a number of birds, particularly the skylark and other seed eating birds. The presence of roots from either the previous cropping plants or the green cover from the stale seed bed bind the soil and prevent erosion. This is of particular importance at this site which slopes directly to the main local water course.

c) **Cover Crops**

Cover crops are those sown specifically to provide ground cover on what would otherwise be bare soil through the winter period. This technique has been long used as a method of absorbing mineral nitrate. The predominance of autumn sown crops in the UK at the present time means that the opportunities to use cover crops are few. However, the advent of set-aside has meant that over the past four years between 5% and 15% of arable land eligible has not been sown with a crop. Since set-aside is also used during the summer period to receive farmyard manure it was considered important that a green cover was present to absorb available nutrient. A number of treatments were established to give a contrast between cost and ability to absorb nitrate.

1. Rape natural regeneration, no cultivation
2. Natural regeneration, cultivated
3. Rape/grass/vetch mix
4. Mustard/rye mix
5. Grass clover undersown

Soil samples taken from each of the plots in December indicated that where the soil had been disturbed to establish the crop soil nitrate levels were significantly higher than where the green cover established without cultivations. (Graph 2). The green matter was subsequently harvested and nitrate analysis carried out. The undersown grass/clover mix which benefited from a longer establishment period and the mustard/rye mix showed significantly greater uptake of N in the crop than all other treatments. (Graph 3).
However, when the total percentage of the conserved in the cover is compared with that remaining in the soil, because of the additional mineralisation caused by the seed bed preparation there was no benefit against the uncultivated control. The undersown treatment, however, showed greatest efficiency of uptake (Graph 3). There is also uncertainty about the release and fate of nitrate following destruction of the green cover. On this soil type the evidence suggests that economically and environmentally natural regeneration is the best option.
3. Precision Agriculture

While the previous sections of this paper deal with the enhancement and conservation of organically derived mineral nitrogen the amounts available in the rotation outlined are insufficient to achieve the optimum economic yield. This can only be achieved by the application of nitrogenous fertilisers such as ammonium nitrate. The cost/benefit relationship of input to yield is great and has been demonstrated through many trials. As we move into an era which focuses more upon efficient resource use and minimal environmental impact, applying nitrogen more accurately to crop requirements assumes increasing importance. Indeed it is the scale of this cost/benefit relationship which has encouraged inaccurate and haphazard use in the past.

Trials underway over the past three years at a number of sites have been carried out to increase the precision with which fertilisers are used and much of this work has focused upon measurement of mineral N present in the soil prior to fertiliser applications.

A number of uncertainties arise. For instance how frequently should a field be sampled and to what depth. Trials have shown that the relative importance of these factors is very dependent upon soil type. Where a series of samples were taken across a series of fields at different points of the rotation at the CWS farm at Stoughton in Leicestershire levels varied from 74 kg/ha N following the grass phase of the rotation and 24 kg/ha N following wheat. All other crops in the rotation fell between these values. In contrast, samples taken at the CWS Coldham Estate in Cambridge showed great variation within a single field.

| Table 1: Soil Mineral N Levels 1994-1995 - Estimated Available N Kg/Ha |
|-----------------|---|---|---|---|---|---|---|---|---|---|---|---|
|                 |   |   |   |   |   |   |   |   |   |   |   |   |
| Ave             | 64 | 156 | 136 | 152 | 96 | 389 | 174 | 59 | 109 | 239 | 114 | 185 | 60 | 157 | 150 |
| East Anglia     |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| Leics.          | 74 | 53 | 38 | 24 | 38 | 40 | 39 | 44 | 51 | 67 | 48 | 68 | 56 | 48 | 49 |

Where individual cores were subdivided into horizons 0-30, 30-60 and 60-90 and analysed separately the location of the mineral N within the profile also showed great variation. At the
Stoughton site almost half the available N is located in the top 30 cm. At Coldham the trend is reversed with almost 50% located in the bottom 30 cm of the profile.

Table 2: Soil Mineral N Levels by Horizon

<table>
<thead>
<tr>
<th></th>
<th>East Anglia</th>
<th>Min</th>
<th>% of Total Available N</th>
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<tbody>
<tr>
<td>0-30</td>
<td>25</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>30-60</td>
<td>37</td>
<td>31</td>
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<tr>
<td>60-90</td>
<td>57</td>
<td>48</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Leicestershire</th>
<th>Min</th>
<th>% of Total Available N</th>
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<tr>
<td>0-30</td>
<td>48</td>
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<tr>
<td>60-90</td>
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<td></td>
</tr>
</tbody>
</table>

This knowledge is of crucial importance to obtain accurate Soil Mineral Nitrogen (SMN) data to use in fertiliser requirement calculations.

Where variability across a single field was found to be very high ranging from 59 to 389 an experiment was established to map the gradient of mineral N across the field and to look at localised variable distribution through the profile.

To achieve accurate sampling a pneumatic sampler was used and fitted with a Global Positioning System (GPS). Using this tracking device a series of samples were taken across a 36cm grid in a 10 hectare field. The 90cm soil core taken at each point was analysed in 3 horizons and SMN maps generated. There was no great differences between nitrate levels at different horizons so a map was generated for the entire 0-90 cm profile.

Fertiliser was applied to the growing crop of winter wheat as per standard farm practice. At flag leaf emergence (Zadoks 37-39) a hand held 'N Tester' which measures chlorophyll density relative to nitrate leaf content was used on 30 plants around each of the sampling points to ascertain the extent to which soil mineral N was influencing the crop at this stage. A map was generated, but the trend did not reflect that of SMN.

At GS73 the field was photographed by satellite and this imagery used to obtain the Normalised Difference Vegetation Index which is essentially a measure of crop canopy density. There was no obvious visible comparisons between this map and the previous maps generated. Ultimately the crop was harvested in mid August using a Massey Ferguson 40 series combine fitted with GPS which recorded yield variations across the field. Visual comparison of the yield map against all the other data sets collected indicated the only correlation which existed was between yield and crop canopy density. To extend this work further information is required as to how fertiliser policy can alter crop canopy density in order to increase yield. The use of satellite imagery and NDVI’s offer a quicker and cheaper assessment of crop performance than SMN measurements although the development of a tractor mounted N tester may provide a contribution in the future.
The Role of Fertilisers in Integrated Farming Systems

This paper has concentrated on the techniques which have been considered to provide sufficient crop nutrient for optimum yield. It is, however, important to evaluate the role of fertilisers within the whole farming system and to consider how they influence other within-field factors such as pests, diseases and weeds. Seven years of experiments with an organic farming system has shown that cultural manipulation and the absence of fertiliser usage greatly reduces certain of these antagonists. Yields are, however, typically halved and hence the need to use fertilisers in a managed way.

Weed control and nitrogen use

Different weed species respond to applied nitrogen in different ways. Wild oats for instance are stimulated to germinate and cleavers are able to become increasingly competitive in more fertile conditions. Even where weed levels in the crop are relatively small they have the ability to significantly impact on yield. Some weeds do this by competing for light while others do it by competing for nutrient.

Table 3

<table>
<thead>
<tr>
<th>Sowing Date</th>
<th>Sowing Rate (Kg/Ha)</th>
<th>Plants m²</th>
<th>Treated Yield £/Ha</th>
<th>Untreated Yield T/Ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.09</td>
<td>190</td>
<td>292</td>
<td>12.8</td>
<td>4.7</td>
</tr>
<tr>
<td>21.10</td>
<td>220</td>
<td>431</td>
<td>11.5</td>
<td>8.0</td>
</tr>
</tbody>
</table>

The table shows the effect of annual meadow grass on a crop of wheat. Where no weed control measures are taken yields are reduced from 12.8 to 4.7 due to competition for nutrient. The grass is not tall enough to compete for light, but its dense mass of fine roots which occupy the soil surface are able to intercept applied N well. This problem can be reduced as demonstrated by the integrated system by delaying sowing and increasing the seed rate to shift the competitive balance in favour of the crop. This usually provides sufficient competition to take the crop safely though to spring. At this stage nitrogen fertilisers can be an extremely useful tool used in conjunction with herbicides. A herbicide may be applied to the crop at a very low dose, sufficient only to check the growth of the weed. The fertiliser is applied around the same stage and the crop grows away vigorously. By the time the weed recovers the canopy is closing and the weed in unable to compete because light is now limiting.

In the organic system which uses stale seed beds difficulties may be experienced in destroying larger weeds and destroying grass/clover fertility building leys. This results in the land being ploughed which can release significant amounts of N into the field drains as dissolved nitrate. While this is highly undesirable in terms of loss of scarce nutrient and for water quality, it is an unavoidable disadvantage of the system.

Pathogen control and nitrogen use

The use of soil mineral N sampling in conjunction with a chlorophyll meter and Hydro Agri’s Extran Plan computer programme allow greater precision of application of N to crop requirements. Using this information has enabled reductions in N applications in certain crops, but also led to increases in others in order to obtain optimum economic yield. (Table 4). Furthermore, by splitting the application into three events crop growth is more even. This avoidance of sudden growth flushes
enables growth regulators to be omitted from the programme and to date no lodging problems have been encountered. Furthermore, in conjunction with disease resistant varieties fungicide use has been reduced by 80% over the first three years since disease pressure appears to be reduced.

**Pest control and N usage**

There are limited examples of how pests may be influenced by crop nutrition. The dead heart symptoms of wheat to wheat bulb fly may be negated by nitrogen by encouraging tiller survival. Conversely the flag leaf and ear of high yielding cereal crop which has been given optimum N and is protected with fungicides provides a host for cereal aphids which are able to multiply over a period, because of the favourable conditions encountered. Crops grown without fertiliser N and fungicides seldom encounter this problem, but yields are already significantly reduced.

<table>
<thead>
<tr>
<th></th>
<th>Extra Plan Application</th>
<th>Total Application</th>
<th>Actual Application</th>
<th>Total Application</th>
<th>N Tester</th>
<th>+/-</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3</td>
<td>1 2 3</td>
<td>12 26 28</td>
<td>56 90 56</td>
<td>202</td>
<td>565</td>
</tr>
<tr>
<td>Field 12</td>
<td>42 102 42</td>
<td>186</td>
<td>56 90 56</td>
<td>202</td>
<td>565</td>
<td>+16</td>
</tr>
<tr>
<td>Field 6</td>
<td>42 72 42</td>
<td>156</td>
<td>62 69 -</td>
<td>131</td>
<td>741</td>
<td>-25</td>
</tr>
</tbody>
</table>

**Micro-nutrients**

Sap testing samples taken for diagnostic pathogen analysis may provide the opportunity for an integrated approach. Micro nutrients can be applied with fungicides to address imbalances. Where crops are producing high yields it is likely that limitations may occur in some elements.

**Livestock manures**

These pose particular problems due to variability in nutrient content and variability in nutrient release. Standard figures may be used for guidance, but an on farm test kit would provide greater accuracy.
CONCEPTS OF BALANCED FERTILIZATION AND
PRACTICAL NUTRIENT ACCOUNTING

by
K.-F. Kummer
BASF, Germany
The concept of balanced plant nutrition has been there from the beginning of scientifically based plant nutrition. After settling his dispute with LAWES over the nitrogen fertilization of crops around the middle of the last century, Justus von LIEBIG stated:

"A soil is completely fertile for plants only when each part of it, which is in contact with the plant roots, contains adequate amounts of nutrients in a form, which allows the roots to take them up in the right amount and ratio in every period of plant development".

This demand for the right amounts and ratios already includes the principle of balanced fertilization. LIEBIG illustrated his empirical findings with the famous graph of a barrel (Figure 1).

Like others, LIEBIG had started from analysing plants to establish the nutrient uptake of crops and thereby the nutrient requirements. Later he found out, that it was not sufficient to replace just the nutrients removed by the harvested parts of the crop. Best yields were obtained by applying sometimes more, sometimes less than the extracted amount of nutrients. From then on, different rates of the various nutrients were used in trials to establish appropriate fertilizer recommendations for crops and locations under investigation. Thus, nutrient demand by crop along with nutrient availability in the soil had become the determining factors for fertilizer use.

**The agronomic concept of balanced fertilization**

Applying the plant nutrients in the ratio, which was the most economic one under given circumstances, became the principle of fertilizer application during the period of vast increase in mineral fertilizer consumption in North America, Europe and other regions with intensively managed agriculture up to the 1970s.

In other parts of the world, less trial work was done and the apparently unlimited availability of agricultural land and the scarcity of cash led to different economic considerations: The return per hectare was of lesser importance than the highest return on the money invested in fertilizers. Therefore, fertilizing practices developed differently. The least available nutrient, generally nitrogen or phosphate, offering the highest return, was preferentially applied. This might have been perfectly right at the start, but sooner or later, after several years of mining them, other nutrients became limiting to the crop growth as well thus depressing the efficiency of the nutrient applied traditionally. And although some more cash had possibly been generated and knowledge from other parts of the world was available, the one sided fertilizing practice had become a deep rooted habit (Figure 2).

It was therefore laudable, that the FAO Fertilizer Programme from its start promoted the idea and the term of "balanced fertilization". The basic 8-plot design (Figure 3) of the thousands of fertilizer trials laid out over decades in more than fifty countries was perfectly suited to check the need for all three major nutrients in an efficient way.

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1 Paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997
Along with the trials there were countless presentations and publications on balanced fertilization and advice by FAO field staff, given to as wide a range as from farmers to governments. FAO deserves the merit of having made the term "balanced plant nutrition or balanced fertilization" a household word in the farming community around the world. In the 1980s it was developed forth into the integrated plant nutrition system, putting more emphasis on organic nutrient sources.

Until the middle of the 1980s, there was a common understanding of the meaning of "balanced fertilization", based on scientific plant nutrition and farm economy: applying plant nutrients to crops in those quantities that the mix of nutrients provided the best return on the money invested in fertilizers. This can - for economic reasons - be at a comparatively low level of nutrient input, or - in the most intensive form of agriculture - at a level which allows maximum yields.

Under the first situation, to be sustainable the nutrient application rates should at least cover the amounts removed and the unavoidable losses. This unavoidable nutrient losses even occur in the untouched nature and they inevitably increase on farmed land. Losses of plant available nutrients due to erosion, leaching and fixation are natural processes, which can be minimised but never totally eliminated. The risk of loosing nutrients in this processes increases as the concentration of nutrients in the ploughed layer rises. But nonetheless, to make his soil produce at its potential yield level, the farmer has to build up the nutrients to the desirable level, which has to be established in field trials. Once this is achieved, the application rates should return to maintenance level, again replacing just the nutrients removed by harvested crops and the nutrient losses.

The environmental concept of balanced fertilization

During the second half of the 1980s, the term balanced fertilization suddenly appeared in the literature in context with the protection of the environment. Since the term was now used by a different group of people - many of them not trained in agriculture - the meaning it stood for differed considerably from author to author. Some supposed that the fertilizing practices in the 1980s were obviously not in balance with the need of crops without specifying this further and asked for re-equilibration, which meant a reduction of nutrient inputs, not yet fixing threshold values.

This thinking was triggered by the occurrence of undesirable concentrations of plant nutrients in surface and underground waters and it was backed in many Western European countries by the amount of nutrients applied in organic and mineral fertilizers considerably exceeding the removal by crops.

It was difficult to understand and to accept by many environmentalists, that this built-up of nutrients in the soil to a large extent was what would be called nowadays "good farming practice". The farmers had to bring up the nutrient concentration in the soil to the desirable levels. In the case of phosphate it needs about 100 - 150 kg P\textsubscript{2}O\textsubscript{5} /ha to raise the phosphate content of the ploughed layer by 1 mg P\textsubscript{2}O\textsubscript{5} CAL/100 g soil (Figure 4).
At the same time animals were replaced by engines as the main source of power for the cultivation of land. As a result, the ploughed layer was gradually deepened, in many cases by more than 10 cm. In all mineral soils, the subsoil is less rich in nutrients and organic matter. If one calculates that the organic matter content of the subsoil ploughed up had to be increased by 1 per cent (many subsoils in Europe have about a 1 per cent lower organic matter content than the old ploughed layer) this built-up of organic matter would fix 1500 kg N/ha (Figure 5).

Nitrogen fixation by deepening the ploughed layer

A deepening of 10 cm means:

- increasing the weight of the ploughed layer by 1500 t/ha
- difference in organic matter content between subsoil and surface 1 %
  ⇒ additional 15 t/ha humus (C:N relation 10:1) fix 1500 kg/ha N
  ⇒ a surplus of 50 kg/ha/a nitrogen is necessary over 30 years

For deep loess soils in Germany, it could be demonstrated that 2000 to 2500 kg N had been incorporated in the organic matter in the course of 30 years.

Therefore, it was not surprising for the agronomist that nutrient balances were highly positive, but environmentalists thought them the major cause for the pollution of surface and groundwater with nitrogen and phosphate. Intensive research began in several European countries to specify and to quantify the different routes of nutrient inputs into water. Measures like the ban of phosphate based detergents, the installation of waste water treatment plants and changes in agricultural practices proved very effective in some European countries (Figure 6).
In the 1990s, the demand of the environmentalists became more precise in asking for a plant nutrient regime, where over a period of time input equals output or - more restrictive - input never should exceed output. This of course is opposed by the plant nutrition specialists, who pointed out, that a simple replacement of the nutrients removed by the crops would lead to decreasing yields due to the unavoidable losses and would never allow nutrient deficient soils to be brought up to the desirable nutrient level, as was already demonstrated by LIEBIG. This dissension was manifested in the definition of balanced fertilization chosen by the Working Group on Nutrients (NUT) of OSPARCOM.

OSPARCOM stands for Oslo- and Paris-Commission, two intergovernmental organisations that aim to reduce the pollution of the North Sea. A similar organisation is the Helsinki-Commission (HELCOM) which takes care of the Baltic Sea. One important target is to reduce the plant nutrient input into these peripheral regions of the North Atlantic. Increasing nutrient contents in coastal waters are held responsible for algae blooms and deteriorating water quality which have been observed since the last decade. To counteract this development, the ministers for the protection of the environment of the subscribing parties, which are virtually all the states adjacent to the North and Baltic Sea, in 1988 agreed to reduce the nutrient input by 50% until 1995: Although substantial improvements have been achieved, especially for phosphate, this deadline was postponed until 2000 particularly with regards to the difficulties in the reduction of nitrogen inputs.

The Working Group on Nutrients intended to minimise the agricultural share in the nutrient input by obliging farmers to apply "balanced fertilization":

"Balanced fertilization" is defined as the supply of nutrients from any source

- which does not exceed the requirements of the crops.
- where the resulting enrichment and losses of nutrients to the aquatic and atmospheric environment are at environmentally acceptable levels".

This definition has been quite agreeable at first sight, since it allowed everyone to interpret it in its own way. But when it had to be defined what are the "requirements of the crops" and what are losses "at environmentally acceptable levels", the internal contradiction became obvious and no agreements could be reached. Therefore, it was finally abandoned.

Using comparisons of nutrient inputs and outputs as a yardstick for environmental correctness of fertilizing practices in scientific publications and studies started during the 1980s. Different types of
nutrient "balances" came into use. The most common is a comparison of nutrient inputs and outputs at farm gate level (Figure 7).

![Diagram of nutrient balances]

It has the advantage, that quantity and quality of purchased products are well documented and for products leaving the farm the quantity is generally measured as well and the quality is relatively uniform. In this approach the internal flow of nutrients on the farm, which would need the use of estimates and standard figures can be excluded. Therefore "farm gate" balances are as well suited to calculate the nutrient surpluses or deficits for regions or whole countries.

In the field/farmyard balance the nutrient flow at the bottleneck between farm land at one side and cow shed, pigsty, stable and barn at the other side is calculated. This type of balance is more complicated and less reliable, since quality and frequently quantity of plant produces leaving the fields and of e.g. farmyard manure or slurry returning to them can only be estimated. Comparing with the farm gate approach, the input figures are generally lower, due to unavoidable nutrient losses in the farmyard, which are not accounted for. This is why farmers may nevertheless prefer this type of balance.

Unfortunately there are no standard procedures for the preparation of such balances and nearly in every publication it is done a little bit differently including or excluding one or the other way of input or output (e.g. gaseous losses of nitrogen as ammonia or oxidised nitrogen gases on the farm, wet and dry deposition of nitrogen, etc.). It therefore needs careful reading to understand, where the boundaries of the system have been laid, for not to misinterpret given results.

**Nutrient accounting systems**

Accounting systems based on the nutrient input and output are used in some European countries as a measure for the environmental performance of farms. The first to start was Denmark, followed by the region of Flanders in Belgium, The Netherlands and Germany.

**Denmark**

Starting already in the 1980th, Denmark was the first country to oblige its farmers to establish written fertilizing plans. After several changes the actual rules demand a detailed nutrient accounting system. The flow of plant nutrients from and into each farm has to be calculated and documented.

When establishing his fertilizing plan on the 1st September of each year, the Danish farmer has first to find out the maximum amounts of nitrogen, he is allowed to apply. There are detailed tables,
giving the admitted nitrogen rate per crop for four types of soil in three climatic regions at standard yield. The farmer can claim to achieve higher yields by demonstrating his true yield level as the average of three years out of the last five, by eliminating the highest and lowest yield. By calculating the admissable nitrogen demand of his crops field by field, the total for the farm is determined.

For the nutrient supply, he starts with the organic manure. The number of animals of each type is multiplied by standard figures representing average nutrient quantities excreted to achieve the total nutrients in organic manure and slurry. If a farmer claims that under his feeding regime lower nutrient amounts are excreted, this has to be proven by analysis of the purchased feed stuff e.g., the concentrate.

While phosphate and potash from organic manures are regarded as 100% plant available, there are fixed rates of 45% (pig slurry), rsp. 40% (cattle slurry) for nitrogen efficiency in the first and 10% in the second year.

Organic manures are only allowed to be applied to a maximum rate per hectare and year. Only the gap between calculated crop demand and supply by organic manure may be applied as mineral fertilizer.

The fertilizing plan has to be completed by the 30th March including also the prognoses for further nitrogen applications. The plan remains "at farmer’s desk", ready for every necessary adjustment to be put down. The existence and proper keeping of the fertilizing plan might be checked at any time. At March of the following year, a random selection of farmers is asked to submit their fertilizing plans for control. Infringements are punished and severe cases taken to court. Whilst the enforcement was thoughtful in the first years, it gets more stringent now. A fine of up to 20 dkr per 1 kg of nitrogen applied wrongly can be imposed.

**Flanders**

The region of Flanders is densely stocked with farm animals, primarily with pigs and poultry. That is why a regulation was enacted in 1995 to control the excess of nutrients in manure and slurry. Nutrient accounting is compulsory for farms which are larger than two hectares or have more than 300 kg P₂O₅ excreted by animals per year. The amount of nitrogen and phosphate is calculated by the number of animals and the intake of other nutrient sources, e.g. mineral fertilizer, compost and sewage sludge.

Maximum amounts for the total sum of nutrients to be applied annually per hectare from all sources are fixed (Figure 8).
Accepted maximum nutrient application rates in Flanders
acc. to the "MESTDECREET"

<table>
<thead>
<tr>
<th></th>
<th>all nutrient sources</th>
<th>mineral fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( P_2O_5 )</td>
<td>( N )</td>
</tr>
<tr>
<td><strong>year 1997</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>grassland</td>
<td>170</td>
<td>450</td>
</tr>
<tr>
<td>maize</td>
<td>155</td>
<td>325</td>
</tr>
<tr>
<td>low demand crops*</td>
<td>125</td>
<td>170</td>
</tr>
<tr>
<td>others</td>
<td>150</td>
<td>325</td>
</tr>
<tr>
<td><strong>year 2003</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>grassland</td>
<td>125</td>
<td>450</td>
</tr>
<tr>
<td>maize</td>
<td>100</td>
<td>275</td>
</tr>
<tr>
<td>low demand crops*</td>
<td>100</td>
<td>125</td>
</tr>
<tr>
<td>others</td>
<td>100</td>
<td>275</td>
</tr>
</tbody>
</table>

*) low demand crops: beans, peas, clover, carrot, chicory, onion, fruit trees

This maximum allowances will be considerably reduced by the year 2003, thus allowing the farmers a period of adaptation to the stricter rules. For areas registered as nature conservation or water protection zones lower maximum amounts are applicable. In some areas predominantly with acid sandy soils the phosphate fixing capacity has been saturated and therefore much lower maximum rates for phosphate have been set. Compliance with the rules is controlled and violation fined.

**The Netherlands**

Since the beginning of the 1990s, several concepts have been developed and discussed in the Netherlands. The major problem in this intensively animal-producing country is to assure, that the arable land is not loaded with more organic manure or slurry than it can deal with under environmental aspects.

That is why the compulsory nutrient accounting system starts in 1998 for those farms holding more than 2.5 animal units per hectare. Gradually this mineral bookkeeping system for nitrogen and phosphate, called MINAS, is extended to farms with lower livestock density (2000) and will finally by the year 2002 include the purely arable farms as well.

The accounting is at "farmgate" level for animals and allows lump sum figures per hectare of arable land and pasture (Figure 9).
For the evaluation of the results, the nutrient surplus is reduced by admissible losses per hectare of arable and grassland (Figure 10).

The "MINAS" balance system of The Netherlands

I. ESTIMATION

INPUT
- organic manures (own)
  (No. animals x Ø figures)
- external organic manures
- mineral fertilizer

OUTPUT
- delivered manure, slurry
- arable, horticult., grassland
  (ha x Ø figures)
- admissible losses

II. REFINED CALCULATION

INPUT
- external organic manure,
  slurry, sewage sludge etc.
- mineral fertilizer
- purchased animals
- purchased feed stuff

OUTPUT
- delivered manure, slurry
- sold animals
- sold roughs
- arable and horticult. land
  (ha x Ø figures)
- admissible losses

Admissible losses and max. application rates in the Dutch MINAS balance system

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>P$_2$O$_5$ cultivated</td>
<td>40</td>
<td>35</td>
<td>30</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>non cultivated</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>N grassland</td>
<td>300</td>
<td>275</td>
<td>250</td>
<td>200</td>
<td>180</td>
</tr>
<tr>
<td>arable + set aside</td>
<td>175</td>
<td>150</td>
<td>125</td>
<td>110</td>
<td>100</td>
</tr>
<tr>
<td>non cultivated</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

max. application rates kg P$_2$O$_5$/ha

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>grassland</td>
<td>120</td>
<td>85</td>
<td>80</td>
<td>75</td>
<td>70</td>
</tr>
<tr>
<td>arable</td>
<td>110</td>
<td>85</td>
<td>80</td>
<td>75</td>
<td>70</td>
</tr>
<tr>
<td>set aside</td>
<td>40</td>
<td>35</td>
<td>30</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>non cultivated</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>15</td>
<td>10</td>
</tr>
</tbody>
</table>

Remaining surpluses are taxed to encourage the farmer to improve his balance. In the beginning 1.00 hfl/kg N/ha is charged for nitrogen and 2.50 hfl/kg P$_2$O$_5$ /ha for the first 10 kg/ha of phosphate and 10.00 hfl for every kg P$_2$O$_5$ ha on top of that. The accepted application rates of manure and slurry per hectare decrease from 1998 to 2002. The admissible losses per hectare will similarly be reduced in four steps till the year 2008, thus forcing the farmer to improve his nutrient balance or pay an increasing amount of money.
As tough as this system may be for a particular farmer, it is cause oriented by focusing on the animal excrements and it acknowledges unavoidable losses.

Germany

In 1996 a fertilizing regulation (Düngeverordnung) was issued, which obliges the farmer to follow the rules for "good fertilizing practice" which have been defined along with the regulation, and to document the information used to calculate the application rates for organic and mineral fertilizers. For farms with more than ten hectares, a comparison of nutrient inputs and outputs has to be established every year for nitrogen and at least once every three years for phosphate and potash. The farmer may calculate this either on farmgate or on field/farmyard level (Figure 11).

---

**Input / output comparison acc. to the German "Düngeverordnung"**

**I. FARMGATE LEVEL**

<table>
<thead>
<tr>
<th>INPUT</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>purchased feed stuff</td>
<td>plant produce</td>
</tr>
<tr>
<td>mineral fertilizer</td>
<td>animal produce</td>
</tr>
<tr>
<td>external org. manures</td>
<td>delivered org. manures</td>
</tr>
<tr>
<td>purchased animals</td>
<td>nitrogen losses from</td>
</tr>
<tr>
<td>symbiot. N-fixation</td>
<td>org. manures</td>
</tr>
</tbody>
</table>

**II. FIELD / FARMYARD LEVEL**

<table>
<thead>
<tr>
<th>INPUT</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>mineral fertilizer</td>
<td>plant produce</td>
</tr>
<tr>
<td>animal excrements</td>
<td>delivered org. manures</td>
</tr>
<tr>
<td>(No. animals x Ø figures)</td>
<td></td>
</tr>
<tr>
<td>external org. manures</td>
<td></td>
</tr>
<tr>
<td>symbiot. N-fixation</td>
<td></td>
</tr>
</tbody>
</table>

ADM/B

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A random selection of farms will be checked for compliance with the regulation by the agricultural services of the Bundesländer. Currently the regulation includes no punishment for excessive nutrient surpluses. The common understanding is that in this case the farmer will be instructed how to improve the nutrient balance, but actually nothing is said about what will happen, if this does not lead to success. Since the regulation does not say "how much is too much", this judgement depends on the enforcing service and it might well be handled differently in the different Bundesländer.

As was shown, the agronomic term "balanced fertilization" was occupied by a new branch of science and given a different meaning as "nutrient balance". From there it developed further to "nutrient accounting" and got a legal content.

**Acknowledgements**

The author thanks Mr. Jac Steevens, DSM Netherlands, and Mr. Mogens Nielsen, Kemira Denmark, for their contribution on the accounting system in their country.
THE MANUFACTURE, AGRONOMICS AND MARKETING OF AGROTAІN®

by

S. Kincheloe
IMC Global Operations Inc., USA
INTRODUCTION

In today’s agriculture, innovation, adaptability and effective use of technology are critical success factors. Whether it’s tillage systems, equipment or crop inputs, farmers are fine-tuning their practices to ensure long-term profitability and sustainability.

Nitrogen fertilization is one of the many critical areas where farmers are adapting to new technology. A new product introduced by IMC Global, called AGROTAIN®, is changing how farmers approach this important aspect of crop production. AGROTAIN is a new urease inhibitor. The use of AGROTAIN stops the volatilization of urea fertilizers when it is surface applied.

New concepts for managing nitrogen become more important as we consider the ever-increasing use of reduced tillage or conservation tillage, as well as other types of management being used around the world, that require large amounts of surface applied nitrogen.

Information from the Conservation Tillage Information Center (CTIC) indicates that conservation tillage, particularly no-till, has been posting consistent gains in the U. S. but, at the same time, other countries are also picking up the adoption pace.

Estimates by CTIC are that conservation tillage may reach 27% of the worldwide cropland by the year 2000, including rice in Southeast Asia. In four years, no-till alone could represent as much as 50% of the conservation tillage acres globally. Conservation tillage not only holds great environmental promise for these regions of the world, but also economic benefits.

Consequently, conservation tillage will increase around the world and continued use of surface applied urea will occur. That’s why AGROTAIN is so important to the farmer today and in the future. AGROTAIN brings greater efficiency to nitrogen management, and offers farmers the flexibility they need as weather and cropping conditions change, particularly when urea is selected as the nitrogen source.

The world’s leading nitrogen fertilizer is synthetic urea. For example, during the past couple of years, the International Fertilizer Association (IFA) reported worldwide nitrogen consumption, in the form of urea, as about 42% of the total nitrogen nutrient tons. This use of urea far exceeds any other fertilizer source of nitrogen.

But there’s another interesting aspect to urea. Much like penicillin, Post-it-Notes, Velcro and X-rays, the discovery of urea was made by accident. This accidental discovery of urea by Fredrick Wohler in 1828 was very significant in at least two ways. It was the first time a natural substance was synthesized and, in turn, led to the science of organic chemistry as we know it today. Secondly, this accidental discovery provided the groundwork for synthetic urea to become the world’s leading source of fertilizer nitrogen.

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1 Paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997
As many farmers have moved to cropping systems with less tillage, such as conservation tillage, and in other extremely large areas around the world that require fertilizers to be applied on the soil surface, the use of urea has caused much concern. The problem is nitrogen lost by volatilization. If urea is not incorporated, mixed or moved into the soil by rainfall or tillage, 30% or more of the nitrogen can be lost in as little as three days as the urea converts to the gaseous form of ammonia. Under extreme environmental conditions, much higher losses have been documented.

Volatilization occurs as the urea hydrolyzes, or reacts with soil water, and breaks down. The hydrolysis reaction is facilitated by the urease enzyme which is produced by soil microorganisms and is found wherever there is soil or crop residue.

Until now, nitrogen volatilization as ammonia has been a problem for every urea-containing fertilizer, including solid granular urea and the urea contained in the UAN solution. That’s why its use in crop production systems that require surface application is limited. But with the urease enzyme inhibitor, AGROTAIN, urea fertilizer can become a convenient, reliable option for today’s farmers, no matter what type of tillage system or application technique is used.

WHAT IS AGROTAIN

AGROTAIN is an urease inhibitor that is used with urea or urea based fertilizers to retard or essentially stop the hydrolysis of urea which is catalyzed by the urease enzyme for as much as fourteen days. The net beneficial effect of the use of AGROTAIN is to reduce the loss of ammonia by volatilization when urea is used in surface applications.

AGROTAIN is the registered trademark for NBPT or N-(n-butyl)-thiophosphoric triamide which is contained in solvent and a green dye. AGROTAIN is a liquid and contains 25% of the active ingredient NBPT.

HISTORY OF AGROTAIN

The active ingredient in AGROTAIN, NBPT, was developed during a research project initiated by Allied Chemical Corporation in 1982. It was patented in July, 1995 as a urease inhibitor. The ownership rights to use NBPT were transferred to EniChem Company of Italy in 1987. Development continued until early 1991 when the project was terminated. In May of 1991, Agrico Company acquired sixteen patents to urease inhibitors developed by EniChem Company. One of these patents is NBPT. In 1993, a joint venture company was formed between IMC Global Inc. and Freeport-McMcRan Resource Partners, Limited Partnership. The merging of the phosphate and nitrogen assets of these two companies formed the basis for the new IMC-Agrico Company. Today, the world-wide marketing rights for NBPT are controlled by IMC-Agrico Company. The introduction of AGROTAIN by IMC-Agrico, in the United States marketplace, was initiated in 1996.

HOW DOES AGROTAIN WORK

The ever present urease enzyme in soils is instrumental in catalyzing the hydrolysis of urea. When urea fertilizers are applied to the surface of soils, it is very rapidly hydrolyzed due to the urease enzymes which can result in significant losses of nitrogen through volatilization. Urease inhibitors are aimed at eliminating these losses of surface applied urea.

The active ingredient in AGROTAIN is NBPT. It has been shown that an oxidation product of NBPT is a molecule with one end similar in size to the urea molecule and has the n-butyl group on
the other end of the molecule. It is believed the end that is similar to urea attaches to the active site of the urease enzyme blocking access to urea and preventing the enzyme from performing its function of catalyzing the hydrolysis of urea. Also, the hydrophobic n-butyl group that constitutes the bulk of the other end of the molecule blocks the approach of water to this active site of the urease inhibitor. Consequently, hydrolysis and breakdown of the urea is stopped. The formulation of AGROTAIN, then, allows this mechanism to effectively retard the volatilization losses from urea fertilizers for approximately fourteen days.

**HOW TO USE AGROTAIN**

AGROTAIN is easy to use. Urea can be impregnated with AGROTAIN and is absorbed by the granule. The recommended rate for impregnation is 1.4 kilograms of active ingredient per metric tonne of urea. This will require a loading of approximately 5.21 liters of concentrated AGROTAIN per metric tonne of urea. In dry bulk blended fertilizers, the urea should be impregnated with AGROTAIN and mixed thoroughly prior to the introduction or blending with other fertilizer materials. The half-life of bulk-stored urea impregnated with AGROTAIN urease inhibitor at the 5.21 liter concentration is about three months.

For urea-ammonium nitrate (UAN) solutions, the recommended concentration is 2.7 liters per metric ton for a 30% nitrogen solution. For other mixtures, the AGROTAIN rate will vary as the urea content varies. To add AGROTAIN to the nitrogen solution, the tank should be about half full with UAN solution. With the agitators on, add the appropriate amount of AGROTAIN. It should be mixed well and, then add the remainder of the UAN solution. Also, the AGROTAIN should be introduced into the UAN solution and mixed thoroughly before adding pesticides or surfactants. The solution should be applied to the field soon after mixing. There is gradual decomposition of the AGROTAIN when it is stored in the presence of water.

**HOW DOES AGROTAIN PERFORM**

Extensive field testing and agronomic research has been conducted with AGROTAIN. In the United States, studies involving corn and urea treated with AGROTAIN have been conducted for eleven years in nineteen states. These involved twenty-two universities and seven private company research and development groups. These efforts resulted in 316 replicated “nitrogen responsive” sites. The average response for all of these 281 sites is a 14.2 bushel per acre (0.89 metric tonnes per hectare) increase in yield.

In contrast to dry urea, studies involving UAN solutions treated with AGROTAIN, there were 119 replicated “nitrogen responsive” sites. The average yield response for corn was 9.0 bushels per acre (0.56 metric tonnes per hectare).

Additionally, similar research has been conducted with other crops. In the case of wheat, studies conducted in five states over seven years resulted in an average of 6.6 bushels per acre (0.44 metric tonnes per hectare) increase for the urea treated with AGROTAIN. The average yield increase for UAN containing AGROTAIN was 4.5 bushels per acre (0.30 metric tonnes per hectare).

An example of the research conducted is the NITROGEN SOURCE STUDY ON CORN by F. R. Mulford at the University of Maryland. He indicated the treatments at two locations were surface applied at 120 lb/acre nitrogen with urea and UAN, and compared to ammonium nitrate, injected UAN and anhydrous ammonia, at corn sidedress stage. Based on these studies, urea with AGROTAIN or UAN with AGROTAIN can be applied at sidedressing in corn and be as efficient as when UAN is injected into soil.
Another study conducted by Mr. Mulford evaluated urea, with and without AGROTAIN, on barley. This was compared to ammonium nitrate. Treatments were initiated on a silt loam soil and nitrogen rates of 40 and 80 lb/acre. When resulting yields were averaged across both nitrogen rates, AGROTAIN increased yield by 3 bu/acre over ammonium nitrate and by 13 bu/acre over untreated urea.

At Purdue University, David R. Mengel conducted AGROTAIN trials in no-till corn. The treatments were surface broadcast into wheat stubble at 140 lb/acre nitrogen with ten rain-free days following application. Yields with AGROTAIN treated urea were significantly different than urea alone and were similar to knifed UAN treatments. Surface applied urea with AGROTAIN was slightly higher yielding than ammonium nitrate.

**EVALUATION OF AGROTAIN IN NO-TILL CORN**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield (bu/acre)</th>
<th>Yield (tonne/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea + AGROTAIN (surface)</td>
<td>117</td>
<td>7.34</td>
</tr>
<tr>
<td>UAN (knifed)</td>
<td>117</td>
<td>7.34</td>
</tr>
<tr>
<td>Ammonium Nitrate (surface)</td>
<td>111</td>
<td>6.96</td>
</tr>
<tr>
<td>Urea (surface)</td>
<td>110</td>
<td>6.90</td>
</tr>
</tbody>
</table>

Even though extensive research has been done with agronomic crops in the United States, the work is continuing. Here is a list of the locations and crops being studied during the 1997 cropping season at ten different universities (See attachment B).
Nine different private or industry organizations in North America are continuing to field test AGROTAIN as well. Corn and wheat are the primary crops.

Similar research has been performed in a number of different countries in addition to the United States. And, the result of the work has been supportive of that conducted in the United States. As previously indicated, one of the first steps in developing the marketing strategy may be the field testing and research with the product. A number of countries have expressed interest in the product. A number of countries have previous research experience with NBPT. However, Canada, Australia, Ireland, United Kingdom and Korea have AGROTAIN research projects in the field during the 1997 growing season. These types of field studies will continue to develop as interest in marketing the product expands.

MARKETING AGROTAIN

Prior to marketing AGROTAIN in the United States, extensive agronomic research was conducted. Also, the rigorous laboratory and field testing for environmental, toxicology, degradation in the soil, human safety, etc. were completed and approval received for agronomic uses in the United States.

The actual marketing and sale of AGROTAIN in the United States was initiated in early 1996. The primary thrust for the advertising and promotion program was designed to work from the “bottom-up.” The effort was to generate interest and demand at the farm level making it easier for the retail distributors to justify purchasing the product. IMC-Agrico Company does control the worldwide marketing rights to AGROTAIN and will market, on a wholesale basis, through established retail distributors that have extensive sales and marketing network for agri-chemicals.

The product is packaged in 2.5 gallon (9.46 liter) high-density-polyurethane containers or bottles. Two polyurethane containers are placed in cardboard cases for shipping. Packaged AGROTAIN is shipped on pallets. Each pallet contains 45 cases or 852 liters. Bulk shipments of AGROTAIN are also available in 120 gallon (454 liters) mini-bulk containers with optional impregnation attachments.

Well into the second crop-growing season, high interest in AGROTAIN by both fertilizer dealers and farmers continues.

The early stages of introducing AGROTAIN to the international market are just underway. Patent registrations have now been filed in thirty-four countries. The product has been approved for sale in Australia, Brazil, New Zealand, and Mexico. Canada is very close with their sales approval. At the same time, several Canadian orders for AGROTAIN are being held until that approval process is final. Australia is the only country that has product actually shipped for sale. Other countries have the applications for registration in process.

In most countries, IMC-Global has local marketing agents that assist with the sales administration for all of our products sold in that country. It is our intent for AGROTAIN to be handled in a similar manner.

HOW TO GET AGROTAIN

To obtain information on purchasing product or acquiring AGROTAIN for research and field testing, the regional vice-presidents for IMC International Sales will assist you. Also, the manager of product development may be contacted (See Attachment A for all contact information).
Prior to requesting product, it is recommended that research information relating to urease inhibitors in the particular country be summarized, if available. IMC Global requires a simple memorandum of agreement that includes a research protocol as an attachment. Typically, one case of AGROTAIN is provided for research or field testing. That quantity, 18.9 liters, is sufficient to treat about 3.6 metric tons of urea. IMC Global also requests a copy of the research or test results on an annual basis.

COST

Once AGROTAIN is approved for sale in a particular country, what will the product cost the farmer? Since IMC Global markets the product on a FOB basis (point of production in the US), the Company does not set the local selling price to the farmer. However, based on observations of the retail market in the United States and assuming comparable marketing, distribution costs and adding some additional freight costs, it is estimated the cost of treating urea with AGROTAIN would be in the range of $66-$68 per metric ton of urea. Obviously, these assumptions are subject to considerable variation but should provide insight into the approximate cost of the product to the farmer.

CONCLUSION

The benefit of using AGROTAIN is to minimize or eliminate nitrogen losses through volatility when urea is surface applied to the soil. What AGROTAIN means to the farmer is greater profit potential by more efficient utilization of nitrogen from urea, increased flexibility, and more peace of mind.

Whether it is corn, top-dressed small grain, coffee, banana, forage crops, or any cropping situation where urea should be used, AGROTAIN can make a difference. And, for convenience, AGROTAIN will be sold in a liquid form that can be added to solid dry urea or AGROTAIN can be mixed with UAN solutions.

AGROTAIN is revolutionary technology for a changing agriculture. For the farmer or grower interested in optimal yields, better nitrogen management, more farming options as well as environmental peace of mind, AGROTAIN is the product.. available today.. for the future.
# ATTACHMENT A

**IMC Global Operations Inc.**
2345 Waukegan Road, Suite E-200
Bannockburn, Illinois  60015-5516  USA

Home Page:  www.imc-agrico.com

<table>
<thead>
<tr>
<th>SALES CONTACT</th>
<th>TELEPHONE</th>
<th>FAX</th>
<th>E-MAIL</th>
<th>AREAS OF RESPONSIBILITY</th>
</tr>
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<tbody>
<tr>
<td>Matthew J. Albrecht (Matt) Regional Vice President</td>
<td>1.847.607.3242</td>
<td>1.847.607.3390</td>
<td><a href="mailto:mjalbrect@imcglobal.com">mjalbrect@imcglobal.com</a></td>
<td>Middle East, Asian Subcontinent, Malaysia, Oceania</td>
</tr>
<tr>
<td>C. James Conner (Jim) Regional Vice President</td>
<td>1.847.607.3422</td>
<td>1.847.607.3390</td>
<td><a href="mailto:cjconner@imcglobal.com">cjconner@imcglobal.com</a></td>
<td>South America, Africa</td>
</tr>
<tr>
<td>Mary R. Engdahl Regional Vice President</td>
<td>1.847.607.3115</td>
<td>1.847.607.3390</td>
<td><a href="mailto:mrengdahl@imcglobal.com">mrengdahl@imcglobal.com</a></td>
<td>Mexico, Central America, Caribbean</td>
</tr>
<tr>
<td>Warren A. Gresham (Bud) Regional Vice President</td>
<td>1.847.607.3099</td>
<td>1.847.607.3390</td>
<td><a href="mailto:wagresham@imcglobal.com">wagresham@imcglobal.com</a></td>
<td>Europe, Far East, Commonwealth of Independent States</td>
</tr>
<tr>
<td>Steven H. Paxton (Steve) Regional Vice President</td>
<td>1.847.607.3418</td>
<td>1.847.607.3390</td>
<td><a href="mailto:shpaxton@imcglobal.com">shpaxton@imcglobal.com</a></td>
<td>China, Taiwan, Southeast Asia</td>
</tr>
<tr>
<td>Allen R. Sutton Manager, Product Development IMC-Agrico Company</td>
<td>1.502.826.6231</td>
<td>1.502.827.4825</td>
<td><a href="mailto:arsutton@imcglobal.com">arsutton@imcglobal.com</a></td>
<td></td>
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</tbody>
</table>

Allen R. Sutton Manager, Product Development IMC-Agrico Company
West Geneva Road
P. O. Box 1629
Henderson, Kentucky  42420
USA
## Attachment B

### 1997 North American University Research

<table>
<thead>
<tr>
<th>CONTACT</th>
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<tr>
<td>Joe Touchton</td>
<td>Auburn University</td>
<td>Corn, Wheat Ryegrass, Cotton</td>
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<tr>
<td>Ed Varsa</td>
<td>Southern Illinois University</td>
<td>Corn, Wheat</td>
</tr>
<tr>
<td>Kevin Barber</td>
<td>University of Illinois</td>
<td>Wheat</td>
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<tr>
<td>Steve Ebelhar</td>
<td>University of Illinois</td>
<td>Corn, Forage</td>
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<tr>
<td>Bob Hoeft</td>
<td>University of Illinois</td>
<td>Corn</td>
</tr>
<tr>
<td>Randy Killorn</td>
<td>Iowa State University</td>
<td>Corn</td>
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<tr>
<td>Ray Lamond</td>
<td>Kansas State University</td>
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<tr>
<td>Bill Hallmark</td>
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<td>Ron Mulford</td>
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<td>University of Nebraska</td>
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<td>Dave Mengel</td>
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<td>Corn</td>
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<td>John Bradley</td>
<td>University of Tennessee</td>
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<td>Tim Fiez</td>
<td>Washington State University</td>
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### North America Industry/Private Research

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<td>Agri Growth</td>
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<td>Mike Chanen</td>
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<td>Amir Varsouli</td>
<td>Lab</td>
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<td>Nutite - Canada</td>
<td>Pierre Fournier</td>
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<td>Terra International</td>
<td>Steve Barnhart</td>
<td>Corn</td>
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<td>Agrium -Canada</td>
<td>Michelle Nutting</td>
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### International Research Projects

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<td>Agriculture Canada</td>
<td>Cynthia Grant</td>
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<tr>
<td>Australia-AGROW</td>
<td>Chris Reynolds</td>
<td>Forages, Sugar Cane, Horticultural, Wheat</td>
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<tr>
<td>Ireland - Dept. of Ag for Northern Ireland</td>
<td>Catherine Watson</td>
<td>Forages, Wheat</td>
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<tr>
<td>Defense Research Agency-United Kingdom</td>
<td>Brian Foulger</td>
<td>Fertilizer Competability</td>
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<tr>
<td>Seoul Nat’l University -Korea</td>
<td>Jun-Han Suh</td>
<td>Rice</td>
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AGRONOMIC AND ECONOMIC ASPECTS OF INTEGRATED NUTRIENT MANAGEMENT IN SUB SAHARAN AFRICA: CASE STUDIES IN EAST AND WEST AFRICAN FARMING SYSTEMS

by

A. de Jager, Agricultural Economics Research Institute (LEI-DLO)

E.M.A. Smaling, Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO)

The Netherlands
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The Netherlands

ABSTRACT

The agricultural sector in sub-Saharan Africa (SSA) is facing a number of major challenges in the near future: produce sufficient food for the growing rural and urban population, increase efficiency and productivity to meet the increased competition in a global liberalized world market and maintain the natural resources base to secure production potential for future generations. Soil nutrient depletion is generally considered to be one of the most serious constraints in agricultural production in SSA. The concept of Nutrient Monitoring (NUTMON) is introduced, which attempts to develop Integrated Nutrient Management (INM) in a participatory approach with the stakeholders concerned.

The preliminary results of the implementation of this approach in three districts in Kenya are presented. On average 71 kg N ha\textsuperscript{-1} year\textsuperscript{-1} and 9 kg of K ha\textsuperscript{-1} year\textsuperscript{-1} are mined. Based upon replacement costs this implies that 32\% of the net farm income is based upon nutrient mining. Unfavourable input/output price ratios apparently lead to low levels of nutrient application in food crops. Given the declining food production per capita and the threat of declining productivity due to nutrient mining, changes in the economic environment are required to change this trend. A large heterogeneity between farms and farming systems is observed in nutrient mining levels and economic performance. This heterogeneity should be used as a starting point for inducing changes towards an increased sustainable agricultural production.

For West African farming systems a similar picture concerning nutrient mining and economic performance emerges. Based upon a study, conducted together with IFDC, an inventory of existing technologies to increase the sustainability of the farming systems is presented. However, a number of constraints prevent large-scale adoption of these technologies. A framework for necessary interventions is presented at three levels, i.e. supranational and regional (West Africa), national and district, and village and farm.

The major challenge to effectively address the soil fertility problems in SSA is to develop national INM programmes, using IPM experiences, involve farm/community level participative INM technology development and development of appropriate policy instruments. This will facilitate an optimal dovetailing between development of technology and creating an enabling environment for implementation.

1 Paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997
1. **INTRODUCTION**

The agricultural sector in sub-Saharan Africa, still the largest contributor to the Gross National Product, is facing a number of major *challenges* in the near future: produce sufficient food for the growing rural and urban population, increase efficiency and productivity to meet the increased competition in a global liberalized world market and maintain the natural resource base to secure production potential for future generations. So far the picture is far from bright: food production per capita is declining (FAO, 1995), cereal and meat production produced more efficiently in Europe, USA and Asia have started to push the African produced products from the market (Holtzman and Kulibaba, 1992) and productivity of the natural resource basis is declining. In particular water is becoming an increasingly scarce production factor (FAO, 1996), fertile top soil is being eroded and soil nutrients are mined (Stoorvogel and Smaling, 1990).

However, underneath this global sketch, a much more *diverse and resilient picture* emerges. The agricultural sector in Africa is characterised by a large diversity in farming systems in completely different agro-climatical and socioeconomic environments. Farm households have developed different strategies to cope with the various and changing environments and have increased productivity by developing indigenous technologies or by adopting (and adapting) available appropriate technology developed by the public and private research sector. Quite a number of cases have been reported where farmers have managed to increase productivity, income levels and conservation of the national resource base (Richards, 1985; Reijntjes et al., 1992; Reij et al., 1996, Wiggins, S., 1995).

**Soil nutrient depletion** is generally regarded as one of the most serious constraints to agricultural production in SSA. The average N, P and K balances for SSA in the period 1982-84 were estimated at -22, -2.5 and -15 kg ha\(^{-1}\) yr\(^{-1}\) respectively (Stoorvogel et al., 1993). In the mountainous and densely populated countries in East and Southern Africa higher nutrient depletion rates occur than in the drier countries in West Africa. This is caused by high values of nutrients in harvested products and erosion, and also by the higher inherent fertility of the soils in East and Southern Africa. In Sahelian soils, there is relatively little left to be lost. At lower scale level even more variation between districts, catchments, farming systems and activities within farming systems are observed.

What are the **main causes** of these negative nutrient balances? An increasing population needs more food and cash and the total agricultural production did indeed increased over the past 20 years, however not sufficient to meet the growing demand (Table 1). Increasing fertilizer consumption rates in the 1970's and 1980's were a major contributing factor to this increase in production. However, with the large-scale implementation of Structural Adjustment Policies (SAPs) the value-cost ratio of fertilizers at farm level reduced dramatically, resulting in a stagnation of the fertilizer consumption. Farm households found it increasingly difficult to sufficiently replenish exported nutrients from the farm and expanded cultivation to more fragile soil types. The farm households are often well aware of the short- and long-term effects and have developed or adopted relevant alternative technologies, but their options to address this situation are limited due to factors like poor property rights, immediate cash needs, high risks, shortage of labour, limited infrastructure and insecure agricultural output markets.
Table 1: Agricultural production (total and per capita), population and fertilizer consumption in SSA in the period 1975 - 1995 (FAO Agrostat; Herner and Harris, 1993; FAO, 1995)

<table>
<thead>
<tr>
<th>Year</th>
<th>Agricultural production index (1979-81 = 100)</th>
<th>Population (million)</th>
<th>Per capita food production index (1979-81 = 100)</th>
<th>Fertilizer consumption (1000 ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>97</td>
<td>318</td>
<td>112</td>
<td>693</td>
</tr>
<tr>
<td>1980</td>
<td>100</td>
<td>367</td>
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<tr>
<td>1985</td>
<td>114</td>
<td>425</td>
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<td>1990</td>
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<tr>
<td>1995</td>
<td>137</td>
<td>564</td>
<td>96</td>
<td>1279</td>
</tr>
</tbody>
</table>

In order to effectively address the problem of soil fertility decline in the current socioeconomic environment, maximum use has to be made of the existing variability in conditions, options and current farming practices between regions, farming systems, farms and even within farms. No blanket recommendations are required but a search for a carefully targeted mixture of optimum use of external inputs and maximum use of locally available, renewable and recyclable resources, in other words development of *Integrated Nutrient Management* (INM) programmes. The development of appropriate policy instruments which facilitate the adoption and implementation of INM practices must be an integrated part of such a programme. The development of such an INM programme requires a thorough knowledge of existing farm management and farm household decision making. This led to the development of the NUTrient MONitoring programme (NUTMON), first described by Smaling and Fresco (1993), and further elaborated by Smaling et al. (1996).

This paper introduces the concept of a nutrient monitoring programme as an approach to develop appropriate INM practices. The diagnostic phase of this approach is illustrated in a case study in Kenya, were diagnostic results are used to formulate a participative technology development programme. In the case study for West Africa, the need for INM is illustrated in a description of a multidisciplinary study of available technologies and policy instruments to address soil fertility problems in that region. The paper ends with some concluding remarks.

2. NUTRIENT MONITORING FOR DEVELOPMENT OF INTEGRATED NUTRIENT MANAGEMENT

One of the major underlying *principles* of the NUTMON approach is to develop a comprehensive multidisciplinary methodology which targets at different actors in the process of managing natural resources in general and plant nutrients in particular. For the NUTMON monitoring approach the following specific objectives have been formulated:

(i) To determine farm households perception of soil nutrient depletion and related constraints and potentials

(ii) To acquire a comprehensive knowledge of a farm system and the dynamic functionality of its internal and external nutrient flows in a spatial and temporal context.

(iii) To quantify nutrient flows and balances of existing farming systems at different spatial scales.

(iv) To quantify the economic performance of existing farming systems at different spatial scales.
(v) To identify, on-farm test and evaluate with stakeholders relevant INM-technology options.
(vi) To identify and evaluate with stakeholders relevant policy instruments enabling INM-technology adoption.
(vii) To formulate development scenarios, research priorities and policy advise to reduce soil nutrient depletion.

Farm monitoring takes place at plot and farm household level, since most of the decisions concerning nutrient management are taken at that level. Influences of processes at lower scales (for instance factors determining leaching) and higher scales (policy instruments influencing farm management decisions) are studied as well and incorporated in the farm level approach. In Figure 1 the NUTMON approach is summarized in a number of sequential methodological steps.

**Figure 1: NUTMON-approach at farm household level**

Two major phases can be distinguished: *diagnosis and analysis* of existing farm and nutrient management and *participatory INM-technology development*. The diagnostic phase aims at analysing the current nutrient management, determining the magnitude and major sources of nutrient depletion, analysing the economic performance, creating farm households awareness of nutrient management aspects and jointly with the farm households arriving at a research and development agenda. The results of this diagnostic phase are the basis for planning and implementation of mainly on-farm trials relating to Integrated Nutrient Management. Farmers, extensionists, NGO-staff and researchers are fully involved in this planning and implementation process and therefore both existing indigenous knowledge and scientific knowledge (or a combination of the two) can be incorporated in this process of technology development. In the past two years extensive experience has been gained in the development of the methodology for the comprehensive diagnostic phase and the tools developed are presented hereafter.

To *classify* the complex and heterogeneous situation at district scale various Land Use Zones (LUZ) are identified using geographical maps, Agro-Ecological Zone maps (AEZ), land use maps, satellite
images and expert consultation. Participatory Rural Appraisals (PRA) are conducted hereafter to identify different farming systems and major constraints in farm management. Based upon these PRAs, farm types within each LUZ are defined

The soil nutrient stock of a farm is defined as the total amount of nutrients present in the top 30 cm of the soil profile. Both nutrients in the organic matter fraction, nutrients absorbed to the solid phase and soluted nutrients are regarded as part of the stock. Between 10 and 25 samples per farm are taken depending on the farm size and heterogeneity of soils and cropping pattern.

In order to enable quantification of nutrient flows in a wide range of different farming systems, the farm is conceptualized in five types of units where nutrients are stocked: primary production units (crop production, pasture, farm yard etc.), secondary production units (animals), redistribution units (compost heap, stable), stock (grains, crop residues) and the farm household. Between those stock units basically three types of nutrient flows are distinguished: flows into the farm, flows out of the farm and internal flows (Table 2).

<table>
<thead>
<tr>
<th>IN flows</th>
<th>Out flows</th>
<th>Internal flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN1 Mineral fertilizers</td>
<td>OUT1 Farm products sold</td>
<td>FL1 Animal feeds</td>
</tr>
<tr>
<td>IN2 Organic inputs</td>
<td>OUT2 Other organic products</td>
<td>FL2 Household waste</td>
</tr>
<tr>
<td>IN3 Atmospheric deposition</td>
<td>OUT3 Leaching</td>
<td>FL3 Crop residues</td>
</tr>
<tr>
<td>IN4 Biological nitrogen fixation</td>
<td>OUT4 Gaseous losses</td>
<td>FL4 Grazing of vegetation</td>
</tr>
<tr>
<td>IN5 Sedimentation</td>
<td>OUT5 Runoff and erosion</td>
<td>FL5 Animal manure</td>
</tr>
<tr>
<td>IN6 Subsoil exploitation</td>
<td>OUT6 Human faeces</td>
<td>FL6 Farm products to household</td>
</tr>
</tbody>
</table>

The distinguished nutrient flows are quantified in various ways (Van den Bosch et al., forthcoming). Firstly, flows directly related to farm management are quantified by monthly discussions with the farmers on inputs to and outputs from the units (chemical and organic fertilizer use, harvest of crop and animal products, redistribution of crop residues and farm yard manure). N, P, and K contents of the ‘nutrient carriers’ are determined in the laboratory, prices are determined directly in the interview or collected during a separate survey (opportunity costs). Secondly, flows that can not easily be quantified by the farmer (like quantity of outside grazing and manure excretion of different types of animals) were estimated by means of a simple submodel. A third group of flows (atmospheric deposition, gaseous losses, leaching and erosion) was quantified fully on basis of off-site knowledge using transfer functions.

Based largely upon the same input and output flows economic performance indicators are calculated at farm and enterprise level using a spreadsheet calculation module (Table 3).

The calculation results of the models are discussed and validated in a workshop between the participating farm households, extensionists and research staff. This participative diagnosis is then followed by discussions focusing on formulating priorities for testing and developing INM-technologies in the different farm types and Land Use Zones. Based upon the results of these meetings a participative on-farm research programme is formulated and implemented.
Table 3: Farm household characteristics and economic performance indicators

- **Farm household characteristics**
  * number of persons
  * consumer units/labour units
  * farm size/R-value
  * total Tropical Livestock Units (TLU)
  * total invested capital
  * land/consumer ratio and land/worker ratio
  * capital - consumer, worker and land ratio

- **Activity level**
  * gross margin primary production units
  * gross margin secondary production units
  * total cash flow primary production units
  * total cash flow secondary production units

- **Farm household level**
  * net farm income
  * family earnings
  * farm net cash flow
  * household net cash flow
  * monthly household net cash flow
  * monthly labour (family/hired)
  * monthly labour (crop/livestock/general/off-farm/household)

- **Performance criteria**
  * crop production intensity and returns
  * livestock production intensity and returns
  * farm level returns to land, capital and labour
  * non-farm income
  * family earnings

3. **CASE STUDY: NUTRIENT MONITORING IN KENYA**

Results of the diagnostic phase of the NUTMON approach are presented for 26 farms in three districts in Kenya over a 12 month period in 1995/1996, covering two growing seasons. The major characteristics of the three districts are presented in Table 4.

Table 4: Characteristics of the studied districts in Kenya

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Kisii</th>
<th>Kakamega</th>
<th>Embu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude (m. a.s.l.)</td>
<td>1500-2200</td>
<td>1250-2000</td>
<td>760-2070</td>
</tr>
<tr>
<td>Soil</td>
<td>nitisols, pheaozem</td>
<td>ferralsols, acrisols</td>
<td>andosols, nitisols</td>
</tr>
<tr>
<td>First rains</td>
<td>well drained, deep</td>
<td>depleted</td>
<td>cambisols, ferralsols</td>
</tr>
<tr>
<td>Second rains</td>
<td>February - June</td>
<td>March - June</td>
<td>March - July</td>
</tr>
<tr>
<td></td>
<td>July - December</td>
<td>July - November</td>
<td>October - November</td>
</tr>
<tr>
<td>Annual precipitation (mm/yr)</td>
<td>1200 - 2100</td>
<td>1650-1800</td>
<td>640 - 2000</td>
</tr>
<tr>
<td>Annual temperatures (°C)</td>
<td>16 - 21</td>
<td>18-23</td>
<td>16 - 23</td>
</tr>
<tr>
<td>Population density (persons/km2)</td>
<td>800</td>
<td>650</td>
<td>130</td>
</tr>
<tr>
<td>Population growth (% / yr)</td>
<td>3.8</td>
<td>2.8</td>
<td>3.7</td>
</tr>
</tbody>
</table>

The total nutrient balances at farm household level amounted to -71 kg N, +3 kg P and -9 kg K ha\(^{-1}\) yr\(^{-1}\) with large variations between farms. Differences between district averages are observed for N and K, but statistically not significant (Figure 2). The partial balance, consisting of the nutrient
flows in farm inputs and product outputs, however is positive (34 kg N, +12 kg P and +27 kg K ha$^{-1}$ yr$^{-1}$). Farmers apparently import more nutrients than are exported through sale of products. Total immisions, defined as the sum of atmospheric deposition ($IN_{3}$) and biological nutrient fixation ($IN_{4}$) made up only 8% of the total inputs at farm level. Total emissions, defined as the sum of the flows $OUT_{3}$ to $OUT_{6}$, made up 86% of the total nutrient outputs. From the four emission flows, leaching ($OUT_{3}$) was the highest with 53 kg N ha$^{-1}$ yr$^{-1}$, while gaseous losses ($OUT_{4}$) were calculated at 24 kg N ha$^{-1}$ yr$^{-1}$. Losses through erosion were estimated at a level of 28 kg N, 10 kg P and 33 kg K ha$^{-1}$ yr$^{-1}$.

On average 21 kg ha$^{-1}$ yr$^{-1}$ of N is imported through fertilizers, but on 46% of the farms less than 5 kg ha$^{-1}$ yr$^{-1}$ of N is applied through fertilizers. Striking is the negligible import of organic fertiliser: of the 26 farms, 25 did not import any organic fertilisers at all. However, import of nutrients through organic feeds and through extensive grazing turns IN 2 higher than IN 1. Outflow of N through crop products ($OUT_{1}$) averages at 11 kg ha$^{-1}$ yr$^{-1}$, while outflow of N through livestock products ($OUT_{1}$) is relatively low with 6 kg ha$^{-1}$ yr$^{-1}$ with no significant differences between the districts. Although not significant, the partial balance for Kisii appears to be lower as compared to the balances for Kakamega and Embu.

**Figure 2: Average nutrient balances at farm level for 3 districts in Kenya**

The average *Net Farm Income* (gross farm income - total farm costs) amounts to US$ 1490 per farm per year (Table 5), with extreme large variations between farms. Between the districts no significant differences are observed. Crop and livestock activities contribute equally to the net farm income, although in Kakamega the share of livestock activities is significantly higher compared to the other districts. The average economic performance of the farm activities is satisfactory when looking at the realised returns to land and to family labour, which are above the district averages for land rent (US$ 55 ha$^{-1}$ yr$^{-1}$) and wages of unskilled labour (US$ 1.5 day$^{-1}$) respectively. However, there is extreme large variation among the farms and 46% of the farms in the sample realise lower returns than these averages.

The average annual farm net *cash flow* (total farm receipts minus total farm payments) amounts to US$ 675, with no significant differences between the districts. Crop and livestock activities contribute equally to the total farm cash income, only in Kakamega a significant higher contribution of livestock is observed. The average market orientation of the farms, expressed in the percentage of the total revenues of crop and livestock outputs sold, is 45% varying from complete subsistence (0%) to almost fully market oriented (95%). The selected farms in Kakamega district appear more subsistence oriented, although the difference is not statistically significant. On average 770 labour
days are used for farm activities, equivalent to two full-time persons, of which around 15% of this labour is hired with again a large variation between farms. The labour intensity of crop activities in Kisii and Embu is considerably higher than in the more extensive farming systems in Kakamega. Labour intensity in livestock between the districts is comparable.

Table 5: Economic performance indicators at farm level for 3 districts in Kenya

<table>
<thead>
<tr>
<th></th>
<th>District</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kisii (n=6)</td>
<td>Kakamega (n=8)</td>
</tr>
<tr>
<td>Net farm income</td>
<td>1435</td>
<td>1655</td>
</tr>
<tr>
<td>Farm net cash flow</td>
<td>490</td>
<td>525</td>
</tr>
<tr>
<td>Returns to land</td>
<td>-200</td>
<td>110</td>
</tr>
<tr>
<td>Returns to family labour</td>
<td>1.4</td>
<td>2.4</td>
</tr>
<tr>
<td>Share crops in income</td>
<td>49</td>
<td>19</td>
</tr>
<tr>
<td>Market orientation</td>
<td>48</td>
<td>30</td>
</tr>
<tr>
<td>Labour intensity crops</td>
<td>258</td>
<td>176</td>
</tr>
<tr>
<td>Labour intensity livestock</td>
<td>65</td>
<td>63</td>
</tr>
<tr>
<td>Farm Income Sustainability Quotient</td>
<td>0.53</td>
<td>0.60</td>
</tr>
</tbody>
</table>

One of the options to estimate the sustainability of a farming system is to relate the costs of replacement of mined nutrients against replacement costs, to the net farm income. The Farmers Income Sustainability Quotient (FISQ) can then be defined as follows: FISQ = 1 - value of nutrient deficit/net farm income (van der Pol, 1993). Over all the farms, an average Farm Income Sustainability Quotient (FISQ) of 0.68 is found, indicating that 32% of the net farm income is based upon nutrient mining. At district level for Kisii, Kakamega and Embu respective FISQ values of 0.53, 0.60 and 0.80 are found, with the differences not statistically different. These figures indicate that given the current prices of fertilizers and agricultural products, replacement of the depleted nutrients would reduce net farm income with around 30%. In addition it is estimated that currently already 54% of the farms in the sample realise income levels from farm activities which are below the poverty line (De Jager et al., 1998). This leads to the conclusion that in the current socioeconomic environment for a large portion of the households, agricultural production takes place in an agronomic and economic unsustainable way and that off-farm income is at this moment essential for large groups of small-scale farm households to achieve economic viability. Creating changes in the socioeconomic environment will therefore be just as important as developing Integrated Nutrient Management technologies to attain more sustainable agricultural systems.

It appears that the market orientation can be used as a discriminating factor for nutrient balances and farm management aspects. Therefore three groups of market orientation are distinguished: < 33%, 33-66% and >66% of the gross revenues sold. Subsistence oriented farms (<33%) have a significant less negative nutrient balance for N and K than market oriented farms (>66%, Table 6). The partial balance for N is positive in all three groups, but the inflow through fertilizers increases with the market orientation. Inflow through organic sources on the other hand decreases with the market orientation due to lower number of livestock which are kept in zero grazing units (less outside grazing) and fed from on-farm produced napier grass. The market orientation is related to intensification of the farming system: capital and labour intensive production on relative small cultivated areas. No significant differences are observed between the groups in economic performance and economic sustainability, although logically the farm net cash flow is higher on the market oriented farms. The FISQ appears to reduce with increased market orientation, although not statistically significant. The market oriented farms import comparable amounts of nutrient, although from different sources, but export of nutrients through products and through losses in leaching and erosion are considerably higher. On the subsistence oriented farms, the nutrient balance is relatively positive through concentration of nutrients from grazing land to the cultivated area for arable crops.
The sustainability of the system is therefore related to the grazing to arable land ratio and increasing land pressure may lead to a decline of this ratio.

Table 6: Farm management, nutrient balances and economic performance according to market orientation of farms expressed in % of gross returns sold

<table>
<thead>
<tr>
<th>Source of income</th>
<th>Market orientation</th>
<th>&lt; 33%</th>
<th>33 - 66%</th>
<th>&gt; 66%</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-balance (kg ha⁻¹)</td>
<td>-26ᵃ</td>
<td>-89ᵇ</td>
<td>-106ᵇ</td>
<td></td>
</tr>
<tr>
<td>P-balance (kg ha⁻¹)</td>
<td>-2</td>
<td>5</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>K-balance (kg ha⁻¹)</td>
<td>32ᵇ</td>
<td>-12ᵇ</td>
<td>-68ᵃ</td>
<td></td>
</tr>
<tr>
<td>Net Farm Income (US$ farm⁻¹)</td>
<td>1380</td>
<td>1615</td>
<td>1455</td>
<td></td>
</tr>
<tr>
<td>Farm net cash flow (US$ farm⁻¹)</td>
<td>182ᵃ</td>
<td>764ᵇ</td>
<td>1236ᵇ</td>
<td></td>
</tr>
<tr>
<td>Cultivated area (ha)</td>
<td>6.7</td>
<td>4.3</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>TLU</td>
<td>4.4ᵇ</td>
<td>4.2ᵇ</td>
<td>1.5ᵃ</td>
<td></td>
</tr>
<tr>
<td>Zero grazing unit (1=yes/2=no)</td>
<td>2.0ᵃ</td>
<td>1.5ᵇ</td>
<td>1.4ᵇ</td>
<td></td>
</tr>
<tr>
<td>Share livestock in income (%)</td>
<td>61ᵃ</td>
<td>63ᵃ</td>
<td>16ᵇ</td>
<td></td>
</tr>
<tr>
<td>N-inflow fertilizers (IN1 in kg ha⁻¹)</td>
<td>9ᵃ</td>
<td>18ᵃ</td>
<td>45ᵇ</td>
<td></td>
</tr>
<tr>
<td>N-inflow organics (IN2 in kg ha⁻¹)</td>
<td>54</td>
<td>21</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Labour intensity crops (days ha⁻¹)</td>
<td>179</td>
<td>226</td>
<td>373</td>
<td></td>
</tr>
<tr>
<td>Labour intensity livestock (days ha⁻¹)</td>
<td>71</td>
<td>48</td>
<td>91</td>
<td></td>
</tr>
</tbody>
</table>

ᵃᵇ - the mean difference is significant at P=0.05 level

At crop level the returns, gross margins and variable costs of the major cash crops coffee and tea are considerably higher than of the major food crops maize and maize-beans (Figure 3). Although not statistically significant, food crops tend to have more negative nutrient balances than cash crops.
On coffee and tea higher levels of fertilizers are applied than on food crops and also the added values realised differs considerably (Table 7). Economic studies of the Fertilizer Use Recommendation Project (FURP) show that application of fertilizers to food crops is not economical in the short term, and the data show this is consistent with actual farm practices. However, this low fertilization levels in food crops, results in high replacement cost levels. For the cash crops coffee and tea the needed expenditures to replace the mined nutrients amounts to 20-30% of the gross returns, while for food crops this is at least 70-80% of the returns. Based on these data a gross margin sustainability quotient (GMSQ) can be calculated as follows: 1 - nutrient deficient value at replacement costs / gross margin. For cash crops this GMSQ is significantly higher than for food crops.

Table 7: Added value, actual and needed fertilization expenditures and sustainability quotient for major crops in 3 districts in Kenya

<table>
<thead>
<tr>
<th>Crops</th>
<th>Coffee</th>
<th>Tea</th>
<th>Maize</th>
<th>Maize-Beans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross returns (US$ ha⁻¹)</td>
<td>1355</td>
<td>620</td>
<td>85</td>
<td>205</td>
</tr>
<tr>
<td>Added value (US$ ha⁻¹)</td>
<td>1120</td>
<td>475</td>
<td>65</td>
<td>190</td>
</tr>
<tr>
<td>Replacement costs (US$ ha⁻¹)</td>
<td>40</td>
<td>50</td>
<td>125</td>
<td>130</td>
</tr>
<tr>
<td>In % of returns:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual fertilization exp.</td>
<td>17</td>
<td>23</td>
<td>23</td>
<td>8</td>
</tr>
<tr>
<td>Needed expenditure</td>
<td>20</td>
<td>31</td>
<td>173</td>
<td>70</td>
</tr>
<tr>
<td>GM Sustainability Quotient</td>
<td>0.97</td>
<td>0.90</td>
<td>-1.46</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Contrary to crop activities, livestock, just like the remaining identified nutrient storage places in the farm (manure stock, food stock, farm family and garbage heaps) show on average positive nutrient balances (Van den Bosch, forthcoming). Three different ‘cattle systems’ are distinguished: zero-grazing, semi-zero-grazing and extensive grazing systems. No significant differences between the gross margins and nutrient balances of the three distinguished cattle management systems are found, but the more intensive zero-grazing system tends to realise higher gross margins and more positive
nutrient balances than the more extensive systems.

Workshops have been organised between farm households, extension staff and researchers to validate and discuss the results of analysis of the monitoring. Based upon the detailed results per land use zone in the district, a start was made during the workshop to **set priorities for development of INM-technologies** for the different farming systems in the distinguished land use zones (Table 8). This output will be the starting point for the process of participatory technology development of INM-technologies. In the coming years emphasis will be given to develop this aspect of the NUTMON approach.

**Table 8: Example of general priority setting for 3 farm types in Embu district Kenya**

<table>
<thead>
<tr>
<th>Market oriented (301) LUZ 1</th>
<th>Medium market oriented (305) LUZ 2</th>
<th>Subsistence (314) LUZ 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main observations</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labour intensive</td>
<td>Labour extensive</td>
<td>Relatively labour extensive</td>
</tr>
<tr>
<td>Land constraint</td>
<td>Land constraint</td>
<td>Grazing land constraining factor</td>
</tr>
<tr>
<td>Ecological unsustainable: N-mining</td>
<td>N-mining</td>
<td>Ecologically and economically sustainable when sufficient grazing land available</td>
</tr>
<tr>
<td>Economically sustainable</td>
<td>Low application level of fertilizers</td>
<td>Low crop-livestock interaction</td>
</tr>
<tr>
<td>Highly dependent on input/output price levels</td>
<td>Economically unsustainable</td>
<td>Independent on input/output price levels</td>
</tr>
<tr>
<td>High crop-livestock interaction</td>
<td>Moderate crop-livestock interaction</td>
<td>Cowpeas, maize and milk are major income earners</td>
</tr>
<tr>
<td>Tea and milk major income earners</td>
<td>Dependent on input/output price levels</td>
<td>Capital constraint</td>
</tr>
<tr>
<td>No capital constraint</td>
<td>Coffee, tea and milk major income earners</td>
<td></td>
</tr>
<tr>
<td><strong>Development priorities</strong></td>
<td>Application of nutrient saving, labour extensive technologies like agroforestry, soil conservation, tailor-made fertilization, N-fixation</td>
<td>Capital extensive intensification of crop and livestock production when reduced availability of grazing land.</td>
</tr>
<tr>
<td>Application of nutrient adding and nutrient saving techniques like increased and efficient fertilizer use, use of organic inputs (manure), N-fixation, composting etc.</td>
<td>Application of nutrient saving techniques like increased crop-livestock interaction, increased use of manure and efficient use of nutrients like composting.</td>
<td></td>
</tr>
<tr>
<td>Increased economic efficiency of activities (management etc.)</td>
<td>Increase cash generating activities (livestock and crop)</td>
<td></td>
</tr>
<tr>
<td>Exploring off-farm income opportunities</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. **CASE STUDY: FRAMEWORK FOR INTERVENTIONS IN WEST AFRICA**

In collaboration with IFDC a multidisciplinary team consisting of agronomists, soil scientists, sociologists and socio-economists reviewed literature and consulted relevant research results and databases to collate existing information on farming systems and soil fertility issues in West Africa, to collate information on policies, infrastructure and technologies that can directly or indirectly improve soil fertility and systematically develop a multidisciplinary, multi-scale framework for action (Mokwunye et al., 1996).

In West Africa data on **nutrient flows** are available mainly at national level (Table 9). Data on the impact of cropping systems and farm management practices on the soil fertility status and nutrient flows are rather scanty. For southern Mali (Van der Pol, 1992) and pasture systems in the SSZ and in the Sahel (Penning de Vries, 1982; Breman, 1994), such details on nutrient budgets are available. More comprehensive studies are actually lacking such as those involving different farming systems in the region and those focussing on relations between farm household strategies, land tenure issues, capital availability, market infrastructure, economic performance gender etc. on soil fertility.
Policy instruments at different scale levels influence farm household decision making concerning soil fertility management. Global policies like the GATT and the IMF and World Bank initiated Structural Adjustment Programs (SAPs) have a great impact on agricultural development and soil fertility in West Africa. But also regional policies, like the EU agricultural policy, directly influence the agricultural sector in West Africa. For instance the increased competition of subsidized beef exported from the EU resulted in lower prices and reduced outlet possibilities of meat produced in the Sahel and eventually discouraged necessary long-term investments in more sustainable and intensive production systems.

Table 9: N-P-K budgets in a number of countries in West Africa 1983
(Stoorvogel and Smaling, 1990)

<table>
<thead>
<tr>
<th>Countries</th>
<th>Arable land (ha* 1000)</th>
<th>Fallow (%)</th>
<th>N (kg/ha)</th>
<th>P (kg/ha)</th>
<th>K (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burkina Faso</td>
<td>6691</td>
<td>50</td>
<td>-14</td>
<td>-2</td>
<td>-10</td>
</tr>
<tr>
<td>Cameroon</td>
<td>7681</td>
<td>50</td>
<td>-20</td>
<td>-2</td>
<td>-12</td>
</tr>
<tr>
<td>Ghana</td>
<td>4505</td>
<td>24</td>
<td>-30</td>
<td>-3</td>
<td>-17</td>
</tr>
<tr>
<td>Guinea</td>
<td>4182</td>
<td>68</td>
<td>-9</td>
<td>-1</td>
<td>-6</td>
</tr>
<tr>
<td>Ivory Coast</td>
<td>6946</td>
<td>31</td>
<td>-25</td>
<td>-2</td>
<td>-14</td>
</tr>
<tr>
<td>Mali</td>
<td>8015</td>
<td>72</td>
<td>-8</td>
<td>-1</td>
<td>-6</td>
</tr>
<tr>
<td>Niger</td>
<td>10985</td>
<td>47</td>
<td>-16</td>
<td>-2</td>
<td>-11</td>
</tr>
<tr>
<td>Nigeria</td>
<td>32813</td>
<td>18</td>
<td>-34</td>
<td>-4</td>
<td>-24</td>
</tr>
<tr>
<td>Senegal</td>
<td>5235</td>
<td>53</td>
<td>-12</td>
<td>-2</td>
<td>-10</td>
</tr>
<tr>
<td>Togo</td>
<td>1503</td>
<td>49</td>
<td>-18</td>
<td>-2</td>
<td>-12</td>
</tr>
</tbody>
</table>

National governments have different instruments to effectively ensure implementation of a certain policy: laws and regulations, financial incentives (subsidies, levies), social regulations and persuasion (extension, research etc.). However they have to operate within the above mentioned supra-national agreements, like SAPs. A distinction can be made between direct price and market interventions and more indirect facilitating instruments for the development of the agricultural sector (research, extension, transport etc.). Hereafter the following instruments will be reviewed in more detail:

- SAP induced instruments (currency devaluation, subsidy removal, fertilizer privatization).
- Market development of agricultural outputs.
- Research, extension, development interventions.

Systematic studies on the impact of the SAP measures on soil fertility maintenance are scarce. The currency devaluation (FCFA in 1994) has largely increased the profitability of the export sector, which may eventually lead to increased fertilizer use and overall investments in soil fertility. By contrast, in the food crop production sector, currency devaluation has not led to an increase in income of farmers since the slight increase in food crop prices could not compensate the increased fertilizer prices. The removal of fertilizer subsidies in most West African countries has, at best, resulted in a stagnation of fertilizer use in the food crop sub-sector and a further reduction of the already low Value/Cost Ratio (VCR) for fertilizer use on cereal crops (Table 10). Given these developments total fertilizer consumption in West-Africa has not increased significantly in the past ten years.

Economies in SSA are currently semi-open, with high transfer costs and large non-tradable rural sectors, suggesting that a deliberate and commodity approach to supporting agricultural production will be necessary (Delgado, 1995). Since increasing farmers’ output prices is a key factor in addressing soil nutrient depletion, increasing the performance of food markets, supporting crop diversification and facilitating the development of processing industry are appropriate policy tools.
for achieving a sustainable agricultural development. The performance of the food markets in West Africa can be improved through increased financing facilities to farmers and traders, improved storage facilities, increased transport facilities, adequate and timely market information. The potentials for crop diversification are limited and it is unlikely that non-traditional exports may replace traditional commodities as dominant foreign exchange earners in the coming 10 years.

Table 10: Value - Cost Ratios for maize and cereals in Ghana and Mali (Gerner, 1995)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ghana</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AS + 15-15-15 (Maize)</td>
<td>-</td>
<td>2.6</td>
<td>3.1</td>
<td>1.8</td>
<td>1.6</td>
<td>1.1</td>
</tr>
<tr>
<td>AS + 20-20-0 (Maize)</td>
<td>-</td>
<td>2.6</td>
<td>3.1</td>
<td>1.7</td>
<td>1.5</td>
<td>1.1</td>
</tr>
<tr>
<td>Urea + 20-20-0 (Maize)</td>
<td>-</td>
<td>3.0</td>
<td>3.6</td>
<td>2.4</td>
<td>2.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Mali</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imported N-P-K (Maize)</td>
<td>2.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Imported N-P-K (Rice)</td>
<td>5.1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.4</td>
<td>4.1</td>
</tr>
<tr>
<td>Imported N-P-K(Sorghum)</td>
<td>1.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.6</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Existing technologies to address the problem of soil nutrient depletion can be partitioned into:
- techniques that save nutrients from being lost from the agro-ecosystem
- techniques that add nutrients to the agro-ecosystem

The technologies identified for restoration of soil fertility and its impact on nutrient flows are presented in Table 11.
Table 11: Restoring soil fertility in West-Africa: technical options and their impact on nutrient flows listed in Table 2 (Smaling et al. 1996)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Fertility effect (see table 2)</th>
<th>Adding/saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mineral fertilizers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- increased use</td>
<td>increase of IN 1</td>
<td>adding</td>
</tr>
<tr>
<td>- more efficient use</td>
<td>reduction of OUT 3-5</td>
<td>saving</td>
</tr>
<tr>
<td>2. Mineral soil amendments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- rock phosphates</td>
<td>increase of IN 1 (P)</td>
<td>adding</td>
</tr>
<tr>
<td>- lime and dolomites</td>
<td>increase of pH, IN 1 (Ca, Mg)</td>
<td>adding</td>
</tr>
<tr>
<td>3. Organic inputs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- from within the farm</td>
<td>reduction of OUT 2</td>
<td>saving</td>
</tr>
<tr>
<td>- from outside the farms</td>
<td>increased recycling FL 1,3,5</td>
<td>mainly saving</td>
</tr>
<tr>
<td>4. Improved land use systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- rotations, green manures</td>
<td>increase of IN 4, reduction of OUT 2-5</td>
<td>adding+saving</td>
</tr>
<tr>
<td>- fallows, woody species</td>
<td>increase of IN 4,6, reduction of OUT 2-5</td>
<td>adding+saving</td>
</tr>
<tr>
<td>5. Soil and water conservation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- combination of IN 1 - OUT 5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Integrated Nutrient Management</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Adoption** of the above mentioned technologies at farm household level has been limited, resulting in a similar slow process of technical change in West African agriculture. Apart from the short-term economic profitability there are other factors influencing adoption decisions:

- the developed technology is not appropriate to the specific situation of farm households;
- farm household short-term strategies conflicts with long-term effects of restoring soil fertility techniques;
- farm households are not accustomed to investing money and in most cases do not have the resources to invest;
- land tenure arrangements prevent long-term investments in the soil;
- perception of the problem is not always very clear at farm household level;
- agro-ecological margins in specific areas are very small, so that chances of total crop failure are too high to justify investments in tools, equipment or fertilizers;
- knowledge at farm household is insufficient because of limited access to research results due to ineffective functioning of extension services and the virtual absence of effective research-extension-farmer linkages;
- limited possibilities of economic development outside agriculture in the region prevent technology developments in the agricultural sector;
- appropriate supportive infrastructures are lacking;
- limited marketing possibilities and market access exist;
- the technology conflicts with existing local knowledge, social events or community structures;
- strong fluctuating prices of inputs and agricultural products increases economical risk.

The review has demonstrated that:

- A wide range of technologies is available. However, adoption of these technologies has been hampered by socioeconomic conditions.
- A comprehensive, integrated rural development agenda, at the system level, is absent. Rural development efforts are fragmented and ad-hoc in nature.
- Existing policies favour attainment of short-term goals and are not geared toward long-term sustainable agricultural development.
Based upon this observations, a framework for possible interventions at different scale levels has been formulated (Annex 1).

5. CONCLUDING REMARKS

The first experiences with a farm-level **multi-disciplinary monitoring** approach, although still in development, have proven to contribute to understanding the current farm management systems, to identify the existing diversity in soil fertility management strategies and to target and prioritize different development options.

The monitoring results have shown that the rather alarming national level nutrient mining figures consist of heterogenic pattern of nutrient balances and flows in different farming systems and enterprises. It is exactly this **heterogeneity** which the NUTMON approach will exploit to develop **appropriate and tailor-made INM-technologies**, which should be geared towards an economically optimum mix of nutrient-adding and nutrient-saving techniques.

From the East and West African case study presented, it is obvious that INM technology development must be matched with adequate **policy instruments** to facilitate adoption of these practices at farm level. In West Africa a wide range of technologies are available, but adoption is hampered by socioeconomic conditions. In East Africa the NUTMON exercise revealed that current agricultural production is not sustainable both from the viewpoint of nutrient management and economic performance. This implies that for a successful adoption of developed INM technologies, favourable socioeconomic conditions for farmers have to be created.

The principles of INM (grow a healthy crop, make maximum use of local available resources and natural processes, science-linkage and ‘the farmer is an expert’) are inspired by Indonesia's IPM Training Project which is part of FAO's IPM programme in South East Asia. Where IPM is about bugs, INM is about nutrients. But that is only half the story. Much as the bugs in IPM are an entry point for a totally different approach to innovation in small-scale irrigated rice production, INM is an entry point for a totally different approach to innovation in African rainfed small-holder production. The major challenge to effectively address the soil fertility problems in SSA is to **develop national INM programmes**, using IPM experiences, involve farm/community level participative INM technology development and development of appropriate policy instruments. This will facilitate an optimal dovetailing between development of technology and creating an enabling environment for implementation.

REFERENCES


FAO, 1995. FAO yearbook Fertilizers, Rome, Italy.


## Annex 1: Recommended actions at different intervention levels to facilitate implementation of technology options to restore soil fertility

<table>
<thead>
<tr>
<th>Technology</th>
<th>Mineral Fertilizers</th>
<th>Mineral Soil Amendments (P&amp;Lime)</th>
<th>Organic inputs (crop residues &amp; manure)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major constraints --&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Capital</td>
<td></td>
<td>- Awareness/R-E-F-linkages</td>
<td>- Labour</td>
</tr>
<tr>
<td>- National policies</td>
<td></td>
<td>- Perception</td>
<td>- Availability</td>
</tr>
<tr>
<td>- Market development agricultural products / input-output prices</td>
<td></td>
<td>- Pay-back period</td>
<td></td>
</tr>
<tr>
<td>Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supra-national and regional (West Africa)</td>
<td>- Review of SAPs</td>
<td>- Perception of Rock Phosphate (RP) as capital investment</td>
<td>- Valuation unaccounted costs and benefits</td>
</tr>
<tr>
<td>- Replacement food aid with fertilizer aid</td>
<td>- Common regional agricultural policy (increased market protection)</td>
<td>- Support World Bank RP initiative</td>
<td>- Awareness/quantification of international flows of Organic Matter and nutrients</td>
</tr>
<tr>
<td>- Joint fertilizer procurement</td>
<td>- Perceived as capital investment</td>
<td>- Valuation of unaccounted costs and benefits (internalise externalities)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Regional coordination of exploitation of deposits</td>
<td></td>
</tr>
<tr>
<td>National and regional</td>
<td>- Government support to private fertilizer sector</td>
<td>- Formalisation/implementation of NARS-Extension/NGO-Farmers linkages</td>
<td>- Energy conservation policies</td>
</tr>
<tr>
<td>(physical/institutional)</td>
<td>(physical/institutional)</td>
<td>- Facilitation of exploitation and distribution</td>
<td>- Waste management policies (recycling of agro-industrial and city waste)</td>
</tr>
<tr>
<td>- Forms of fertilizer subsidies</td>
<td></td>
<td>- Establishment of national resource management unit</td>
<td></td>
</tr>
<tr>
<td>- Policy support to agricultural sector</td>
<td></td>
<td>- National P/Lime investment policy</td>
<td></td>
</tr>
<tr>
<td>- Finetune fertilizer recommendations for various crops to soil and AEZs</td>
<td></td>
<td>- Extension message and methodology development</td>
<td></td>
</tr>
<tr>
<td>- Gender specific extension activities (e.g. more women extension staff)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Village/ farm household</td>
<td>- Financial support services to farmers (selective rates, credit)</td>
<td>- Participatory on-farm trails</td>
<td>- Improved animal husbandry management</td>
</tr>
<tr>
<td>- Development of group-banking systems (Grameen)</td>
<td></td>
<td>- Extension message and methodology development</td>
<td>- Measures to reduce/avoid bush burning</td>
</tr>
<tr>
<td>- Development of women banking groups</td>
<td></td>
<td></td>
<td>- Maximization of biomass production</td>
</tr>
<tr>
<td>- Cash crop development (diversification)</td>
<td></td>
<td></td>
<td>- Increasing quality of Organic Matter (composting)</td>
</tr>
<tr>
<td>- Local processing agricultural products</td>
<td></td>
<td></td>
<td>- Improvement of transport facilities and techniques</td>
</tr>
<tr>
<td>- Participatory fertilizer trials with farmers and women groups</td>
<td></td>
<td></td>
<td>- Training in use of green manures</td>
</tr>
</tbody>
</table>
## Annex 1: Recommended actions at different intervention levels to facilitate implementation of technology options to restore soil fertility (continued)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Improved Land Use Systems (LEISA)</th>
<th>Soil conservation</th>
<th>Integrated Nutrient Management (LEISA+HEIA)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Supra-national and regional (West Africa) | - Foster international initiative for greening the region  
- Policies to integrate pastoralism and sedentary agriculture  
- Valuation of unaccounted costs and benefits | - Valuation of unaccounted costs of soil erosion and off-site effects | - Awareness/support international approach  
- Shift in paradigm to eco-regional research and development approach |
| National and provincial | - Formalisation/implementatio | - Facilitate maximum use of indigenous knowledge and materials  
- Development of national soil conservation development scheme (incentives to farmers)  
- Policies to secure land tenure systems | - Formalisation/implementatio of NARS-Extension/NGO-Farmers linkages  
- Shift from commodity to eco-regional approach  
- Strategy to maximize internal input and optimize external input use  
- Integration of indigenous knowledge with scientific knowledge systems  
- Niche differentiation | |
| Village/ farm household | - Participatory technology development and demonstration on technical components of improved LUS (AEZ-specific) | - Promoting community conservation programs  
- Development of labour-saving soil conservation technologies  
- Participatory technology development and demonstration | - Participatory technology development and demonstration  
- Exploitation of farm heterogeneity |
GESTION DES ELEMENTS FERTILISANTS ET DEMANDES SOCIALES
par
J.C. Ignazi
COMIFER, France
GESTION DES ELEMENTS FERTILISANTS ET DEMANDES SOCIALES

par

J.C. Ignazi

COMIFER, France

L'approche d'un changement de millénaire prédispose bien à s'interroger sur l'évolution des techniques face aux perspectives de développement de l'humanité. Cette réunion du Comité Agro-Economie de l'IFA doit être l'occasion d'éclairer les conditions d'évolution des techniques de l'agriculture des pays développés, et tout particulièrement, de la fertilisation. Or, si l'Agriculture, en tant que telle, est bien l'une des plus anciennes activités humaines, jamais son rôle, ses techniques, voire sa légitimité, n'ont été autant discutés, tout au moins dans nos pays.

C'est pourquoi il nous paraît utile d'analyser les demandes de la société humaine d'aujourd'hui, face aux activités de l'agriculture, pour en tirer quelques conséquences pour la fertilisation de demain.

Les demandes de la Société à son agriculture :

Des produits abondants, variés et à faible coût

Fertilisation, protection des cultures, semences sélectionnées, travail du sol, ont constitué la base technique des systèmes agricoles modernes, développés dans les cinquante dernières années, principalement en Europe, dans le but d’assurer l'autosuffisance alimentaire des populations. En d’autres termes, on peut dire que la ‘demande sociale’ des citoyens aux agriculteurs de leur pays a été d’abord de produire récoltes et produits animaux au moindre coût, pour retrouver après la deuxième guerre mondiale abondance, et confort. L’intensification de l’agriculture Européenne a découlé de ce ‘contrat’ établi entre la Société et les agriculteurs, grâce aux progrès techniques développés par la Recherche agronomique, les industries d’agro-fourniture, et les organismes de vulgarisation agricole.

La fourniture alimentaire reste la base de la demande en produits agricoles: céréales, fruits, légumes, viandes, produits laitiers, le consommateur désirant trouver un choix toujours plus large sur les marchés ou magasins de distribution.

Une autre mission a, de tout temps, été confiée à l’agriculture : Elaborer des produits végétaux ou animaux à usage non alimentaire : tels que fibres textiles, plantes médicinales, colorants etc. Le souci de trouver des sources d’énergie renouvelable conduit à développer des cultures à usage énergétique: céréales, betteraves pour le ‘bioethanol’, ou colza pour le carburant ‘Diester’, etc. Le développement des techniques de biotechnologie devraient également aboutir à la production de substances chimiques complexes à partir de biomasse d’origine agricole.

Des produits "de qualité"

En plus de cet abondance, liée à une production de masse, le consommateur exige des produits "de qualité", de belle présentation, bien conditionnés, à la saveur fine et "naturelle". Ce concept de "qualité" est par ailleurs difficile à définir clairement, car très subjectif. Néanmoins, la référence à la qualité ne figure-t-elle pas sur tout message publicitaire ? C'est pourquoi, reconnaissant l'importance de ces notions, les prochaines "rencontre de la fertilisation raisonnée" qui se tiendront à Blois en novembre prochain auront pour thème: Qualité des sols, Qualité des productions végétales".

De plus, la fourniture de produits alimentaires doit être diversifiée: chaque espèce ou variété étant perçue au travers de ses caractéristiques (aspect, saveur) et de son origine géographique : ceci explique le développement des produits "d'origine contrôlée" ou à "label".

---

1 Exposé présenté à la réunion du Comité Agro-Economie de l'IFA à Tours, France, les 23 et 25 juin 1997
Des produits "sains"

Les consommateurs modernes sont de plus en plus préoccupés par l'influence de leur alimentation sur leur santé : longévité, risque de maladie, maintien de la "forme", etc. Bref, ils demandent la parfaite innocuité des produits alimentaires.

Or la plupart d'entre eux, vivant en milieu urbain, ignorent les techniques de production agricoles modernes, qu’ils jugent inadaptées à une production de qualité, et critiquent de ce fait l’emploi de fertilisants et de pesticides, dont ils craignent un effet nocif sur leur santé. Bien que ne reposant pas sur des données scientifiquement établies, l’idée que la technique de production d’une récolte peut en influencer la qualité, est maintenant très répandue dans l’opinion publique. La récente "crise de la vache folle" a bien montré l'impact puissant de ces craintes sur le niveau de consommation de la viande de boeuf. De plus, la diffusion large auprès du public de débats d'experts sur des thèmes touchant l'alimentation (OGM par exemple) conduit le plus souvent à une méfiance accrue des techniques de l'agriculture moderne.

A cet aspect alimentation et santé, mettant en cause les produits de l'agriculture, il faut rattacher la prise en compte par l'opinion publique de la qualité de l'eau potable distribuée, et qui n'est qu'un aspect d'une autre demande sociale:

Protéger l'Environnement et conserver notre cadre de vie

La protection de l'environnement est apparue récemment comme une nouvelle mission pour l'agriculture. Sensibilisée par la grande Presse, l’opinion publique a conduit le monde agricole à prendre conscience de l’influence de ses pratiques sur la qualité de l’eau, de l’atmosphère, et des sols. Un récent sondage (fév.97) de la SOFRES réalisé en France a montré que plus de 75% des citoyens estiment que l’Agriculture ne prête pas assez attention à l'environnement! Nitrates et phytosanitaires dans l’eau, dégagements d’ammoniac, dégradation des sols, autant de sujets qui ont déjà été largement abordés dans les années récentes. Toutes ces préoccupations doivent inciter les agriculteurs à poursuivre l'adaptation de leurs techniques pour limiter les risques, afin de ne pas être perçus comme des pollueurs.

Conserver notre cadre de vie

En revanche, l’effet positif d’une activité agricole bien conduite sur la biodiversité et la qualité du milieu, confère clairement à l’agriculteur une mission de protection de la nature et d’entretien des paysages. La société humaine, de plus en plus urbanisée, attend de l’agriculteur qu’il lui offre un espace rural ‘naturel’, à l’air pur et aux eaux claires, riche en espèces animales et végétales "sauvages". Mais concilier les demandes écologiques avec les données agronomiques et les contraintes économiques des systèmes de production agricoles demande des efforts de recherche et de concertation.

Face à l’évolution de la demande de la Société, l’agriculture doit adapter ses activités

Tout d’abord, elle doit continuer à fournir les produits de base, céréales, sucre, oléagineux, produits animaux, fruits, légumes, etc. à des prix acceptables, tout en recherchant la qualité. Les récentes flambées des cours internationaux des céréales ont montré la fragilité de l’équilibre entre les stocks et la demande.

L’agriculteur devra ensuite diversifier sa production : nouvelles cultures ou nouvelles variétés, cultures florales ou ornementales, nouveaux animaux d’élevage. Ne voit-on pas se développer des fermes d’autruches ou de daïms !
Aux productions de culture ou d'élevage pourront s'ajouter d'autres activités telles que le tourisme rural (fermes-auberges), fermes équestres, centres de loisirs, etc.

Les systèmes de culture ou d'élevage devront aussi s'adapter pour mieux répondre aux besoins du marché, mais aussi pour mieux tirer parti de la nature des sols, du climat et des ressources de chaque ferme. Il est probable que dans les régions aux sols peu profonds et à la pluviométrie irrégulière, des assolements plus extensifs permettraient à des exploitations de plus grande taille d’être économiquement viables.

De même, les systèmes de culture fondés sur le recyclage systématique des résidus organiques (organique farming) pourront trouver un certain développement, ainsi que l’élevage d’animal de plein air.

Les techniques de culture ou d’élevage devront aussi s'adapter dans le sens d’une meilleure efficacité, tant quantitative que qualitative, mais aussi dans celui d’un meilleur respect de l’environnement: Travail du sol simplifié, fertilisation raisonnée, épandages fractionnés, lutte intégrée contre les parasites, etc. Cet ensemble de pratiques optimisées constitue ce que l'on commence à désigner par "agriculture raisonnée". Des réseaux d'exploitations suivant ces principes se mettent en place et s'ouvrent au public : réseau FARRE, LEAF, etc.

L’obligation pour certains agriculteurs de mettre en jachère une partie de leur ferme devrait offrir des possibilités nouvelles : créations de bandes enherbées pour protéger captages ou cours d’eau, constitution de friches non cultivées pour favoriser le développement des animaux sauvages, plantation d’arbres, etc. Bref, tout cela peut conduire à un véritable ré-aménagement du paysage. Il ne faut pas se cacher qu’une difficulté majeure vient de ce qu’en ce domaine, les décisions et les actions doivent être collectives, et non pas seulement individuelles.

Les règles d’emploi des fertilisants doivent s’adapter

Il ne s’agit pas, bien évidemment, de remettre en cause les données scientifiques de la science du sol ou de la physiologie végétale. L’évolution de la Société ne modifie pas les lois de la dynamique du phosphore dans le sol et ne remet pas en cause le cycle de l’azote !

Nous dirons, cependant, que pour prendre ses décisions en matière de fertilisation, l’agriculteur devra tenir compte de nouvelles considérations :


De plus l’analyse de la plante en cours de végétation devrait renseigner sur son état de nutrition et permettre de mieux ajuster les apports d’azote aux besoins réels de la plante.

La fertilisation raisonnée ne doit plus viser simplement à enrichir le sol, mais plutôt à assurer aux plantes une nutrition correspondant à leurs besoins tout au long du cycle de leur développement.

Minimiser l’impact des pratiques sur l’environnement
Les risques d'entraînement vers les eaux par lessivage ou ruissellement des nitrates ou phosphates sont bien connus. Les conseils de fertilisation et les recommandations des codes de bonnes pratiques tiennent largement compte: évaluation plus précise des doses d'engrais azoté, fractionnement des apports, interdiction d'épandage en période à risque de lessivage, mise en place de cultures-piège, etc.

L'usage des effluents d'élevage est aussi très réglementé : apports limités en quantité, évaluation plus précises de leur valeur fertilisante, capacité de stockage suffisante, époque d'épandage limitée, etc.

Le conseil de fertilisation moderne doit intégrer obligatoirement la préoccupation de protection de l'environnement. D'ailleurs, la mise en application dans les pays membres de l'Union Européenne de la directive "Nitrates" offre l'opportunité de diffuser ces concepts auprès des agriculteurs, et de le faire savoir à l'Opinion Publique.

Les récents progrès dans la domaine de la navigation par satellites (GPS) alliés à ceux de la cartographie ainsi que les performances des matériels d'épandage modernes permettent le développement des techniques dites d'agriculture de précision. Il y sera largement fait allusion au cours de ces journées.

**Recycler des sous-produits à valeur fertilisante**

L'augmentation des concentrations de populations urbaines et le développement des industries aboutissent à des quantités toujours croissantes de sous-produits et de déchets. L'agriculture, par ses surfaces, semble être un utilisateur tout désigné. Encore faut-il s'assurer que le produit à épandre a bien une valeur fertilisante (teneur en nutriments assimilables), que cette valeur soit stable, et que le coût réel du produit épandu soit économique.

Il faut également que soit garantie l'absence de substances nocives pouvant polluer le sol ou affecter la qualité des produits des cultures ou des animaux, tels que métaux lourds, radicaux organiques, etc. C’est dans cet esprit que normes et règlements s’attachent à préciser les caractéristiques des produits recyclables en agriculture : composts d’ordures ménagères, boues de stations d’épuration des eaux, sous-produits des industries agro-alimentaires, etc.

Certains de ces produits constituent sûrement une opportunité par l’apport de nutriments aux sols agricoles, mais doivent soigneusement être surveillés, pour éviter qu’ils ne conduisent à une dispersion dans la nature de substances indésirables.

**Produire et distribuer les fertilisants efficacement et proprement**

Comme toute activité de production, il est évident que l'industrie des engrais ne peut pas ne pas être à la pointe des meilleures technologies pour produire économiquement des produits de qualité, dont les caractéristiques physiques et chimiques permettent une mise en oeuvre précise et régulière assurant à la fois efficacité agronomique et respect des milieux air, sol, et eau. Ces aspects offrent encore des champs de recherche important, en particulier dans le domaine des dégagements atmosphériques.

En matière de distribution, il semble de plus en plus nécessaire d'accompagner la fourniture de fertilisants de recommandations d'usage de caractère agro-économique mais également "environnementaux". L'idée de certification des agents économiques progressent dans différents pays.

**En conclusion**

Face à l’évolution de la Société, l’agriculture de nos pays est conduite à s’adapter. Cette adaptation porte sur ses activités même, qui débordent largement la simple production végétale ou animale et qui l’oblige à se diversifier et à prendre en compte de manière active la protection de l’environnement et l’entretien de notre cadre de vie.
Les techniques spécifiques de l’agriculture en sont affectées. L’apport de nutriments reste une condition d’efficacité économique de la production agricole du double point de vue quantitatif et qualitatif. Si les bases agronomiques de l’usage des fertilisants ne changent pas la mise en œuvre pratique doit tenir compte de nouveaux objectifs de qualité et des contraintes de protection de l’environnement, de même que de la mise à disposition de sous-produits utilisables sous condition en agriculture. Il est clair que tous ces domaines soulèvent de nombreux problèmes scientifiques et techniques que la recherche publique et privée devra s’attacher à résoudre.

Cela conduira l’agriculture à élargir sa fonction sociale, en ajoutant à son rôle de fourniture de produits abondants et de qualité, celui, plus large, de responsable de l’espace rural.

Je forme des voeux pour que nos discussions contribuent à éclairer cette nouvelle approche.

**Conclusion**

In view of trends in society's demands, agriculture in our countries must adapt its activities. This adaptation goes well beyond just crop or animal production; it obliges the farmer to diversify and to take active account of the protection of the environment, and respect for our quality of life.

Agricultural techniques are involved. The provision of nutrients remains necessary for the economic efficiency of agricultural production, both from quantitative and qualitative points of view. The agronomic basis of fertilizer use remains unchanged, but its practical application must take account of new objectives as regards quality, constraints concerning environmental production and the availability of by-products which may be used, with certain conditions, in agriculture. It is clear that all these factors raise numerous scientific and technical questions which public and private research must attempt to resolve.

This will require a wider social function for agriculture, adding the responsibility for the countryside besides its role of supplying plentiful, quality products.
GLOBAL FERTILIZER CONSUMPTION TRENDS

by

The IFA Secretariat
Global Fertilizer Consumption Trends

by

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1. The Global Fertilizer Situation

Figure 1.

FERTILIZER CONSUMPTION
from 1960/61 to 1995/96

World

Between 1930 and 1960, world nitrogen, phosphate and potash consumption, developed in line with each other, in similar quantities for each nutrient. From 1960 onwards the consumption of nitrogen increased faster than that of phosphate and potash but the consumption of all three nutrients grew substantially.

During the period 1960 to 1970, there was an abundant supply of fertilizers and prices fluctuated little and at a rather low level. However, this situation changed at the time of the 1973/74 oil crisis as prices soared to unprecedented heights, following a perceived shortage of fertilizers. The almost panic buying resulted in a real shortage and a number of developing countries in 1974 had a shortfall of 15 to 20% in their fertilizer demand requirement.

No doubt as a result of the sharp price increases, fertilizer consumption fell in 1974/75. However, the growth of nitrogen consumption quickly resumed. The consumption of phosphate and potash fertilizers also recovered but to a lesser extent. There was a further pause in world fertilizer consumption following the second oil crisis, in 1979/80.

The previous growth pattern then resumed, more or less, until 1988/89. Then world consumption began to fall. Between 1988/89 and 1993/94 world fertilizer consumption fell from 145 Mt to 120 Mt nutrients, or by 17%, due to a decrease in the fertilizer consumption of developed countries. The declines were essentially in Central Europe and the former USSR (FSU), but there was a substantial fall also in West Europe.

In 1993/94 world fertilizer consumption began to recover, and between that year and 1996/97 world consumption increased by more than 12 Mt nutrients.

1 Paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997

* Note: Mt = million tonnes
2. The Global Agricultural Situation

After 20 years of over-supply, in 1972 world cereal stocks fell sharply, as a result of sharp falls in cereal production in the main producing regions. Cereal prices tripled or more. In 1974 there was another fall in cereal production and there was a risk that the more vulnerable developing countries would not be able to cover their requirements. In November 1974, the UN's World Food Conference was convened.

American agriculture responded quickly to the increased demand and production increased rapidly in some other regions such as West Europe. Some countries, such as China and India, responded to the crisis with a massive effort, including investment in fertilizer facilities, to improve their agricultural production.

Then came the financial crises of the developing world during the 1980s, followed by the collapse of demand in the countries of the FSU and Central Europe at the end of the decade. The potential supply of agricultural products substantially exceeded demand during this period, and prices fell. By 1992, most of the fall in the FSU and Central Europe had occurred, cereal demand from developing countries continued to increase and there were some disappointing harvests. As a result, world grain stocks as a percentage of world cereal consumption fell from 22% to 14%. The 1995 world cereal stocks were at the lowest level since the first oil crisis of 1973/74.

Concern about the world food situation was a major reason for the organization of the FAO's "World Food Summit" of November 1996. However, unlike the situation in 1974, the situation was relieved by a 1996 harvest which was generally good. The low level of world cereal stocks and concern about the coming harvest in the first half of 1996 pushed grain prices up. This provided an impetus to agriculture in several parts of the world and the area planted to cereals increased in several major producing countries. In 1996, with favourable weather, there were good harvests in several regions of the world. However, this new production caused agricultural prices, particularly those of wheat and maize, to fall again.

Higher grain prices have been supported by more favourable prices for other agricultural commodities. This is the case with oilseeds, sugar, cotton, coffee and rubber. The price of coffee has increased substantially in recent weeks.

Oilseed prices, particularly those of soybeans, are currently strong. This no doubt reflects the increasing demand for animal products, hence animal feed, in developing countries as standards of living improve. The developing countries still have a long way to go before they catch up with developed countries in this respect.
In fact the world aggregate use of grains for feed has fluctuated between 500 and 650 Mt p.a. since 1985. Half the total is accounted for by the USA, the EU and the FSU. The use of feedgrains has in fact fallen substantially in the FSU and Central Europe since 1989, but this has been compensated by a steadily increasing use in the developing countries. China accounts for more than half the total increase in feed use, mainly from its own production, since 1990. The fall of feed-grain consumption has now ceased in the FSU and Central Europe and in view of the increasing demand of the fast developing economies in Asia in particular, an upward global trend can now be expected.

Efforts to link fertilizer consumption to specific crops or crop groupings pose a considerable challenge. This linkage will becoming increasingly important with globalization and the WTO agreement to open up agricultural trade. The FAO/IFA/IFDC surveys on specific fertilizer use by crop provide a partial glimpse of the complexity of the situation.

The survey covered 787 million hectares, about 70% of the crop groupings. Fertilizer use on cereals, fibre and sugar crops was relatively well covered in the survey. Table 3 shows the fertilizer application rates of the crop groupings.
Table 3.

Fertilizer Application Rates

<table>
<thead>
<tr>
<th>Area</th>
<th>Tonnage (000s t) Applied</th>
<th>Rate kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P₂O₅</td>
</tr>
<tr>
<td>Cereals</td>
<td>515,677</td>
<td>36,964</td>
</tr>
<tr>
<td>Oilseeds</td>
<td>103,599</td>
<td>3,522</td>
</tr>
<tr>
<td>Vegetables</td>
<td>19,209</td>
<td>2,543</td>
</tr>
<tr>
<td>Sugars</td>
<td>20,534</td>
<td>2,058</td>
</tr>
<tr>
<td>Roots/Tubers</td>
<td>19,537</td>
<td>2,089</td>
</tr>
<tr>
<td>Fibres</td>
<td>29,570</td>
<td>2,833</td>
</tr>
<tr>
<td>Fruits</td>
<td>19,870</td>
<td>1,718</td>
</tr>
<tr>
<td>Beverages/timulants</td>
<td>11,763</td>
<td>852</td>
</tr>
<tr>
<td>Pulses</td>
<td>42,940</td>
<td>665</td>
</tr>
<tr>
<td>Total</td>
<td>782,699</td>
<td>53,244</td>
</tr>
</tbody>
</table>

Although cereals dominate in terms of area and the amount of fertilizers used, other crop groupings show a diverse range of rates and NPK ratios. While the present data do not permit trend studies, such data will become increasingly important since globalization will diminish the ability of national policies to influence global agriculture. Further, the advent of precision agriculture and the use of genetically modified crops will necessitate a close examination of specific fertilizer usage among crops.

3. Fertilizers: Regional Shares

Figure 3.

World fertilizer consumption
Regional shares

<table>
<thead>
<tr>
<th>Year</th>
<th>Developed</th>
<th>Developing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960/61</td>
<td>88% 42%</td>
<td>30.0 million tonnes nutrients</td>
</tr>
<tr>
<td>1985/86</td>
<td>64% 36%</td>
<td>129.5</td>
</tr>
<tr>
<td>1991/92</td>
<td>49% 51%</td>
<td>134.5</td>
</tr>
<tr>
<td>1995/96</td>
<td>41% 59%</td>
<td>129.2</td>
</tr>
</tbody>
</table>

In 1960, 88% of the world fertilizer consumption was accounted for by the developed countries: West Europe, North America, Oceania, East Europe, the USSR, South Africa and Japan.

From 1980 to 1990 fertilizer consumption in the developed countries tended to stabilize, apart from the USSR, where it increased until 1988. Population growth had leveled off, almost everyone was adequately fed, and world agricultural exports had stagnated due to economic problems in the importing countries. Then, between 1989 and 1995 fertilizer consumption fell
sharply, by 70% in total, in the formerly communist countries of Central Europe and the Former
Soviet Union, the FSU. Consumption also fell in West Europe, although to a much lesser
extent. As a result, fertilizer consumption in developed countries fell from some 84 Mt nutrient
in 1988/89 to 52 Mt nutrient in 1994/95.

Phosphate and potash consumption were affected more seriously than nitrogen. In fact, in the
developed countries, phosphate and potash consumption has tended to fall since 1979. Despite
this, crop yields have continued to increase. In general, soils had been well fertilized for several
decades. Hence, for the time being farmers are able to reduce their applications without a
detrimental impact on yields.

Figure 4.

While the fertilizer consumption of developed countries faltered, that of developing countries
has continued to increase steadily. By 1995/96 fertilizer consumption in the developing
countries had reached some 75 Mt nutrients or 59% of the world total, compared with 12% in
1960. The increase was particularly strong in the case of nitrogen. In 1991/92, fertilizer
consumption in developing countries for the first time exceeded that of the developed countries.
Correspondingly, cereal production is increasing steadily in the developing countries.

Figure 5.

However, in many developing countries fertilizer application has become unbalanced i.e. too
much nitrogen in relation to the other nutrients, especially in Asia. In other countries the
"mining" of soil nutrients is severe, and falls in yields have been observed as nutrients removed
by the crops are not replaced. This problem is particularly severe in sub-Saharan Africa.
4. Products

The consumption pattern of the different products has also changed. Since 1973/74, most of the increase in world nitrogen consumption is accounted for by urea, most of the phosphate by diammonium phosphate and most of the potash by potassium chloride. It is no coincidence that each of these is a product with a high nutrient content, which offers considerable savings in storage, transport, handling and application costs, compared with otherwise excellent but low-analysis fertilizers - at least in terms of the three major nutrients.

Another development is the increase in the production and use of blends. Just as the bringing together of geographically separated sources of phosphates, nitrogen and potash has favoured bulk blending in the USA, the bringing together of these materials at a global level favours the international development of blending.

The economic imperatives have over-ridden the need for fertilizer products which are most suitable from an agricultural and environmental point of view. Urea and diammonium phosphates and blends are sometimes not the most suitable agronomic choices.

5. Fertilizer Use Regulations

Another development, starting in West Europe, is that of compulsory “nutrient book-keeping” by farmers, whereby the supply of plant nutrients from various sources, such as the soil and organic materials, is measured against the crop requirements. A limit to total nutrient application is imposed, the balance being supplied by mineral fertilizers. The preparation of such balance sheets is now a legal requirement in Denmark and Germany. In Denmark the first prosecutions of farmers who have exceeded the limit have occurred. In the medium term this is likely to result in the farmer being more selective in the fertilizer he is permitted to apply, in order to obtain maximum advantage from the application. The implementation of the EU Nitrate Directive will also lead to a more selective application of plant nutrients, both organic and inorganic.

6. The Regions

In 1995/96 South and East Asia accounted for 48% of the world's fertilizer consumption, North and South America together for 24%, Europe and the FSU for 20%, the Middle East for 4% and Africa and Oceania for 2% each.

6.1. West Europe

Figure 6.
France accounts for 28% of fertilizer consumption in West Europe, Germany for about 16%, the UK for 13%, Spain for 11% and Italy for 10%.

The sharp rise in prices in 1973/74 had a negative impact on phosphate and potash consumption and it never fully recovered. Nitrogen, however, benefited from the considerable increase in cereal production in the EEC countries, and from the more intensive fertilization of grassland in countries with favourable climatic conditions for this crop. However, nitrogen consumption too started to fall in 1986. By 1992/93 phosphate consumption had fallen 45% from its 1979/80 level, potash by 32%. However, between 1993/94 and 1996/97 total nutrient consumption stabilized at about 17.8 Mt nutrients.

In spite of the fall in phosphate and potash use since 1979, crop yields have continued to increase in West Europe. In general, soils in West Europe had been well fertilized with phosphate and potash for many years and it seems that some reduction of application could be permitted during periods of economic difficulties for the farmer. Improved crop varieties and management practices also are no doubt important factors.

We assume that the medium term trend is still towards a gradual fall, due largely to continued pressure to reduce the cost of the Common Agricultural Policy, the CAP, to further improvement in the efficiency of nutrient use, both organic and inorganic, the impact on grassland fertilization of the BSE disease in cattle, and the implementation in certain countries of compulsory fertilizer plans. Even with increased set-aside, wheat stocks could increase to intolerable levels around the end of the century, if policies are not changed.

6.2. Central Europe and the FSU

Between 1988 and 1993 fertilizer consumption in the countries both of Central Europe and of the FSU fell by 70%. Today the countries of Central Europe and the FSU account for only 6% of world fertilizer consumption, compared with 16% in 1989. In both regions, it is unlikely that the 1988 peak levels of fertilizer consumption will be reached again within the period of the present forecasts, if ever. It should, however, be possible to regain former levels of agricultural production with less fertilizer as market disciplines reduce waste and increase the efficiency of use. The fall in the countries of Central Europe appears to have reached its lowest point in 1993, in the FSU in 1995.

6.2.1. Central Europe

Within the region, in 1995 Poland is estimated to have accounted for 45% of total fertilizer consumption.

During the 20 years up to 1980, fertilizer consumption in Central Europe increased regularly and strongly. From 1980 to 1990, the consumption of all three nutrients leveled off. Around 1990, consumption began to fall sharply in the region. Total nutrient consumption fell from 8.3 Mt in 1989 to an estimated 2.6 Mt in 1993.

Phosphate and potash consumption have been particularly affected by the fall.

After experiencing a sharp decline in their GDP in relation to the 1980s, the economies are reviving in the Czech Republic, Hungary and Poland. However, a recovery is yet to come in Bulgaria and Romania. Slovakia's economy lies between the two groups. However, even in countries with thriving economies, the agricultural sector is lagging behind.

Cereal production in the CEEC is seriously hampered by restrictive government policies and inefficient marketing systems. The combination of the reduction of state aid to agriculture,
price controls and inefficient marketing results in low farm-gate prices for most commodities. Credit for the purchase of inputs tends to be expensive and farmers without title to their land lack an important form of collateral.

### 6.2.2. The Former Soviet Union, FSU

Figure 7.

There are 15 Republics in the FSU. In 1995 the Russian Federation accounted for 39% of the region's fertilizer nutrient consumption, the Ukraine for 21%, Belarus and Uzbekistan each for 12%.

Unlike the situation in the countries of Central Europe, nutrient consumption in the USSR continued to progress steadily both before and after 1980, as a result of the high priority given to increasing agricultural production. Supplies increased considerably, but usage was inefficient and the crop responses were not commensurate with the quantities applied. The upward trend in consumption ceased in 1989.

Between 1989 and 1994 fertilizer consumption in the FSU fell from 24.5 to 4.4 Mt nutrient. In 1995 consumption stabilized and there was probably a significant increase in 1996, albeit from a low level.

The pace of economic reform among the different countries of the Former Soviet Union, the FSU, varies. Some, including Belarus and some of the central Asian countries still retain much of the old system. In Belarus the government has financed the totality farmers’ requirements of fertilizers, to be repaid from the sale of their crops, also to the state i.e. more or less the old system. Little progress is being made in the Asian Republics of the FSU.

### 6.3. North America

The USA accounts for 90% of fertilizer consumption in North America, Canada for 10%.

**The 1970s**

Fertilizer consumption in North America rose from 16.4 Mt nutrients in 1970/71 to 23.4 Mt in 1980/81. There was a substantial increase of US corn exports in the 1970s, with increasing demand from Europe, the USSR and certain developing countries. Credit was easily available world-wide and North American agriculture was at full production.
The 1980s
From 23.4 Mt in 1980/81, consumption fell back to 20.7 Mt in 1989/90. During the 1980s, Europe turned into a substantial net exporting region as a result of the EU's Common Agricultural Policy. The demand from over-indebted developing countries fell.

The U.S. share of grain and oilseed trade peaked at 43% in 1980. When the credit boom burst, weak export demand and falling incomes returned. The US share of world grain and oilseed trade fell to 27% in the 1980s. Fertilizer consumption was hit every time land was taken out of cultivation to reduce the agricultural surpluses.

The 1990s
From 20.7 Mt in 1989/90, fertilizer consumption has recovered to an estimated 22.9 Mt this year. The situation of US agriculture has greatly improved since 1990. Cash receipts from crops have grown steadily in that time, from $64 billion in 1986 to an estimated $108 billion in 1996. Total farm debt has been reduced from $194 billion in 1984 to $142 billion. The debt-to-equity ratio of the U.S. farmer decreased from 29.8% in the mid-1980s to below 19% in 1993.

Nitrogen use efficiency has been increasing in the United States. For example, on corn, between 1985 and 1995, the yield per unit of nitrogen, expressed in terms of bushels/lb, increased from 0.79 to 0.95. Similar efficiency improvements have been made for phosphorus and potassium.

The medium-term outlook for the export of American agricultural commodities is favourable, especially in view of the economic growth in Asia and lower grain stocks. The drastic fall in grain exports to the FSU has now ceased, at a fraction of the former level, and US agricultural exports to regions other than Europe and the FSU are developing well. Taking North Africa and the Middle East as an example, U.S. farm exports to this region increased by over a third from 1990 to 1996.

6.4. Latin America
Latin America accounts for about 7% of total world fertilizer consumption. Brazil and Mexico account for 67% of total fertilizer consumption in Latin America.

Fertilizer consumption in the region increased sharply from about 1960, as a result of government policies favouring agricultural development. However, consumption in the region stagnated from about 1980 onwards, due largely to economic problems. An assumption that consumption in Latin America would continue to grow in the 1980's, as it had done in the two previous decades, was partly responsible for the over-estimates made in the 1970's of world fertilizer demand.

In the early 1990s the economies of several Latin American countries were recovering well, to be set back again by the Mexican peso crisis towards the end of 1994. However, real economic growth in the region recovered in 1996, due largely to improvements in Argentina and Mexico. The IMF expects Latin America as a region to grow by four or more percent annually over the next five years.

6.4.1. Central America
Mexico accounted for 58% of the sub-region's consumption in 1995, but its share is normally nearer 70%. Fertilizer consumption in Mexico has been disturbed in the 1990s by the privatization of the fertilizer industry and of the distribution system, and by the reduction of subsidies. The devaluation of the peso in 1994 was a further set-back, lowering prices for
Mexican agricultural products in export markets, but increasing the prices of fertilizers to levels which many farmers could not afford. Fertilizer consumption fell substantially in 1995. Some recovery of fertilizer consumption occurred in 1996, with the government increasing its support for agriculture.

6.4.2. South America

In 1995 fertilizer consumption in Brazil, accounted for 67% of the consumption of the sub-region.

In Brazil in 1994, fertilizer consumption rose by almost 14%, following increases of 16% and 12% respectively in the two previous years. In 1995 it is estimated that fertilizer consumption fell by 9% primarily due to credit problems. The financial situation of Brazilian farmers improved in 1996 and a more favourable exchange ratio between fertilizers and agricultural products resulted in an increased demand for fertilizers. The Brazilian government is taking various measures to stimulate agriculture. The government is also investing in the national transport infrastructure and has increased farm credits to $5.7 billion compared with $3.7 for the previous year.

Fertilizer use has made spectacular progress in Argentina. The growth rates of Argentina's fertilizer imports in 1994, 1995 and 1996 were 70%, 33% and 74% respectively. The increase in 1996 was made possible by the increase in agricultural prices observed in the first semester. The planted area of wheat increased by 30% and that of maize by 10% compared with the previous season. The 1996 season ended with a record harvest of 15.2 Mt.

We forecast that fertilizer consumption in Latin America as a whole will increase from 8.6 Mt to 12 Mt by the year 2001, a rate of increase of almost 6% p.a.

6.5. Oceania

The use of phosphate fertilizers predominates over that of the other nutrients in Australia and New Zealand due to the requirements of the pastoral industry. Phosphate consumption fell sharply following the price rises in 1973/74 and consumption is still well below the pre-1974 levels. A crisis in the wool sector resulted in a substantial fall in phosphate fertilizer consumption in Australia. Wool prices are still depressed but crop production in Australia is, in general, thriving. In Australia, fertilizer nutrient consumption increased by 13% in 1995/96, due to the record wheat crop and the end of the drought that had depressed cotton planting and summer crop production. Good production levels are expected in 1996/97 for grain, oilseed crops, rice and cotton. New Zealand agriculture, however, is suffering from low cattle and wool prices.

6.6. Africa (excluding Egypt and Libya)

The Republic of South Africa accounts for 34% of fertilizer consumption in Africa, the Maghreb for 18%, Nigeria for 9% and Zimbabwe for 7%.

Africa accounted for only 2% of world fertilizer consumption in 1995/96, whereas the region contains 12% of the world population, with a high rate of demographic growth.

According to FAO's most recent indices of per caput food production, with the average of 1989-1991 at 100, the index in 1993 was 98.5 and in 1996 96.6, i.e. the situation continues to deteriorate as food production fails to keep pace with the increasing population.
Since 1965 the average per capita income in Africa has halved from 14% of the average industrial country levels to 7%. However, last year Sub-Saharan Africa's economy grew by 5%, the best performance for twenty years. There was strong activity in agriculture in 1996 as several countries recovered from drought. Net resource flows to the region rose 12% last year, half from official sources. The Franc zone economies are recovering following the 1994 devaluation of the CFA, and Ghana, Kenya, Malawi and Uganda are achieving some success.

Fertilizer consumption is increasing in certain other countries of Sub-Saharan Africa, but starting from a low base level.

6.7. Near East (including Egypt and Libya)

The Near East accounts for 4% of world fertilizer consumption. Egypt, Iran and Turkey account for 75% of fertilizer consumption in this region, Saudi Arabia for a further 6%.

Regional consumption has been increasing since about 1960 but accelerated after 1973/74.

In Egypt, with good water stocks in the high dam, and an increase in the area of irrigated land, nitrogen consumption in Egypt is expected to increase at a rate of 5% p.a.

Consumption developed strongly from about 1980 onwards in Saudi Arabia, due to a policy of agricultural self-sufficiency - at almost any price. Fertilizer use in Saudi Arabia fell in 1993 and 1994 after the high subsidy on wheat was reduced, but it is anticipated that consumption will now stabilize, at around the present level.

In Turkey crop yields were good in 1996 due to favourable weather conditions, crop prices were favourable and farm income was higher than in 1995. Fertilizer subsidies remained high, at 50%. Fertilizer consumption is expected to continue to increase, with newly irrigated land coming into cultivation.

The region's coarse grain imports are the second largest in the world after Japan's. The region imports one fourth of the world's rice and wheat. Egypt; Saudi Arabia, Israel and Turkey are major markets for US products. Strong population growth, at 2 to 3% p.a. and GDP growth at 3 to 4% p.a. to the year 2000, with somewhat higher oil prices are all factors favouring the demand for agricultural products.

For the region as a whole, we anticipate an annual rate of increase of almost 5% per annum between 1995 and 2001.
6.8. South Asia

India accounts for 77% of fertilizer consumption in this region, Pakistan for 14% and Bangladesh for 7%.

Foodgrain production in India increased from 51 Mt in 1950 to 82 Mt in 1960. Since then production has risen to about 190 Mt. Even so, a large section of the population is still underfed.

The rapid increase of fertilizer consumption, from about 1965, coincided with the introduction of high-yielding varieties, increased irrigation etc., i.e. the "green revolution". Prior to this technical break-through economists and agronomists were predicting imminent famine for the sub-continent.

Since 1991/92 the consumption of phosphate and potash fertilizers in India has been adversely affected by a substantial reduction in the subsidies for these products, whereas nitrogen remained heavily subsidized and consumption continued to increase. The resulting changes in the balance between the nutrients has given increasing cause for concern - crop production is tending to stagnate in the most productive areas.

Fortunately, crop production has been favoured by good weather, and the 1996/97 season began again with a normal monsoon, for the ninth year in succession. It is estimated that foodgrains production may reach 191 Mt, 6 Mt higher than the previous year's depressed level, but only to return to the 1994/95 level.

Largely as a result of the concern about the imbalance between the nutrients, in July 1996 the Government increased the subsidies on fertilizers containing phosphate and potash. In February 1997, the selling price of urea was increased by 10% through a reduction in the subsidy, and the subsidy on phosphate and potash was further increased.

The past president of the National Academy of Agricultural Sciences, Dr. MS Swaminathan, recently stated that "unless policies are adopted to narrow the gap between the annual drain of nutrients from the soil and their external application, India may fail to provide security to its people. Working on a conservative population forecast of 1.3 billion by 2025, India would need 30 to 35 Mt NPK from chemical fertilizers in addition to 10 Mt from organic and biofertilizer sources to produce the minimum foodgrain needs of 300 Mt".

Fertilizer use is progressing steadily in both Bangladesh and Pakistan. However, the imbalance between nitrogen and the other nutrients is even greater in these countries than in India. In both countries there have been reports of poor response to additional applications of nitrogen, in fact
at levels well below the theoretical optimum, which indicates that there are other limiting factors, no doubt other nutrients.

India, Pakistan and Bangladesh each experienced continued economic development in 1995 and 1996, but the agricultural sector is lagging behind.

In the region as a whole, between 1995/96 and 2001/02 an average rate of increase of almost 5% p.a. is expected.

6.9. East Asia

East Asia accounts for 7% of world fertilizer consumption, one third of the total being in the mature markets of North-east Asia, two thirds in the developing markets of South-east Asia.

6.9.1. North-east Asia

In 1995/96, Japan, Korea and Taiwan accounted respectively for 52%, 31% and 17% of the consumption in this sub-region. Fertilizer consumption in this region has increased steadily since 1945 but the markets are now mature. All these countries are now highly industrialized but with a highly protected agriculture. However, they are now under considerable pressure to open up their agricultural markets.

6.9.2. South-east Asia

Indonesia accounts for 41% of the consumption in this sub-region, Malaysia for 21%, Thailand for 25%, the Philippines for 10%.

The rapid growth of the economies of the south-east Asian countries, the general availability of foreign exchange and rising nutrition expectations has permitted a steady increase in fertilizer consumption. It is primarily the non-agricultural sectors which are benefiting from this prosperity, but certain countries, notably Indonesia, continue to attach great importance to agricultural development.

With the increasing populations, continuing prosperity and limited scope for increasing the cultivated area in the region, the consumption of fertilizers in this region is expected to continue steady if moderate growth.

6.10. Socialist Asia

Figure 9.
China accounts for 95% of the fertilizer consumption in this region, Vietnam and North Korea for almost all the rest.

China's population growth rate of 1% p.a. is much less than the growth of the GNP, and hence the consuming power of individual Chinese is growing rapidly. This results in an increasing demand for higher-value food products, especially animal products, which results in a substantial increase in the demand for feed grain.

China has 22% of the world's population but only 7% of the world's arable land. Furthermore, the area of agricultural land has declined by 14% over the past 15 years, due to urbanization, but also to salinization. The government has now taken several measures to prevent further encroachment on agricultural land.

Fertilizer consumption in China began to increase significantly from the early 1960's. However, the substantial growth of fertilizer consumption in China, especially nitrogen consumption, began around 1975, when the limit to increasing crop production by the efficient use of organic manures and highly skilled agricultural techniques had more or less been reached, while there was still a growing population to feed. Nitrogen supplies increased sharply as new, modern plants came into production.

Rates of fertilizer application per hectare are already high in China, compared with other developing countries, but the population's rising food requirements can be satisfied only by continuing the intensification of the agricultural systems.

According to a CAAS, Chinese Academy of Agricultural Sciences, Report Dec. 1996. "Influences of N-fertilizer application on the environment in China", nitrogen fertilizer consumption per ha of arable land is 211 kg/ha, on multiple-cropped land cropped land 134 kg/ha per crop. In intensive cropping regions, N rates are usually over 500 kg N/ha arable land. Rates of 800 to 5700 (sic!) kg/ha are applied in vegetable production areas, with considerable losses. Many regions have high nitrate contents in drinking water and at the very high rates there are substantial losses.

It is estimated that China must increase yields by 60% to 80% within the next 30 years, and this will require a doubling of present N fertilizer application rates. It is important to develop realistic management practices to minimize losses, taking account of the fact that the average farm size is 0.4 ha."

In China, policy decisions have had, and continue to have, a major impact on fertilizer consumption, in particular the policies as regards subsidies, food and fertilizer imports and distribution. In 1993/94 changes in pricing and subsidy policies resulted in a substantial fall of fertilizer consumption. However, after a period of relative neglect, the Chinese government has paid more attention to the agricultural sector since 1994. Agriculture-related expenditure was raised by 12% in the 1996 budget; food security and production have become a priority.

There is a recognized need for a better balance between nitrogen and the other nutrients, and there should be a relative move towards P and K. However, there is still substantial investment in new N capacity and the ratio is improving very slowly.

Nitrogen consumption has increased strongly in Vietnam during the 1980s but supply problems around 1990 restrained further growth. The supply situation eased in 1991. The medium term prospects are favourable since the country relies on the exports of agricultural products to underpin economic growth. The agricultural sector contributes 40% of GDP, 42% of export earnings, and provides a livelihood for three quarters of the population.
Our forecast is for the region as a whole is an average annual increase of 3.3 % p.a. between 1995 and 2001.

7. The Outlook

Between 1995/96 and 2001/02 we forecast an average increase of 3% p.a. in world fertilizer consumption, rising from 129.2 to 153.2 Mt. We forecast that 32% of the increase will be in Socialist Asia, mostly China, 24% in South Asia, 14% in Latin America, 11% in Central Europe and the FSU, and 8% in North America. The remaining 11% will be in the Middle East, East Asia and Africa.

In 1988/89 world nitrogen consumption amounted to 79.4 Mt N. If our estimate materializes, it should reach this level again in 1996/97. During this period increases in countries such as China and India have compensated for the falls in the FSU, Central Europe, and to a lesser extent in West Europe. However, according to our forecasts, world phosphate consumption in 2001/02 will still be slightly below the 1988/89 peak (36.7 against 37.8 Mt P₂O₅) and potash consumption will be significantly below its peak (24.1 against 28 Mt K₂O).

The greatest uncertainty is future fertilizer consumption in China, where there wide variation even between the estimates of different Chinese official bodies. On the one hand the agricultural authorities are pressing for more balanced fertilization, on the other hand farmers want to use more nitrogen and the Ministry of Industry is investing heavily in nitrogen plants.

8. Discussion

This overview of the global fertilizer situation demonstrates:

- The good prospects for cereals and other agricultural commodities.
- That North America is well placed to benefit from increased global trade in agricultural products.
- Europe may have problems with wheat surpluses.
- A gradual recovery of fertilizer use and agricultural production can be expected in Central Europe and the FSU.
- The prospects for growth in fertilizer consumption are good in Latin America and South Asia.
- There are conflicting views concerning the outlook in China.
- Global fertilizer use is sensitive to political changes and decisions.
- In some regions, especially Asia, the efficiency of fertilizer use in terms of the proportion of the nutrient applied to that taken up by the crop is very low.
- In others, especially Africa, there is serious "soil mining" of plant nutrients.
- Globalization, precision agriculture and genetically modified crops are likely to influence future fertilizer consumption trends.

Precision agriculture is likely to improve the efficiency of fertilizer use even in the most sophisticated agricultural systems. For the first time, in certain European countries, the farmer has to comply with regulations limiting the amount of plant nutrients he may apply. He is likely to become more selective in his choice of fertilizers. In the medium to long term it is likely that these factors, together with advances in bio-technology, will result in major changes not only in fertilization practices but also perhaps in the fertilizers themselves.
PLANT NUTRIENT MANAGEMENT IN THE "PRECISION" AGE:
A NEW PARADIGM

by
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(Note: a copy with all the figures and graphs can be sent by email)

SUMMARY

The new technologies and paradigms of Precision Agriculture are part of our on-going journey of change. These technologies have enabled farmers to reevaluate their input and management practices and facilitated opportunities to improve profits. Even more important is the effect this technology will have on business processes at all levels of the agricultural market. How to manage and control the movement of this information as our business and agronomic processes become electronic will be the next issue as we continue down the path of precision agriculture.

CHAPTER 1. CONCEPT, COMPONENTS AND CONSEQUENCES

Affordable global positioning was a major factor enabling the development of crop production systems where the basic unit of production is no longer defined by field boundaries but rather by more homogeneous areas within fields. The direction agriculture is headed has been determined, but what specifically lies beyond the horizon in this journey is of course unknown. One thing is for certain based on the rate of change during the last three years, precision in the future will be markedly different than it is today.

The concept of Precision Management

The major objectives of precision management are to identify and quantify variability, understand the impact of variability, and to manage the variability to increase profits and environmental quality. Increasing yield, improving crop quality or marketability, and/or avoiding over-application of inputs are the means by which precision management increases profitability.

Precision agriculture represents a paradigm shift. The shift is away from general recipes for management to specific prescriptions; away from tradition-based implementation to knowledge-based implementation; away from a «Give me the answer» technology transfer system to a «Teach me to find my answer» system. It is a new paradigm for growers, crop advisers, input suppliers, and for research and extension. Once precision is recognized as a paradigm shift, certain predictions can be made about how our industry will react to the new dynamic model of operation. Joel Barker, in his book Future Edge, writes, «New paradigms put everyone practicing the old paradigm at great risk. The higher one’s position the greater the risk. The better you are at your paradigm, the more you have invested in it, the more you have to lose by changing paradigms.»

All of us need to ask ourselves if the reaction a new idea solicits is honest intellectual skepticism or a response to a threatened paradigm. This message applies not only too conventional vs. precision tension but also to today’s precision approach vs. tomorrow’s precision approach. For example, if we convince our customers that point sampling on a 4-acre rectangular grid is the only way to sample and successfully use that approach for a few years, it may be difficult to

1 Paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997
change to the next generation of sampling procedures. Precision is a dynamic approach that requires its practitioners to have a high propensity for change.

It is worth noting that paradigm pioneers are often outsiders, people not in the mainstream of the old paradigm. Dr. Gary Kachanoski, a soil physicist and director of the Water Quality Institute of the University of Guelf in Ontario, Canada, is a good example of a precision paradigm pioneer. Dr. Kachanoski was not in the mainstream of soil fertility, soil testing or fertilizer recommendation development, yet he has made substantial contributions to precision management and knowledge in part because he was not blinded by the discipline’s standard assumptions. We need to listen carefully to the «outsider».

The precision or site-specific approach to crop management is universally applicable. It is not uniquely suited to any one cropping system or geographic region. The tools involved and the management practices employed will vary among systems, regions and managers, but the approach always fits. Components common to most precision ag solutions include:

**Geographical Information System (GIS).** Software that will display information stored in a database at its correct geographic position (longitude and latitude) on the map. This software also facilitates analyzing multiple layers of information to assist in decision making; e.g. a map giving the topography, soil test results and the previous year’s yield data as an aid to determining nutrient needs for each site within the field.

**Global Positioning System (GPS).** A constellation of 24 satellites orbiting above the earth. Using these satellites, mobile receivers can be used to provide accurate location information anywhere in the world. With the addition of a known reference station (Differential GPS) accuracy can range from 5 m to less than a meter.

**Yield Monitor.** A sensor mounted on a combine or other harvesting equipment. When coupled with GPS, accurate harvest yield information corrected for moisture content is collected every 1-3 seconds.

With these tools to assist collection and management of information, precision ag principles can be applied anywhere in the world. The diversity illustrated in the following examples of how precision management is being applied in North America demonstrates this point.

- **Sugar beet production in the Red River Valley of North Dakota & Minnesota.** Management focus is on nitrogen (N) because too little N reduces yield and too much N reduces recoverable sugar, which is the basis of grower payments (Figure 3). Fields to be planted to beets are sampled in the fall to a 1.2 m depth on 1.5 to 2 ha grids. Nitrogen rate is varied based on soil nitrate levels. Various remote sensing techniques are in early stages of adoption for refining N rate decisions. Studies show precision N management typically results in an increase in N use and excellent net returns. One two-year study showed an average increase in net return of $300/ha (Smith & Rains, U. of Minnesota and American Crystal Sugar Co.).

- **Vineyards in California.** Aerial photography helps pinpoint areas that need scouting. Growth problems can be identified earlier often resulting in less crop damage and more treatment options.

- **Corn/soybean production in the Midwest.** A combination of yield mapping, soil survey information, intensive sampling (often 1 ha grids), and variable rate application are employed for managing phosphorus (P), potassium (K), lime, sometimes N, and for general diagnosis of yield limiting factors such as impaired drainage and plant pest problems.
Wheat production in the Great Plains. The limited cash flow of these cropping systems poses a significant challenge when adapting the precision approach. However, using landscape position as a fundamental management unit is showing excellent promise as a means of reducing the costs of identifying meaningful variability. Variable rate controllers for anhydrous ammonia and for banding other fertilizers are in early stages of evaluation by producers and their suppliers. Considerable interest exists in the new grain protein sensing technology.

Adoption of the Precision Approach

The current adoption rate of precision approaches to crop management varies with region and with the individuals within a region. But one thing is certain… Adoption is occurring. Yield monitor sales in North America have been growing steadily since 1993 (Figure 4). Many soil-testing laboratories are seeing phenomenal increases in sample volume. Producer surveys indicate that farmers expect to utilize more precision practices in the future. For example, a recent survey of Nebraska farmers showed that 25 to 35% expect to be using yield monitors within five years and a similar amount expect to be using variable rate application. Most Land Grant Colleges in the U.S. have one or more precision agriculture research or extension programs and some have added precision courses to their formal curriculum. Job opportunities for well-trained agronomists are outstanding. Ready or not, agriculture is accepting the logic of precision management.

The Reality of Within Field Variability

Extensive documentation of agronomically significant within-field variability and the existence of technology to respond to that variability suggest that precision approaches will continue to grow in importance in crop production. The variability genie is out of the bottle and she’s not going back. Numerous summaries of grid sampling results show that variability is the norm, not the exception in today’s production fields. The data in Table 1 are examples from the Midwest. The apparent limited K variability for some states in this summary is due in part to the preponderance of very high testing soils in those states. The data in Table 2 and Figure 5 are typical of the Great Plains and Prairie regions where historical fertilization has been limited.

The discovery that significant portions of many fields test very high while similar portions test very low, carries a powerful message about what must be done to increase efficiency, productivity, and profitability. It is becoming increasingly apparent that for many growers the most limiting factor for further reduction in unit costs of production is managing within field variability. The scale of the variability of some fields may be difficult to economically manage with today’s technology and knowledge. However, future improvements in technology and growth in our knowledge base will continue to make the sampling and data collection process more efficient and site-specific.

Identifying Within-field Variability in Nutrient Needs

The data generated over the last three years are rapidly causing field agronomists, scientists and farmers to recognize the serious agronomic, economic and environmental errors frequently associated with the standard recommended practices for accessing the nutrient supplying capacity of soils. We now realize that with or without variable rate nutrient application, following the traditional approach to soil sampling and soil test interpretation frequently leads to the incorrect management decision. This will be discussed later in this paper.

Numerous tools can be utilized to assist in the determination of nutrient needs of a specific crop growing in a specific area of a field. Other tools are under investigation and look promising. The role of each tool is defined by the scale and structure of variability in the fields being managed and by the cropping system itself. Some of these tools follow.
• **Soil sampling.** Soil sampling, it seems, has become a science in and of itself. Doing it properly is a bigger challenge than most realized and appropriate sampling methods are more site-specific than most of us predicted. In much of the Corn-belt of the U.S., the major factors influencing soil nutrient variability are historical manure and fertilizer application, consolidation of fields, and long-term differential nutrient removal. In this region, some form of grid sampling is normally practiced with grid size varying from 0.4 to 1.2 ha (1 to 3 acres). The trend is clearly for a reduction in grid size and for the incorporation of additional information in the selection of sampling node location. In contrast, in the Great Plains and Prairie regions where past fertilization has been limited and very little manure has been applied, the local factors of soil formation are the major sources of variability and landscape position based sampling appears to be appropriate. In still other situations, research has suggested that the scale of variability is such that accurately mapping it will likely never be economically feasible using any soil sampling method and other characterization tools will need to be utilized. The bottom line is that no universally appropriate sampling method exists.

The scale and structure of the variability of the fields being sampled define the appropriate sampling approach.

• **Yield maps.** Yield maps are a good indicator of nutrient removal from the field and can be useful in determining fertilizer rates needed for the maintenance of existing fertility levels. However, they do not indicate whether the existing level is in fact optimal and should be maintained. After several years, they can also be useful in defining and refining zones of different average yield potential for the purpose of setting yield goals for some nutrient recommendations. However, the relationship between N fertilizer needs and yield maps has proven to be complex. For example, in some Minnesota studies the greatest N response and highest fertilizer N need has occurred in some of the lowest yielding areas of the field.

• **Grain quality maps.** Yield and moisture are the parameters commonly measured by combine monitors. However, on-the-go grain protein sensors have recently entered the market place using either near-infrared or optical technology. This technology is too new to draw conclusions relative to its role in nutrient management but intuitively it would seem to be a useful information layer. A map of field protein levels may be useful in management of N for the next crop and as feedback on the adequacy of N for the crop just grow. Research on this application is underway.

• **Plant sensors.** Various plant sensors are being studied for use on ground, aircraft, or satellite systems that range from indicating total biomass to current N status like the chlorophyll meter. A rebirth of remote sensing applications in crop management has begun in some regions and will likely continue as sensor technology evolves.

• **Soil survey maps.** Soil maps are often useful layers of information, especially for refining soil pH and organic matter maps and as an aid in developing landscape-based maps of management units. These are sometimes limited in accuracy but serve as a useful starting point. Digital-ortho soil surveys are being developed by the NRCS in the U.S. with the needs of precision farming in mind (Figure 6).

• **Aerial or satellite imagery.** Such imagery can be useful in determining the current nutrient status of the crop (Figure 3) or in setting up landscape based management units. Scientists in Saskatchewan have demonstrated how black and white aerial photographs can be converted to digital images and image analysis used to stratify soil landscapes into management units such as knolls, mid-slopes, lower-slopes, and depressions (Figures 7 and 8). These are used to guide soil sampling and the development of nutrient application maps.
• **Scouting maps.** GPS systems allow field scouts to accurately note field areas that may have special nutrient problems.

• **Soil and soil nutrient sensors.** The scale of variability in some fields will spur interest in the development of various types of sensors to facilitate the mapping of soil properties. Substantial research is being conducted on the application of existing sensors and on the development of new sensors. Electromagnetic induction sensors are being used to measure soil conductivity that may reflect soil salinity or in some fields be highly correlated with depth of topsoil, a major determinant of yield potential. In other studies, the relationship between sensed conductivity and soil organic carbon is being investigated. Ground penetrating radar is being evaluated as a tool for determining soil profile properties. Resin probes have been developed in Saskatchewan to estimate nutrient release from the soil and potentially improve traditional grid sampling (Figure 9).

**Impact on Quantity of Fertilizer Used**

The impact of precision nutrient management on the quantity of fertilizer used is influenced greatly by how conventional use rates were being determined. If soil testing was not used and followed in determining rates applied, the impact of precision nutrient management on use cannot be predicted.

If the conventional approach was soil testing based, precision techniques will frequently increase the amount of fertilizer used. Numerous and careful studies in both the U.S. and Canada have shown that soil variability leads to under fertilization. The more variable the soils, the greater the degree of under fertilization. The cause of this phenomenon is that soil test levels in individual fields are not normally distributed (when a frequency diagram is bell shaped). Instead, they are positively skewed as is illustrated in Figure 10. Because of the long «tail» that stretches out to higher soil test levels, the mean overestimates the field’s fertility level. Since composite or conventional sampling generates an estimate of the mean, it tends to overestimate soil fertility. Thus, more intensive sampling of variable fields will usually result in an increase in the total quantity of fertilizer recommended.

The concept is illustrated in its simplest form by looking at soil test data from a single field (Table 3). In this grid sampled field, the mean soil P level of 10 ppm fell in the medium category while 58% of the field tested low or very low. The mean soil K level of 192 ppm fell in the very high category resulting in a recommendation of zero K fertilizer when in fact 52% of the field-tested in a responsive range. Calculations like these indicate that more intensive sampling could increase profitability whether variable rate application is used or not by generating a better estimate of the optimum uniform rate.

**Incentives for Implementing Precision Nutrient Management**

Yield maps combined with information on soil properties, past management, scouting data, and other environmental information, improves our ability to determine limiting factors within and among fields. The task is not easy considering the myriad of factors that could be limiting, that some factors are controllable while others are not, and that those factors often interact. In fact, a major future use of yield monitors may very well be to conduct field trials that allow the establishment of cause and effect relationships and that allow the refinement of input levels. Farmers with a few years of yield mapping under the belt often view their whole farm as a test site for on-farm research.
Consider the possibilities. Twelve years ago this coming fall, Herman Warsaw, a farmer near Saybrook, Illinois, harvested 23.3 metric tons/ha (370 Bu/A) of corn from his dry-land test area. No, the soil type was not unusual for Illinois but it had been subjected to his soil building management for decades. That reveals the potential of the technology and genetics of 1985. What is the potential of 0.5 ha areas in the fields of 1997? Who knows, but a real 25 ton corn yield will undoubtedly be measured by someone’s monitor by the end of this decade. It will not come by assuming that the highest yielding areas of the field are already at their potential. In many landscapes it’s those high-yielding areas that often show sub-optimal pH, P, K, Zn, etc. Developing the full potential of soil areas having superior inherent yield potential has not been a realistic goal until the advent of precision tools.

In other landscapes, the poor soil chemistry and biology of low yielding eroded hills may respond well to more intensive management. On the other hand, such areas may be places to save on inputs and recognize that they will always be low yielding. Each situation will need a site-specific program based on the limiting factors of the site.

Information is indeed the power and the challenge of precision farming. Information integration with GIS as the linchpin is the hub of the whole concept. This must go far beyond the intuitive association of multiple data layers. Tools to aid in this more rigorous knowledge-based integration of layers will likely be developed in the near future. The scientific literature is full of information on how various soil and environmental factors influence crop growth and nutrient needs. User friendly tools that allow use of these standard relational forms but with locally derived coefficients from strip trials or other controlled evaluations will likely be developed. This will unleash the power of precision technology.

Precision agriculture is far from a «plug and play» technology. Successful implementation and improvement is dependent on a trained team dedicated to the goal of improved efficiency and productivity. Precision agriculture will continue to change at a rapid rate due to growth in knowledge caused by data feedback, advances in technology, competition, and the development of strategic alliances. Some form of precision agriculture will become the conventional agriculture of the future. Global food needs, economics, and environmental concerns demand it.

CHAPTER 2: PACKAGING AND DELIVERING PRECISION TECHNOLOGY TO THE MARKETPLACE

In this century «precision farming» has evolved from managing the whole farm, to managing each field, to managing the cropping enterprise within a field. Each of these advances in farming has increased our understanding of the land and created new opportunities for farmer profitability.

Twelve years ago, the first site specific technology was introduced by Soil Teq, Inc. of Minnetonka, MN. They patented the process of having a computer in the fertilizer spreader read a fertilizer application map based on nutrient recommendations; thus incorporating considerations for within field variation in soil test levels and yield potential. The computer automatically adjusts the fertilizer application rate and blend as the vehicle moves across the field. However, the real revolution began about four years ago. Desktop computing, Geographical Information Systems (GIS), commercialization of the Global Positioning System (GPS), yield monitors, a new generation of farmers and agribusiness’ drive for new profit opportunities all came together to usher in the age of site specific farming, just as we read about in the trade journals.

In the previous chapter, we discussed the science and technology that makes this revolution possible. We looked at variation within the landscape, some ideas on how to manage it, and the tools that help us audit whether we were successful or not. The challenge is pulling all of this
information together into a system that can be profitably implemented by businesses, agriculturists and farmers.

COMPONENTS OF A SUCCESSFUL PRESCRIPTION AG PROGRAM:

Implementation of a precision ag program involves successful integration of three major of components. People, Technology and Knowledge.

Unfortunately, the trade journals and corporate marketing materials lead us to believe that if we buy the technology, everything will fall into place and the steps to improved profitability will be obvious. This is far from the truth. Without people trained in agronomics, interpretation, diagnostics, marketing and sales, a precision ag program will never get off the ground. Similarly, unless all of the technology is integrated into natural work processes, it will never be used. Precision ag tools by themselves are quite exciting and provocative. However, unless they are uick, easy to use, and part of normal business processes, experience has shown that no matter the level of interest or intent, day-to-day business needs will prevail and «time consuming» new solutions will never be implemented.

PEOPLE

Developing and implementing new ideas, processes and procedures require people to work with people. Since most employees are already fully employed, stepping into precision agriculture usually means hiring staff or reallocating tasks. For staff to develop and maintain the required knowledge to support and implement precision ag concepts will take all of the allocated time and more. Precision agriculture requires rethinking existing theories on crop production, learning new processes and procedures, new sales and marketing skills and new software systems. This takes time, expense and unique learning capabilities.

The area most affected in our industry is rural agribusiness. They are faced with a shortage of trained agriculturists living in rural communities. These are the agriculturists that work with our growers and ranchers providing agronomic expertise, helping implement prescription ag programs and implement site specific technology. Expert systems are often developed to balance the shortage of seasoned agronomists. The irony is that a high skill level is required by agronomists to use the systems.

Rural youth have been migrating into the cities to go to school and search for higher paying jobs. At the same time agriculture has become more complex, requiring better trained agronomic experts. This has been an increasing problem for the past 20 years, but with the needs of site specific agriculture it is reaching a crises. We need agriculturists that are computer literate, technologically savvy and well based in agronomics to aid farmers in analyzing their information so they can make the correct decisions. There are few of these people to be found.

Cenex/Land O’ Lakes, a regional co-op serving farmers in the north central and north western United States, has addressed this need by recruiting university graduates in agriculture and leasing them to affiliated co-ops throughout their territory. They found that many agriculturists do want to return to the rural communities, but within the infrastructure that comes from working for a larger company. With Cenex/Land O’ Lakes, they work as sales agronomists under the direction of the local co-op but with the career, salary and supervision expectations set by the regional co-op.

Sales agronomists typically increase local sales 8-12% per year when compared with similar co-ops without sales agronomists. This program has grown from 20 such men and women in 1987 to 250
today. The number of sales oriented agronomists that are available at the university limits the growth of this program.

The more innovative of these agronomists have become the ones in high demand by businesses who focus on marketing and implementing precision ag solutions for farmers. The best people are always being recruited away for new opportunities and greater salaries. Recruiting and maintaining successful local staff is just another symptom of the labor shortage associated with precision ag.

KNOWLEDGE

Providing local agronomic experts with the ongoing training and education to keep them up-to-speed with changes in production practices and technology is also a major challenge. Traditionally the state Extension Service filled this role in the United States. However, state and federal funding for the Extension Service is decreasing at a time when need is rapidly increasing. Thirty years ago there were 2-3 extension agents in many counties working to transfer the knowledge and technology from universities and other sources to farmers and agriculturists. Today, there are fewer county level agents and more regional agents whose focus is more and more on the urban population.

In New Zealand, the government went so far as to fully privatize the entire consulting and extension arm of the government. Wrightson Enterprises, purchased the government consulting system and is now looking for ways to make it profitable. Their challenge is similar to the one we all face: How to change paradigms and generate revenue to support people and processes that once were free. There are no easy answers.

A result of this change is that agriculturists hired by the local fertilizer and ag chemical dealers are increasingly filling the role of local agronomic expert. US studies from 1988 showed, even then, that 70 percent of the farmers looked to their local dealer for their primary source of information about fertilizers and chemicals. However the sales agronomists hired by dealers frequently have a farm background, a major in ag business or ag marketing and unfortunately, a limited number of true agricultural science courses. The result is that they need to be trained in the basics of soils, plants, herbicides, insects, etc. to grow their general expertise and to have the analytic skills required for interpreting site specific farming information.

Site specific farming creates an even greater need for education. Pulling together an understanding of soils, crops, pests, weather, production practices, machinery, geology and economics to make decisions that affect a farmers’ profitability is a major responsibility. With yield monitors, remotely sensed data and GIS, the effect of agronomists’ recommendations can be measured and agronomists can be held accountable for the results.

Ten years ago Cenex/Land O’ Lakes implemented a university style, fee-based training program for the agronomic staff of our co-ops. Each year they train approximately 2500 students through 80 schools in regional population centers. Students receive transcripts and must take exams on the completion of each 1.5-day course. This has been an overwhelmingly successful program. Because of state licensing requirements and demand for similar programs, many agricultural universities have started to formalize their extension training programs in a similar manner. This allows the rural agriculturists a choice in continuing education.

Adequate access to ongoing course work is further limited by the lack of time for these professionals to take courses. What used to be the winter «slow» season for agriculturists is now filled with input planning for farmers, on-the-farm sales, training on new technology, production practices and marketing programs, sessions on new products, etc. Our agriculturists have less and less time for schools. The greater need for training, coupled with less time available, has created a
major problem. An emerging requirement is to develop new ways to train and provide information that reduce the amount of time required for travel and put more information at the fingertips of the expert when it is needed.

TECHNOLOGY

Site specific agriculture is being driven by innovative farmers who are looking for greater profitability. We do not find very many consultants, dealers or distributors who are saying, «I want to make the investment in people, knowledge and technology to promote site specific agriculture to my farmers». It is the other way around. The early adopting farmers believe in the concept, are investing in the technology, and are looking for partners to help make it happen.

This rapid rate of change is partially driven by the introduction of the combine mounted yield monitor. Riding with a farmer in a combine equipped with a yield monitor is a unique experience. As the yield and moisture levels vary across a field, the grower’s understanding of how yield is affected by topography, weeds, drainage etc. are quantified. These revelations always create discussions on how to manage the variation to optimize profitability. Farmers have always known areas in their fields which were higher yielding or problematic, but now they can partition the variables and develop management strategies to improve production.

Last fall, hundreds of farmers came into their dealers with their yield cards. They wanted their yield maps printed off and assistance in interpreting them. If their traditional service provider could not meet their needs, they would find one that could. This change in grower expectations was a major awakening for many providers of agricultural inputs and services.

As the need for understanding variation within fields starts to increase, the amount of data needed for the decision-making processes increases. Management of these data requires well-designed databases and a Geographical Information System (GIS). Geographical Information Systems have been used for years to manage the infrastructure of our forests and cities. Only recently has the agricultural community adopted them. GIS technology’s main attributes are the ability to capture and store information by longitude and latitude so that it can be displayed exactly where it is located on the earth’s surface, the ability to overlay information, and the ability to analyze multiple layers of data to form a new layer of information (Figure 1).

When GIS technology is coupled with the Global Positioning System (GPS), farmers, consultants, and agribusiness have a very powerful tool to capture spatial information. This technology is also the foundation for the decision-making software and the integrated controller systems that vary fertilizer and pesticide rates on the go across the field. Plant cultivars or any other aspect of crop production can be varied as well.

Packaging all of the components of a precision ag system together into a full program that meets local needs, capitalizes on existing workflow, and actually works is not always a straight forward task. In the earliest days of precision agriculture, different precision solution providers felt they could deliver a complete packaged solution to meet every need. As it has evolved, software providers are delivering components that must be combined to form a complete process to meet local needs.

Pesticide manufacturers and seed producers offer jointly market crop production packages. Business systems that include precision ag processes will further facilitate the package approach to input sales. Cenex/ Land O’Lakes has implemented such a concept where the business, agronomic and precision ag records are all stored in one data management system. This will facilitate using common customer, product and pricing within the precision analysis software. One result of this
strategy is reduced support and implementation challenges, major factors when trying to maintain systems in rural markets.

Figure 12 shows a typical soil management workflow. Soil samples are collected, and analyzed. Recommendation and application maps are generated and fertilizer is applied according to these prescriptions. The results of all of the inputs are evaluated in maps generated from the output of yield monitors. These general processes are the same ones that have always been used to manage whole farms and fields. Now we are using them to manage the variability within fields.

Once the system is designed, implementation, training and support become a serious issue. Any business that has tried shifting paradigms through technology-based solutions has discovered that a tremendous amount of hand holding, support, training and re-training is required; we must also remember that the goal of most of our applicators and business units is to sell and apply fertilizer and to have satisfied customers. Academically we can discuss the theory and nuances of variable rate application and deriving our own fertility recommendations, etc. but farmers, employees and business units may have entirely different goals.

The challenges of developing and implementing a precision ag program are worth it. These concepts, in whatever form they are implemented, represent part of the ongoing change in our industry. There are many benefits to service providers, which include: new services, new revenue opportunities, greater linkage to customers and more sales opportunities. The result is a much closer relationship with customers and a greater understanding of their business and needs. This approach changes the focus of a retail business away from commodity sales and toward a value added service approach.

In the first year of their precision ag programs, four Cenex/Land O’ Lakes coops reported the following successes:

Co-op 1. Fee based soil testing volume increased 40%, service income increased $140,000 and plant food sales increased 15%.

Co-op 2. Charged for soil testing for the first time, which resulted in a significant offset of expenses. Charging for services did not «cost» them any customers.

Co-op 3. Their soil-testing program increased 8-fold, their service income net increased $30,000 and their micronutrient sales were up significantly

Co-op 4. They were able to move to a 30% margin on soil sampling, they introduced variable rate lime, which doubled their break-even numbers ($16,000 net), and their yield map printing business broke even at $2.00/ha.

One requirement for successfully implementing a precision ag program is a good marketing plan and strategy. Very few retail outlets have any concept of how to price intellectual and technology-based products, and even less of an idea of how to market them. They are used to dealing with tangible products like plant food, crop protection products and feed, and services like custom application, delivery, etc. These services frequently are given away or are loss leaders to increase sales of the commodities. Site specific farming services require significant capital, operating expenses, time and expertise. The expenses are great enough that they can no longer be wrapped into margins.

The issue of how much to charge is a major dilemma for most service providers. They don’t have any idea how much the services are worth or how much their farmers should pay. The greatest
mistake is charging too little. History has shown that consultants who make their living selling intellectual services charge enough to make a true profit. Dealers who follow consultants into a market have the opportunity to improve or expand these services with similar profit levels. The Hatch Act and other programs designed to improve agricultural productivity set a national precedent of free agricultural information and technology. It is a legacy, which has come to haunt agribusiness now that the traditional information infrastructure can no longer carry the «Free» load.

The availability of site specific farming has let to an improvement in the overall knowledge and expertise of the existing businesses and farmers in the market today. This increased understanding and accountability is also becoming part of the banking and regulatory communities as they evaluate the requirements for loaning money and regulatory compliance. As this plays out, successful businesses will redefine themselves and those that don’t will fade away. Site specific farming is just one more factor accelerating this natural process of change.

CHAPTER 3: DELIVERING PRECISION AG TO THE FARMER

There are several different levels of implementation: the farmer level is different from the dealer level, and the software or equipment level, although each of these areas overlaps significantly. Each person or organization has a different vision of how precision agriculture will be implemented and where. However, there is no doubt that part of the equation will include a local service provider who acts as an information center with agronomic and technological expertise. The data and information that this provider uses may be stored and managed in a distant location and accessed through the Internet but the face-to-face contact will still be local.

Implementing a site specific farming program is unique for every geography. The local customers, climate, crops, management, and competition are all different. When starting to design a program, the first questions are: «What do you want to do and what services would interest your customers»? In some areas, dealers only need to be able to read yield monitor cards while in other areas they may want a simple drawing package to display soil test results as a color picture within a field boundary. In some locations it makes sense to grid soil sample; in other areas sampling by topography makes the most sense. Some geographic areas have a need to vary the rate of all nutrients to optimize the fertility, while others only need to vary nitrogen. Some locations have shown that soil pH is the most limiting factor for crop production and only want to vary the application rate of lime. Some growers want to use controllers linked to the Global Positioning System to automatically vary application rates, while in other areas they want to flag a field and vary the rate of an input manually. Some areas want to do their own soil sampling and manage everything themselves; while others want to contract out all of the labor services but do their own data analysis. Every market is different, and in markets where there is competition, several different options may be available.

The most important consideration is, «What does the customer want». Note in figure 12 that every action is followed by consultation with the grower. For example, after the soil samples are analyzed there may be insufficient variation within the field to justify variable rate fertilizer applications. This provides a good opportunity for a farmer and agronomist to rethink the goals of their program. In the Red River Valley of North Dakota where sugar beets are grown, consultants have even implemented a «discovery» program. They take a small number of composite samples instead of starting with a complete grid-sampling program. If nitrogen fertility levels in the composite samples are all less than 30 kg/ha, they will not recommend grid sampling or variable rate spreading. The test values are uniformly low (requiring greater amounts of added N) and there is insufficient variation to merit varying the fertilizer application rates. If the levels of N in the composite samples is high (for example, 70 kg/ha) then they would recommend grid testing because experience has shown that there is significant variation in the nutrient levels within the field. Variable rate fertilizer application is designed to manage this level of within field variability.
After the spread map is generated and plant food is variable rate applied, remote sensing imagery can sometimes be used to check the success of the application prior to harvest (Figure 3). In this situation uniform crop quality was a goal. This is as good time again to meet with the farmer and discuss the value of precision applications. The final evaluation really only comes with yield monitor data. At this time a Return on Investment map could also be created. These analyses show whether the variable rate treatments paid off or not. Precision ag is really an on-going process that continues to refine our production practices.

Similar rotations can be developed for herbicide and pesticide decision making, variety management, and other production variables. As we get better and better, we will incorporate these variable rate workflow processes into all of our decision making.

However, not all farmers are ready for a full precision ag program. Precision ag can be implemented at many different levels. Many farmers may simply want to evaluate their yield monitor data for a number of years. They find that these «reports» show significant opportunities to improve their production practices without having to implement variable rate applications of inputs.

The low-tech benefits of prescription farming are often the ones that result in the greatest long-term profitability. By simply analyzing their yield maps, farmers are able to visualize and quantify many ways to improve their management techniques. This includes being able to financially quantify the cost of not spraying for weeds, the importance of liming to improve productivity, or the true differences between varieties on dry down and yield.

In Minnesota, inadequate tile drainage can seriously limit yield. One farmer determined from his yield monitor data that 5 hectares of inadequately tiled land reduced his soybean yield from 3000 kg/ha down to 1800 kg/ha. This amounted to US$280/ha or US$1400 lost profit. He subsequently tiled the area for $7000 and expects pay back in about 5 years. Many of the success stories of prescription farming are centered around changes in production practices and are equally as positive. The point is that precision ag has a different meaning to different people, and that it really reflects a continuously improving management processes that will grow with each customer. Precision ag is not a destination; it’s a journey.

**HOW MUCH DOES IT COST?**

For many of the farmers implementing precision farming is an issue of understanding a new set of costs and returns. They do not know how to shop for precision ag services and at the same time most service providers do not know how to market them.

A typical site specific program for corn in Minnesota might cost $US20.00/ha and includes sampling the soil on a 1 ha grid, sample analysis and interpretation, a computer generated nutrient map, and a computer generated recommendation map if variable rate spreading if warranted. Alternatively, some consultants will flag a field for manually varying the rate of selected inputs if the higher priced automated systems are not desired. These costs can be amortized over a normal 3-4 year soil sampling cycle. Variable Rate spreading costs an additional US$15.00-22.00/ha depending on the equipment and application. Conventional spreading costs US$4.50-9.00/ha. In the dryland wheat areas, soil sampling is often done in zones that represent significant landforms. One composite sample may include several occurrences of a zone and represent 10-15 hectares. A site-specific program for this area may cost US$10.00/ha plus application charges. Nitrogen is usually the only nutrient that is varied on dryland wheat. Yield map printing and interpretation usually cost about US$2.00/ha although competition is already lowering the price in some areas to US$1.00/ha.
DOES THIS PAY?

There are not a lot of facts available on the financial benefits to farmers who implement site-specific production practices. Site specific farming is too new and the implementation of this technology did not follow the traditional implementation scheme. This technology went from an idea to implementation.

Only recently have the universities become involved and started to collect the basic information required for long term agronomic and economic studies. One realization is that the broad based fertilizer recommendation models developed 20-40 years ago for regional climates and soils will need to be reevaluated. The large amount of quality georeferenced soil test data collected by site specific practitioners, analyzed by certified labs and validated with input and yield records should create many interesting opportunities for cooperation between farmers, local agriculturists and university researchers.

Economic studies are starting to be published and the results are exciting. Managing the rates of applied nitrogen on sugar beets in the Red River Valley of North Dakota provides returns ranging up to $300/ha. The increased profitability is the result of optimized sugar contents in the beets. Farmer adoption of variable rate fertilizer application on sugar beets was fairly rapid after the sugar beet processing co-op stopped paying on the number of tons produced and started paying on the amount of sugar recovered per ton of beets.

However, precision ag is not a solution that will have instant adoption. Even in these high return sugar beet areas only 25% of the customer base of the sugar cooperatives have adopted the technology after 4 years. Changing peoples’ paradigms is a slow process.

Varying the application rate of N, P, and K on soils in the state of Minnesota has been shown to increase net profitability of corn production US$10-50/ha. This has been primarily due to increased yields and reduced nutrient applications in the areas that have low production potential and increasing the rates in the higher producing areas. Results from the Midwestern United States show the average amount of fertilizer applied within a trade territory generally remains constant. Some land gets more, some less. The real success for dealers comes from market leadership and winning at the farm gate.

Variable rate applications in the dry land wheat areas are really just starting, so financial return data are quite scarce. The focus will again be fertilizing the soil where there is the greatest chance for improved yield. Variable rate applications on wheat will really take off when yield monitors that can also measure protein, starch and oil are available. These are expected for the 1997 or 1998 growing season. Protein monitors will provide farmers with the information to vary the rate of nitrogen to optimize protein levels (and profitability) across a field, as well as to segment their high protein grain for a marketing advantage.

FUTURE:

So far we have discussed site specific farming from a very narrow perspective. We have measured the soil test levels or the weed pressure etc. and then varied the rates of inputs and recorded the result as yield. But, in reality, site specific farming is the harbinger of some major changes that are occurring in agriculture.

Most important is the change that is occurring in business infrastructure. The site-specific mapping tools that are required to perform site specific farming tasks are the same tools that can be used to manage business information systems. In their simplest form GIS systems display data and GPS
systems tell you where you are. Integrated with business systems, they will be used by agribusiness of all types to display sales information specific to the farmer and to the field to which products were applied. For example: visually comparing sales and application location information of farmers that purchased products and services compared to those that did not, may result in new marketing plans. As manufacturers bar code their products, market share, distribution and application information can be more accurately traded between partners.

Part of the business infrastructure will be the use of GIS in logistics. In a business, the most expensive resources are people and capital items. Today, geographical information systems coupled with GPS systems can continuously track the location of all vehicles belonging to a business. This can assure that products are delivered on time to application equipment, assure that application equipment is in the right field, assist in vehicle routing and much more.

Another step will occur as satellite imagery with 1-5 m resolution starts to become available. Today, we are using 10-20 m resolution imagery in wheat fields to identify zones for sampling and therefore reduce the need for expensive grid sampling. In the future, imagery collected less than 24 hours earlier will show farmers where fields need to be scouted, which fields are ready to harvest and facilitate the most efficient routing of people and equipment to get the job done. Already farmers are using GPS and GIS to tell property boundaries in fields where fences no longer exist. This has made the operation of equipment for 20 hours a day even more feasible.

GIS coupled with GPS systems having sub-meter accuracy allows custom spraying equipment to use a light bar in the cab rather than foam markers to show what ground has been treated. Applications can also be made at night when there is less wind for pesticide drift. This technology can also be used to increase equipment utilization. When application equipment can be run 20 hours a day instead of 12, there is a significant business advantage. Similarly, when these systems are incorporated into ag spray aircraft, the need for flagmen is eliminated, thus reducing human exposure to pesticides.
IMPLEMENTATION OF PRECISION AGRICULTURE PROGRAMMES WITH DEALERS AND GROWERS

by

D.S. Fairchild
Cargill Incorporated, USA
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Summary

Precision Agriculture dealer programs continue to expand in North America and are gaining attention in South America and Western Europe. Dealers are encouraged to discuss variability issues with their University scientists and farmer customers, explore equipment and mapping options, and affiliate their business with suppliers that offer precision ag support services.

INTRODUCTION

Precision farming concepts continue to attract customers, media, and government attention. This growth rate is fueled by increased net returns for growers and Agri business, reduced production costs, value-added products, service marketing, and environmental benefits.

This development has been a gradual evolution the past 30-40 years with rapid changes the past 5-10 years. The concept developed from farm management decision progressing from farm to field to soil type to 1-5 acre grid zones levels. For example, implementation of bulk blending could be traced to site-specific applications by field and soil test levels. This concept expanded to variable-rate fertilizer applications by fertility zones. Terminology appeared in the marketplace including: soil-specific management, farming-by-the-foot, V.R.T. fertilizer applications, and precision agriculture. Technology developments of personal computers, digitized mapping software, variable-rate fertilizer applicators, navigation systems, yield monitors and information management system have accelerated this adoption of precision farming.

A key point in the development cycle of precision agriculture is that the present excitement is directed towards technology, but greater opportunities exist with development of information production formulas to better direct this technology.

Adoption of Precision Ag by Farmers and Dealers

The adoption by farmers will vary by crop, region, and complexity of the services. Rapid acceptance is noted in crops where both yield and crop quality are improved. For example; University of Minnesota research has shown net returns of over $80 per acre with variable nitrogen applications on sugar beets.

Cargill's research trial with variable rate herbicides on corn showed $6.40 - $21.25 increased profit per acre.

It should be noted net increases are a function of the interaction of efficiency of crop inputs and increases in yields.

Retail crop input dealers and crop consultants are playing a key role in providing precision ag programs to growers. Table 1 shows farmers are expecting these two segments to provide 70 percent of their precision ag products.

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1 Paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997
Table 1: Where Farmers Will Go For Help With Precision Agriculture

<table>
<thead>
<tr>
<th>Segment</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm supply dealers</td>
<td>40</td>
</tr>
<tr>
<td>Consultants</td>
<td>30</td>
</tr>
<tr>
<td>Software Co.</td>
<td>13</td>
</tr>
<tr>
<td>Universities</td>
<td>10</td>
</tr>
<tr>
<td>Extension</td>
<td>4</td>
</tr>
<tr>
<td>Others</td>
<td>3</td>
</tr>
</tbody>
</table>

*Source: Farm Chemicals*

Early adoption of precision ag by North America dealers has resulted in:

1. Increased service revenues
2. New customers
3. Increased fertilizer sales
4. Crop consulting revenue
5. Micronutrient sales
6. Frustration with incompatible electronic equipment and software.

Example: One dealer identified 34% of his growers' acres were testing very low in zinc. Increased zinc sales result.

**Variable Rate Controllers**

Various crop inputs are being applied by management zone maps

A. VRT Fertilizers
   - N,P,K - broadcast/band - liquid or dry
   - Ammonia + or - N-serve
   - Micronutrients
   - Animal wastes
   - Lime - liquid or dry

B. VRT Herbicides
   - Pre-plant or pre-emergence based on soil factors (O.M., pH, C.E.C or soil texture)
   - Post-emergence applications from weed maps or remote sensing

C. VRT Seeding
   - Variable seed population with corn and soybeans
   - Soybean varieties for iron resistance
D. Future VRT Controllers
   - Tillage
   - Corn hybrids
   - Nematodes
   - Insecticides
   - Soil moisture
   - Planting depth

VRT Pricing Options

Dealers are pricing VRT services by various methods. Efforts continue to price VRT services separate from products and at a level to generate service profits. Examples from various dealers follow.

A. Soil testing - grid size 2.5-4.4 acres
   Cost will vary with grid size and lab analysis requested.
   Typical soil testing costs are $5.00 to $5.45 per acre.
   Retail grid pricing range from $5.00 to $8.00 per acre.
   Most soil tests are used four years before retesting.

B. VRT Fertilizer Applications
   - Fall application $5.50 to $6.00/acre
   - Spring application $6.00 to $8.00/acre

C. Bundled VRT program including:
   Soil testing, mapping, and application $5.50/acre/yr - 4-year total $22.00/acre

D. Yield Mapping
   - Typical charge of $1.00/acre
   - Additional charges for interruption

Successful VRT Dealer Elements

Implementation of precision farming concepts requires dealers to ask various questions about their operation. Do you have?

A. Farm call programs and salesmen
B. Innovative owners and/or management
C. Customer application programs
D. Employees that accept change
E. Professional applicators
F. History of charging for services
G. Crop consulting
H. Agronomist
I. Plans for custom soil sampling
J. Area farmers doing well and have a history of trying new services and products
K. Field sized greater than 20 acres
All of the above services do not have to be part of the retail dealership. Many dealers contract these services from consultants or receive support from their various suppliers.

**Dealer Steps to Precision Agriculture**

Precision agriculture programs can appear complex and expensive. To reduce these concerns dealers can develop a program in stages or different product sets.

<table>
<thead>
<tr>
<th>Limited Products</th>
<th>Precision Ag Products</th>
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<tbody>
<tr>
<td>Complete Precision</td>
<td></td>
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<tr>
<td><strong>Ag Program</strong></td>
<td></td>
</tr>
</tbody>
</table>

- GPS soil sampling
- Improve fertility recommendations
- Yield monitors
- Mapping program
- GIS grower files
- Crop scouting with hand-held computers
- Farmer-owned VRT equipment
- Dealer VRT
- All of the above
NUTRIENT EFFICIENCY IN IRRIGATED RICE CULTIVATION

by
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International Rice Research Institute, Philippines

K.G. Cassman
University of Nebraska-Lincoln, USA
1. Irrigated rice systems

Examples of intensive, irrigated rice systems in Asia include rice-rice, rice-rice-rice, rice-rice-pulses, rice-wheat, or rice-maize systems. Annually, more than 370 million tons of rice (paddy) are produced in such cropping systems, accounting for about 75% of the global rice supply in Asia. Rice monoculture systems (double or triple cropping) and rice - wheat systems, cover at least 36 million ha in Asia and account for about 50% of the global rice supplies. There is no doubt that the intensive lowlands will remain the major source of rice production until and probably beyond 2025 [10,11].

Present rice (paddy) yields average about 5.0 t/ha in the intensive rice systems, which is less than 60% of the climate-adjusted yield potential of existing high-yielding varieties [10,34]. To keep pace with population growth, yields in both irrigated and rainfed lowland environments have to increase by 60-70% within the next 30 years. Closing the existing yield gap and increasing the biological yield potential [40] will have equal importance to meet the demand during the next three decades.

The demand for nutrients will increase substantially. Before the Green Revolution, natural components of the nutrient balance such as sedimentation, crop residues, organic manure, and biological N fixation played a major role in sustaining traditional rice systems at relatively low yield levels. Currently, in most double- or triple-cropping rice areas of South and Southeast Asia, the total amount of grain produced is 10 to 15 t ha⁻¹ yr⁻¹. The fluxes of nutrients involved in this have become large and cannot be met by natural sources alone. Mineral fertilizers inputs are the dominant factors of the overall nutrient balance in intensive rice systems. To achieve the projected yield goals in irrigated rice systems of Asia, total annual crop uptake will be about 9-13 x 10⁶ t N, 9-15 x 10⁶ t K, 1.2-2.4 x 10⁶ t P, and 0.9-1.5 x 10⁶ t S in 2025 [17].

Issues of the sustainability of intensive rice systems, particularly the question of a yield or productivity decline, have been discussed in recent publications [4,8,12,16]. This paper focuses on the role of mineral fertilizers and their management in irrigated rice. At issue are questions such as:

- Have research and technology development kept pace with the demand for improved nutrient management technologies in irrigated rice?
- Are the current fertilizer management strategies practiced by rice farmers adequate to maintain the yield gains achieved over the long term and to support the future yield increases needed?
- What changes in the global fertilizer consumption will be required to enable the increase in rice production required over the next 30 years?
- Can we implement precision nutrient management in small rice farms?
- What should the fertilizer industry contribute to research and farm development?

This paper summarizes some of IRRI’s recent research on N, P, and K management in irrigated rice. We will focus strictly on the biophysical nutrient requirements and implications for research and development towards a more resource-oriented nutrient management. Implementing such
recommendations will be a difficult task, rendered by political, economic, and socioeconomic factors driving the actual fertilizer use.

2. Status of nutrient management in irrigated rice systems of South and Southeast Asia

Compared to the immense improvements in rice germplasm, much less progress in improving nutrient use efficiency in rice-based cropping systems was made. We have recently reviewed the state of the art [9,21,32] so that only a few key issues will be highlighted here again.

Nitrogen

Nitrogen is the most limiting nutrient in practically all intensive irrigated rice systems. Due to secured water supply good yield response to fertilizer N is usually observed and N management is the key factor for achieving high productivity [3,9,14,44]. However, diminishing returns to fertilizer N application have been reported for many irrigated rice regions in Asia [12]. Rice farmers often need to apply more N to obtain similar yields than 10 or 20 years ago, raising concern about declining soil N-supplying capacity, apparently associated with changing soil organic matter quality [4,6,38].

Nitrogen research in the 1970s and 1980s focused on reducing gaseous N losses, but there was little impact on N fertilizer management practiced by rice farmers [9]. Numerous technologies for improving nitrogen management were proposed. Examples include green manure [1], rice-legume systems [31], nitrogen catch crops [24], technologies to stimulate biological N fixation [30], innovative fertilizers such as supergranules, coated urea, or slow release fertilizers [46,47,57], nitrification or urease inhibitors [2], deep fertilizer placement [35], technologies for improved management of subsoil nutrients [29], or new diagnostic tools such as the chlorophyll meter [42] and leaf color charts [50]. All of them have different importance for different environments, but, in any case, economic rationality determines the choice of nutrient management strategies that are available and adaptable by farmers [56]. Unfortunately, many of the technologies proposed have not found very broad acceptance among farmers.

Research on a better understanding of the indigenous N supply from the soil-floodwater system (INS) did not receive the same attention as research on N losses from applied fertilizer. The ability to adjust the quantity of N applied to variation in INS is equally important to increased partial factor productivity of applied N (PFPN, grain yield per unit N applied) as are the timing, placement and source of applied N [9]:

1. Enormous variation in INS (measured as total N uptake in minus N plots or N release to ion-exchange resin) was found among individual farmers’ fields [7,17,39]. Table 1 and Figure 1 show examples of two such studies in various irrigated rice domains of Asia. For example, INS in farmers’ fields across five sites ranged from 15 to 117 kg ha\(^{-1}\) (Tab. 1). In some cases, rice yields in unfertilized plots even exceeded 6 t ha\(^{-1}\) [39]. The INS is very sensitive to climate and season-to-season variation in INS within the same field tends to be large as well [7].

2. Farmers’ fertilizer rates applied varied greatly (Tab. 1), but there was no relationship between applied N rate and INS [7,39].

3. Many farmers tend to apply much N during early growth stages. Limited N supply during late vegetative growth and grain filling often seems to limit high N use efficiency at high yield levels [42,53].

4. Because of the lack of congruence between fertilizer N applied, INS, and crop N demand recovery efficiency (RE\(_N\), \(\Delta\) N uptake per unit N applied), agronomic efficiency (AE\(_N\), \(\Delta\) grain
yield per unit N applied), and PFP$_N$ are often low in farmers’ fields [7,39,41]. For example, average RE$_N$ in farmers’ fields at five sites was only 30% (with a high standard deviation of 15%) and this value has not changed much during the past 25 years [10].

5. Despite differences in nutrient uptake patterns, the overall system-level N use efficiency of broadcast-seeded rice seems to be comparable to that of transplanted rice [41].

Table 1. Averages and ranges of soil nutrient supply, fertilizer use, and crop performance in irrigated rice domains of Asia. Values shown are based on a total number of 481 crop x farm seasons sampled between 1994-1996 in farmers’ fields in Tamil Nadu (India), the Mekong Delta (Vietnam), Central Luzon (Philippines), Central Thailand, and NW Java (Indonesia).²

<table>
<thead>
<tr>
<th></th>
<th>mean</th>
<th>sd</th>
<th>min</th>
<th>max</th>
<th>Frequency model used in global simulations</th>
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<tbody>
<tr>
<td>Indigenous N supply</td>
<td>kg/ha</td>
<td>59</td>
<td>15</td>
<td>117</td>
<td>Lognormal</td>
</tr>
<tr>
<td>Indigenous P supply</td>
<td>kg/ha</td>
<td>12</td>
<td>3</td>
<td>20</td>
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<tr>
<td>Indigenous K supply</td>
<td>kg/ha</td>
<td>78</td>
<td>15</td>
<td>124</td>
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<td>Fertilizer N use</td>
<td>kg/ha</td>
<td>113</td>
<td>38</td>
<td>260</td>
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<td>kg/ha</td>
<td>17.4</td>
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<tr>
<td>Fertilizer K use</td>
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<tr>
<td>Recovery of applied N</td>
<td>%</td>
<td>30</td>
<td>15</td>
<td>92</td>
<td>Truncated lognormal</td>
</tr>
<tr>
<td>Grain yield</td>
<td>t/ha</td>
<td>5.2</td>
<td>1.3</td>
<td>1.8</td>
<td>8.5</td>
</tr>
<tr>
<td>N uptake</td>
<td>kg/ha</td>
<td>89.9</td>
<td>24.0</td>
<td>184.5</td>
<td></td>
</tr>
<tr>
<td>P uptake</td>
<td>kg/ha</td>
<td>15.1</td>
<td>5.1</td>
<td>35.8</td>
<td></td>
</tr>
<tr>
<td>K uptake</td>
<td>kg/ha</td>
<td>82.7</td>
<td>27.8</td>
<td>165.3</td>
<td></td>
</tr>
<tr>
<td>Harvest index</td>
<td></td>
<td>0.49</td>
<td>0.06</td>
<td>0.70</td>
<td>Normal</td>
</tr>
<tr>
<td>N content in straw</td>
<td>%</td>
<td>0.70</td>
<td>0.20</td>
<td>1.21</td>
<td>Lognormal</td>
</tr>
<tr>
<td>P content in straw</td>
<td>%</td>
<td>0.10</td>
<td>0.05</td>
<td>0.23</td>
<td>Lognormal</td>
</tr>
<tr>
<td>K content in straw</td>
<td>%</td>
<td>1.45</td>
<td>0.60</td>
<td>2.83</td>
<td>Normal</td>
</tr>
</tbody>
</table>

Contrary to the common belief, the rice plant has the potential to be highly N-efficient. In field experiments at two sites in the Philippines, maximum uptake rates of 9-12 kg N ha$^{-1}$ d$^{-1}$ were measured over a 4-d period following application of 100 kg N ha$^{-1}$ compared to previously reported maximum values of 6 kg ha$^{-1}$ d$^{-1}$. Presumably, these are the highest N uptake rates reported for a cereal crop under field conditions. In the same study, recovery efficiency of topdressed urea-N reached 39-55% at midtilling and 74-78% at panicle initiation [43].

Tremendous potential for improving N use efficiency through field-specific N management focusing on better congruence between N supply and plant demand exists [9]. Developing simplified diagnostic field tools as well as affordable innovative products such controlled release fertilizers will be important components of future N management strategies aiming at improving congruence of supply and demand.

**Phosphorus**

² The data used for computing these summary statistics were collected by researchers participating in the Reversing Trends of Declining Productivity in Intensive Irrigated Rice Systems project lead by R. Nagarajan (TNRRI, India), P.S. Tan (CLRRI, Vietnam), P.C. Sta. Cruz (PhilRice, Philippines), S. Satawathanont (FTRRC, Thailand), S. Abdulrachman (RIR, Indonesia), K.G. Cassman, and D.C. Olk (IRRI).
In our analysis of 11 long-term experiments in five countries, the agronomic efficiency of applied P varied from 0-114 kg grain kg\(^{-1}\) P (mean=49 kg grain kg\(^{-1}\) P). Uptake of 2-4 kg P is required to produce one ton of grain yield, but, particularly depending on the N nutrition status, the physiological P use efficiency typically varies between 200 to 600 kg grain kg P\(^{-1}\) [18]. At fertilizer P rates of 17 to 25 kg P ha\(^{-1}\), there was an average net gain of 4 to 5 kg P ha\(^{-1}\) per crop and a similar slightly positive average P balance was estimated in on-farm studies in the Philippines [23] and in five countries of South and Southeast Asia (Tab. 4).

The present average level of fertilizer P use of about 17 to 20 kg P ha\(^{-1}\) seems to be adequate to maintain yields of 5-6 t ha\(^{-1}\). However, indigenous P supply (IPS, Fig. 1) and fertilizer P rates (Tab. 1) are highly variable among farmers so that both over- and under-supply are issues of concern in irrigated rice systems.

**Figure 1.** Variation in soil nutrient supply among farmers' fields in irrigated rice domains of the Philippines and South Vietnam. Values shown are quantities of nutrient adsorbed on mixed-bed resin capsules during 7-d anaerobic incubation (RAQ). Measurements were taken for three different domains including 78 farmers in a 19,176-ha area of Nueva Ecija in 1994, 24 farmers in two villages of Nueva Ecija in 1996, and 32 farmers in 8 villages in the Omon district, Mekong Delta.

In the long-term fertility experiment at Shipai, China, applying 17 kg P ha\(^{-1}\) crop\(^{-1}\) was not sufficient to maintain the available P level in the NPK treatment (Tab. 2). In a regional survey of irrigated riceland in Central Luzon, Philippines, 64% of the total area was classified as low in available P, even though this region is generally regarded as the most productive riceland of the Philippines and P rates averaged 21 kg ha\(^{-1}\) in the dry season [23].

In contrast, due to high fertilizer subsidies, rice farmers in Java, Indonesia, have been applying triple superphosphate at rates higher than the rates suggested by the blanket recommendation during the rice intensification program. About 85% of the total lowland rice area now has a high soil P status [49] so that there is no longer a yield response to applied P, and there is increased risk of pollution...
from P leaching. Accumulation of available P and lack of P response due to high P fertilizer rates were also reported from Taiwan [33].

**Figure 2.** Partial net K and P balance for one rice crop in five different fertilizer treatments. Values shown are averages and standard deviations (error bars) of long-term experiments at 11 sites in five countries sampled in 1993. Stubble was recycled at five sites and all straw was removed at six sites, reflecting standard farmer practices for each location [18,20].
**Potassium**

At the onset of the “Green Revolution”, most soils in the alluvial floodplains of South and Southeast Asia had relatively high contents of plant available forms of K. It was thought that its increased availability under submerged conditions as well as additional supply from irrigation and sedimentation would make it a rare limiting factors in irrigated rice systems. In most early fertilizer trials with modern HYV no significant responses to K additions were observed, whereas tremendous yield gains could be achieved by applying N fertilizer. Thus, sufficient K nutrition and maintenance of soil K reserves have been neglected in most fertilizer recommendations. There is now much evidence that depletion of soil K reserves is a general trend in intensive rice systems.

Table 2. Long-term P and K balance of 9 rice crops (1989-1993) and change in extractable soil nutrients in different fertilizer treatments of a long-term experiment at Shipai, China. The cropping system at this site is rice - rice and all straw is removed at harvest (A. Dobermann and K. Cassman, unpublished data).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Control</th>
<th>+N</th>
<th>+NP</th>
<th>+NK</th>
<th>+NPK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean grain yield (early rice)</td>
<td>kg/ha</td>
<td>3148</td>
<td>4254</td>
<td>5136</td>
<td>4570</td>
</tr>
<tr>
<td>Mean grain yield (late rice)</td>
<td>kg/ha</td>
<td>3450</td>
<td>4152</td>
<td>4893</td>
<td>4296</td>
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</tbody>
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**Phosphorus**

<table>
<thead>
<tr>
<th></th>
<th>kg/ha</th>
<th>0</th>
<th>0</th>
<th>153</th>
<th>0</th>
<th>153</th>
</tr>
</thead>
<tbody>
<tr>
<td>Σ Fertilizer P</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Σ P uptake</td>
<td>kg/ha</td>
<td>81</td>
<td>84</td>
<td>176</td>
<td>91</td>
<td>179</td>
</tr>
<tr>
<td>Σ P balance</td>
<td>kg/ha</td>
<td>-81</td>
<td>-84</td>
<td>-23</td>
<td>-91</td>
<td>-26</td>
</tr>
<tr>
<td>Initial Olsen-P in 1989</td>
<td>mg/kg</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
<td>8.6</td>
</tr>
<tr>
<td>Olsen-P in 1993</td>
<td>mg/kg</td>
<td>4.5</td>
<td>3.6</td>
<td>8.4</td>
<td>4.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Δ Olsen-P †</td>
<td>mg/kg</td>
<td>-4.1</td>
<td>-5.0</td>
<td>-0.2</td>
<td>-4.4</td>
<td>-0.4</td>
</tr>
</tbody>
</table>

**Potassium**

<table>
<thead>
<tr>
<th></th>
<th>kg/ha</th>
<th>0</th>
<th>0</th>
<th>0</th>
<th>297</th>
<th>297</th>
</tr>
</thead>
<tbody>
<tr>
<td>Σ Fertilizer K</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Σ K uptake</td>
<td>kg/ha</td>
<td>406</td>
<td>474</td>
<td>553</td>
<td>574</td>
<td>732</td>
</tr>
<tr>
<td>Σ K balance</td>
<td>kg/ha</td>
<td>-406</td>
<td>-474</td>
<td>-553</td>
<td>-277</td>
<td>-435</td>
</tr>
<tr>
<td>Initial extractable K in 1989</td>
<td>cmol/kg</td>
<td>0.143</td>
<td>0.143</td>
<td>0.143</td>
<td>0.143</td>
<td>0.143</td>
</tr>
<tr>
<td>Extractable K in 1993</td>
<td>cmol/kg</td>
<td>0.124</td>
<td>0.112</td>
<td>0.116</td>
<td>0.153</td>
<td>0.124</td>
</tr>
<tr>
<td>Δ extractable K ‡</td>
<td>cmol/kg</td>
<td>-0.019</td>
<td>-0.031</td>
<td>-0.027</td>
<td>0.010</td>
<td>-0.019</td>
</tr>
</tbody>
</table>

† 0.5M NaHCO₃ extractable P.
‡ 1N NH₄-acetate extractable K.

Recent research has shown, for example, that on soils with 2:1 layer clay minerals K fixation increases due to wetting and drying cycles so that K availability does not increase after submergence [5,37]. The partial net K balance in long-term experiments was found to be highly negative in all NPK combinations tested (-34 to -63 kg ha⁻¹ crop⁻¹, Fig. 2) and fertilizer K application at an average rate of 40 kg ha⁻¹ in the +NK and +NPK treatments was not sufficient to match the K removal at most sites [20]. For example, at one site in China a cumulative net K loss of 435 kg ha⁻¹ was estimated over a period of 9 rice crops in the NPK treatment that received 33 kg K ha⁻¹ crop⁻¹ (Tab. 2).

Surveys conducted by IRRI in collaboration with NARS in five countries suggest an average use of only 18 kg K ha⁻¹ per crop with a very large standard deviation of 22 kg K ha⁻¹ (Tab. 1). In this
study, farmers in Thailand, for example, did not apply any K fertilizer whereas average K use was highest in Tamil Nadu, India (43 kg K ha\(^{-1}\)). In a survey of 63 farms in Central Luzon, Philippines, the K balance was negative in most farms and average losses of 38 kg K ha\(^{-1}\) per crop were estimated in the 1994 dry and the wet seasons [23]. In the same study, 54% of the total rice area surveyed was classified low in available K. Other examples for K depletion observed in farmers’ fields include alluvial, illitic soils in India [54] and lowland rice soils of Java, Indonesia [49].

It is safe to conclude that the indigenous K supply (IKS) and current fertilizer K use in most lowland rice soils are still sufficient to obtain average yields of 5-6 t ha\(^{-1}\). It has become clear, however, that sufficient application of K is required to fully express the yield potential of modern rice varieties and sustain soil quality over the long run [21]. Rather conservative estimates suggest a negative K balance of -20 to -40 kg K ha\(^{-1}\) per crop in most farmers’ fields. A key problem is the increasing removal of straw from rice fields to use it as forage or fuel or to facilitate land preparation. Although researchers started to raise concern about the danger of negative K balances and soil K depletion many years ago [13,28,55], this has not yet led to a significant improvement of K management. As in the case of INS and IPS, the indigenous K supply tends to be highly variable (Fig. 1, Tab. 1) and its quantification is of pivotal importance for improving K use efficiency.

3. Scenarios for future fertilizer use on irrigated rice in Asia

A simulation model for analyzing nutrient management scenarios

Given the current unsatisfactory status, the question arises how fertilizer use should change to meet the global rice demand during the next 30 years by achieving high use efficiency of the major nutrients applied. Often, such forecasting is done by economists based on generic response functions and official statistics of population growth, rice production, and fertilizer consumption. Because there are no reliable data about the use of single nutrients applied to irrigated rice alone, such an approach has obvious limitations. Moreover, forecasting has to take into account the interactions between nutrients.

We developed a simulation model for forecasting fertilizer use and nutrient balances for irrigated riceland in Asia. Calculations are restricted to N, P, and K and the model developed takes their interactive effects on grain yield into account. The major model features include:

1. Estimation of nutrient uptake and grain yield for any combination of indigenous nutrient supply, fertilizer nutrient addition, and RE of applied nutrients. This component is based on a spreadsheet version of the QUEFTS model [27,48] adjusted for irrigated rice.
2. Estimation of the nutrient balance, including inputs from rain, irrigation, fertilizer, manure, and crop residues and outputs as leaching, gaseous losses, and crop removal.
3. Uncertainty analysis. All model parameters and input values are handled as frequency distributions (see examples in Tab. 1) and the correlation between parameters is specified. All simulations presented below are the result of 1000 model iterations using Latin Hypercube sampling [26] to account for the variation in input data and model error.
General model assumptions

The population in the major rice producing and consuming countries in Asia will grow from about 2.2 billion in 1995 to 3.4 billion in 2025. If rice prices are to be maintained at current levels, rice production has to increase by about 1.8% per year over the next 30 years [25]. For irrigated rice, we assume an average increase by 1.5% per year and production must reach about 590 million tons in 2025. This is equivalent to an increase of the average yield from 5 t ha\(^{-1}\) in 1995 to 7.9 t ha\(^{-1}\) in 2025 (Tab. 3).

The harvest area of irrigated rice will remain unchanged at 74 million ha. Losses of prime irrigated rice land to urbanization and industrialization are counterbalanced by slight increases in the irrigated area and increase in cropping intensity (move to triple cropping) in areas with good water supply. In general, water availability remains sufficient to grow rice under irrigated conditions. This will require improvement of water use efficiency through better infrastructure and irrigation technologies.

The yield potential of modern rice varieties increases at a rate of 1% per year through conventional breeding and development of a new plant type. A similar increase was achieved during the past 30 years (S. Peng, IRRI, personal communication). Across all climatic zones and growing seasons in Asia, the current yield potential is about 8.1 t ha\(^{-1}\) [34] and it will rise to 10.9 t ha\(^{-1}\) in 2025 (Tab. 3). There will be no significant change in the harvest index of modern varieties (0.48 ±0.05) or their internal nutrient use efficiency as also determined by the nutrient harvest indexes.

As the yield level increases better nutrient and pest management prevent any potential higher yield loss due to weeds and pests. Economic and socioeconomic factors that may make rice production more or less attractive are not included (changes of rice price, changes in rice consumption patterns, or trends of cost of major production inputs).

Specific model parameters and data inputs

Using a database of 1500 samples collected from on-station and on-farm experiments in 10 countries the equations describing the relationships between nutrient uptake and grain yield in QUEFTS [27] were adjusted for irrigated rice.

For the nutrient balance calculations, we assumed that on average 30±5% of the straw is returned to the field with nutrient losses of 70±10% N, 40±5% P and 30±5% K from the crop residues through burning and leaching. This is a rather conservative estimate and, most likely, the actual amounts of N, P, and K returned as crop residues are smaller than those used in our model.

There are no data about global inputs of farmyard (FYM) or green manure (GM). Green manure is mostly grown in situ so that the nutrients accumulated (except biological N\(_2\) fixation in legumes) mostly originate from the same soil and do not represent a net gain. For FYM, we assumed an average input of 1±0.25 t ha\(^{-1}\), considering that many rice farmers do not use FYM at all. Nutrient concentrations (% of fresh FYM) were set at 0.5±0.1% N, 0.1±0.025% P, and 0.5±0.1% K.

With few exceptions, NPK inputs from rain, sediments, and irrigation are small [9,21]. Conservative model inputs were used (kg ha\(^{-1}\) per crop cycle, mean ± SD):

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input from rain</td>
<td>2±1</td>
<td>0.5±0.2</td>
<td>5±1</td>
</tr>
<tr>
<td>Input from irrigation/sediments</td>
<td>2±1</td>
<td>1.0±0.3</td>
<td>10±2</td>
</tr>
</tbody>
</table>
Leaching losses

|       | 10±2  | 2.0±0.5 | 15±3 |

Figure 3. Comparison between predicted (QUEFTS model) and measured average rice yields (during 1994-96) for rice-growing domains in India (TNRRI), Indonesia (RIR), Thailand (PTRRC), Vietnam (CLRRI) and the Philippines (PhilRice). Filled circles show yields for farmers’ fertilizer practice (FFP) whereas open circles refer to yields measured in unfertilized plots established in farmers’ fields.

While the table and accompanying text do not provide comprehensive data, the graph illustrates the comparison between predicted and measured rice yields across different domains.

Considering an average contribution of 28-51 kg N ha\(^{-1}\) per crop through biological N fixation [9], N input from BNF was estimated at 30±5 kg N ha\(^{-1}\). The starting year of all simulations was 1995. Model input data (mean, standard deviation, frequency distribution model) for indigenous nutrient supply, current fertilizer use, RE of applied nutrients, and nutrient concentrations in straw were derived from recent on-farm studies in five irrigated rice domains in Asia (Tab. 1) and long-term experiments conducted at 11 sites in five countries [6,18-20].

The five on-farm research sites in India, Indonesia, Vietnam, Thailand, and the Philippines represent a wide range of environmental conditions (climate, yield potential, seasonal differences) and Entisols, Inceptisols, Vertisols, Alfisols and Ultisols as soil types. Considering their geographic location in some of the most important large irrigated rice areas of Asia, they are probably directly representative for at least 1-2 million ha of land. Some countries with high fertilizer use (Korea, China, Japan, Taiwan) are not represented in this data set, but we assume that this is balanced by others with lower fertilizer use (Bangladesh, parts of India, Laos, Nepal, Myanmar).

Model validation for these five domains was done using (1) generic functions describing the relationship between nutrient uptake, (2) measured INS for each farm, (3) estimated values of IPS and IKS for each farm (from nutrient uptake in farmers’ fertilizer plots, assuming values of \(\text{RE}_P = 0.2\) and \(\text{RE}_K = 0.4\)), (4) measured actual fertilizer use in each farm, (5) measured RF\(_N\) in each farm (based on difference in N uptake between farmers’ fertilizer plot and +PK plots), and (6) generic estimates of RF\(_P\) (0.2±0.05) and RF\(_K\) (0.4±0.1) for all sites. Results showed good agreement between the average predicted and measured grain yields (Fig. 3). The average grain yield achieved by these farmers (5 t ha\(^{-1}\)) was equal to the current average yield of irrigated rice in Asia.
The on-farm data were collected during 1994-1996 (Tab. 1) using a standardized methodology and included both biophysical and socioeconomic information. They are probably the best available set of farm-level data. Considering also the geographic characteristics and the good agreement between model prediction and measured yields we assume that the frequency distributions defined for the model input data in the starting year of all simulations (1995) are representative for the whole irrigated rice area in Asia.

Scenario 1: Increase in NPK consumption by 1.5% per year

In the first scenario, we assumed that fertilizer consumption of N, P, and K would increase at the same rate as the required yield growth rate of 1.5% per year so that the N:P:K ratio will remain at current levels (Fig. 4, Tab. 3). We also assumed that the average recovery efficiencies of applied N, P, and K could increase at a rate of 1% per year leading to REN of 42% in 2025 (Tab. 3). Such a moderate increase in N use efficiency to levels that are common for current field experiments would be mainly achieved through better agronomic N management.

Nitrogen has little residual effect in irrigated rice systems and we assumed no change in INS (constant at 59 kg N ha⁻¹). Considering the current slightly positive P balance (+5 to 6 kg P ha⁻¹ per crop, Tab. 4) and the known residual effects of P, we assumed that IPS would increase at a rate of about 1% per year (from 12 kg P ha⁻¹ in 1995 to 16 kg P ha⁻¹ in 2025). The K balance would remain negative (starting at -24 kg K ha⁻¹ per crop in 1995, Tab. 4) and fertilizer K use would only increase from 18 kg ha⁻¹ in 1995 to 29 kg ha⁻¹ in 2025 (Tab. 3). Thus, we assumed a decline in IKS at a rate of 1% per year (1995: 78 kg ha⁻¹; 2025: 58 kg ha⁻¹).

Under this scenario, global annual fertilizer consumption in irrigated rice would rise from 8.4 to 13 x 10⁶ t N, 1.3 to 2.0 x 10⁶ t P, and 1.3 to 2.1 x 10⁶ t K within the next 30 years (Fig. 4). However, even though the average fertilizer rates used by rice farmers would increase to 177 kg N ha⁻¹, 27 kg P ha⁻¹, and 29 kg K ha⁻¹ by 2025, average grain yield would be below the required target yield to meet global rice demand beyond 2000 (Fig. 4, Tab. 3). In 2025, global rice production from irrigated rice systems would be about 130 x 10⁶ t less than the required production.

The main reason for this shortfall is an increasingly imbalanced nutrition, particularly increasing K deficiency. Despite the increase in fertilizer K use and yield increase from 5.1 to 6.2 t ha⁻¹, total K uptake was estimated to decrease from an average 82 kg ha⁻¹ in 1995 to 72 kg ha⁻¹ in 2025, suggesting increasing dilution of K in the plant [27]. Within the next 20 years the yield producing uptake efficiency of K (YPUEK = ratio potential yield-producing K supply/actual yield-producing K uptake; Janssen et al., 1990) would reach its theoretical maximum value of 0.99, whereas the yield producing uptake efficiency of N (YPUEN) would decline to below 0.90. Thus, although farmers would have to invest much into increasing REN to 42% in 2025, their average PFPN would decline from about 48 kg grain kg N⁻¹ in 1995 to 37 kg grain kg N⁻¹ in 2025.

Similarly, the PFPp of rather expensive P fertilizer would decline substantially (Tab. 3). Due to an increasing positive P balance P would tend to become accumulated in rice soils, whereas K depletion would continue (Tab. 4).

Simply increasing fertilizer rates parallel to expected yield growth is an unacceptable strategy that will not allow to achieve the gains in yield needed. It would also lead to inefficient use of renewable (N) and non-renewable (P) resources and a decline in soil fertility (IKS).
Figure 4. Predicted trends in rice production and total fertilizer consumption in irrigated rice systems of Asia. Symbols and error bars represent means ± 1 standard deviation of 1000 models runs. **Scenario 1: Increase in fertilizer use parallel to rice demand growth:**

- **Fertilizer use:** Increase in NPK fertilizer consumption at the same rate as increase in rice demand (1.5%/year). No change in the N:P:K ratio.
- **Fertilizer recovery efficiency:** Increase in recovery efficiencies of applied N, P, and K at a rate of 1%/year, mainly due to improved N management.
- **Indigenous nutrient supply:** No change in indigenous N supply. Increase in indigenous P supply (1%/year) due to positive P balance. Decline in indigenous K supply (1%/year) due to negative K balance.
Table 3. Scenarios for fertilizer use on irrigated riceland in Asia during 1995-2025. Estimates of average rice yield, fertilizer use and partial factor productivity of applied nutrients. All values shown are means of 1000 model iterations. All nutrient data are given on elemental basis.

<table>
<thead>
<tr>
<th></th>
<th>1995</th>
<th>2005</th>
<th>2015</th>
<th>2025</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Predicted rice production</strong></td>
<td>10^6 t/yr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production required to meet demand</td>
<td>375</td>
<td>435</td>
<td>505</td>
<td>586</td>
</tr>
<tr>
<td>Scenario 1</td>
<td>377</td>
<td>405</td>
<td>431</td>
<td>455</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>377</td>
<td>427</td>
<td>495</td>
<td>585</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>377</td>
<td>423</td>
<td>484</td>
<td>564</td>
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<tr>
<td><strong>Predicted rice yield</strong></td>
<td>t/ha/crop</td>
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<tr>
<td>Predicted potential yield</td>
<td>8.1</td>
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<td>9.9</td>
<td>10.9</td>
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<tr>
<td>Yield required to meet demand</td>
<td>5.1</td>
<td>5.9</td>
<td>6.8</td>
<td>7.9</td>
</tr>
<tr>
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<td>5.8</td>
<td>6.2</td>
</tr>
<tr>
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<td>6.7</td>
<td>7.9</td>
</tr>
<tr>
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<td>6.5</td>
<td>7.6</td>
</tr>
<tr>
<td><strong>Fertilizer N rate</strong></td>
<td>kg/ha/crop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario 1</td>
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<td>131</td>
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<td>177</td>
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<tr>
<td>Scenario 3</td>
<td>113</td>
<td>138</td>
<td>168</td>
<td>205</td>
</tr>
<tr>
<td><strong>Fertilizer P rate</strong></td>
<td>kg/ha/crop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>kg/ha/crop</td>
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<td><strong>Recovery efficiency of applied N</strong></td>
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<td><strong>Partial factor productivity of applied N</strong></td>
<td>kg grain/kg N</td>
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<td><strong>Partial factor productivity of applied K</strong></td>
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Table 4. Scenarios for fertilizer use on irrigated riceland in Asia during 1995-2025. Estimates of the average nutrient balance. All values shown are means of 1000 model iterations. All nutrient data are given on elemental basis.

<table>
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**Scenario 2: Balanced nutrition with high nutrient use efficiency**

In the second scenario, we estimated the fertilizer requirements for the nutritional optimum (maximum yield producing uptake efficiencies of all three nutrients) under the constraint that we should achieve the yield target (match rice demand) and also have high RE\(_N\), RE\(_P\) and RE\(_K\).

We assumed that the average RE\(_N\) would increase by 2% per year, leading to RE\(_N\) of 56% in 2025, almost double the current RE\(_N\) in most farmers’ fields (Tab. 3). Such an increase in N use would be mainly achieved through site-specific N management taking account into account the variation in INS and better congruence between supply and plant demand. Most likely, this would also lead to improvement of RE\(_P\) (growth rate 1%) and RE\(_K\) (growth rate 1.5%). Other assumptions were that INS and IKS would not change significantly whereas IPS would increase at a rate of about 1%.

Results showed that to achieve average yields equivalent to those needed to meet rice demand, fertilizer consumption of N and P can grow parallel to rice demand (1.5 % per year), but K consumption would need to grow at a rate of 6%. In 2025, farmers could get average yields of almost 8 t ha\(^{-1}\) by applying 177 kg N ha\(^{-1}\), 27 kg P ha\(^{-1}\), and 104 kg K ha\(^{-1}\) (Tab. 3). Compared to current levels, global annual fertilizer consumption in irrigated rice would need to increase by about 55% for N and P, but almost 600% for K (about 7.7 ± 5.8 x 10\(^6\) t in 2025, Fig. 5).

Associated with this would be maintenance of PFP\(_N\) and PFP\(_P\) at current levels. Yield producing uptake efficiencies of all three nutrients would remain in the range of 0.95-0.97. The P balance would remain almost unchanged, whereas we would be able to reverse the negative K balance within the next 30 years (Tab. 4). The nonlinear increase in K demand seen in Figure 5 is somewhat unrealistic and, given the trends towards positive K balance beyond 2010, a deceleration of the K use growth rate may be sufficient.
Scenario 2: Balanced nutrition in combination with high nutrient use efficiency:

- **Fertilizer use:** increase in fertilizer N and P use parallel to the required yield growth rate (1.5%/year). High rate of increase in fertilizer K consumption (6%/year). Decreasing N:K ratio.
- **Fertilizer recovery efficiency:** Increase in recovery efficiencies of applied N at a rate of 2%/year through site-specific nutrient management. Increase in recovery efficiency of P and K at a rate of 1-1.5%/year.
- **Indigenous nutrient supply:** No change in indigenous N and K supply. Increase in indigenous P supply (1%/yr) due to positive P balance.

Scenario 2 suggests that (1) the future yield increases can be achieved with moderate increase in N and P fertilizer use, which will also have less negative effects on the environment, (2) policy decisions are needed that would allow 2- and 5-fold increase in K use within the next 12 and 30 years, respectively, and (3) irrespective of increases in total fertilizer use, much attention has to be given to improving nutrient use efficiency, particularly that of N.
**Scenario 3: High N consumption**

The tremendous increase in K consumption proposed in scenario 2 will be difficult to achieve. Moreover, world P reserves are limited and the positive P balance simulated in scenario 2 (+6 to 8 kg P ha\(^{-1}\) per crop) indicates that a reduction in the growth rate of P might be a sustainable option. Therefore, we tested the hypothesis that rice production targets could also be achieved by applying more N at the cost of applying less P and K.

Settings for scenario 3 were: (1) increase in fertilizer N by 2% per year (above rice demand growth rate), (2) increase in fertilizer P by 1% per year (below rice demand growth rate), (3) increase in fertilizer K by 5% per year, and (4) increase in IPS by only 0.5% per year. Recovery efficiencies were the same as in scenario 2.

Under this scenario, N consumption would average 205 ± 54 kg ha\(^{-1}\) in 2025 (about 15 ± 4 x 10\(^6\) t compared to 8.4 ± 2.3 x 10\(^6\) t in 1995, Tab. 3, Fig. 6). Phosphorus consumption would only rise from 1.3 to 1.8 x 10\(^6\) t, K consumption from 1.3 to 5.8 x 10\(^6\) t (Fig. 6). At least during the next 10 years, predicted rice production would be equivalent to demand (Fig. 6). Thereafter, the simulation analysis suggests yields and production somewhat below required levels, although still within the range of standard deviations.

As in scenario 1, PFP\(_N\) would substantially decline to about 39 kg grain kg N\(^{-1}\) (Tab. 3). The yield-producing uptake efficiencies of P and K would remain high (0.96-0.97), whereas YPUEN would be suboptimal (0.92). It would take about 20 years to neutralize the average K balance so that some further decline in IKS may be expected (Tab. 4). The P balance would remain at current levels.

It seems to be possible to achieve the future yield gains with a focus on higher N rates, but at the cost of lower PFP\(_N\). Moreover, even in this case a more than 4-fold increase in the K consumption will be required during the next 30 years.

**Comments**

Only three scenarios were presented and, due to the uncertainties associated with many input parameters, model outputs were quite variable. The model itself requires improvements. A more quantitative link between net nutrient balance and net change in INS, IPS, and IKS as well as economic optimization and simulation need to be incorporated. The model accounts for increases in biological yield potential, but breakthroughs in biotechnology and breeding might also allow increase in the internal nutrient use efficiency (grain yield per unit nutrient taken up).

Our simulations are rather conservative and the actual fertilizer requirements may be in the upper half of the standard deviation bands shown. For example, we always assumed no change in INS, but considering the trends observed in various long-term experiments, it is more likely that INS might decline [4]. This would increase the demand for fertilizer N. We used rather optimistic estimates of crop residues recycled, whereas the actual trends suggest a decline in use of straw so that the decline in IKS and the fertilizer K requirements may be larger than predicted.
The trends predicted may have a slightly different form, depending on the actual changes in growth rates of population and rice demand. We used a constant growth rate of rice demand (1.5%) for the entire simulation period. It is more likely that the population growth rate in Asia declines from 1.8% in 1995 to 1.1% in 2025 [25], and, along with this, the growth rate in rice demand may also decelerate.

**Figure 6.** Predicted trends in rice production and total fertilizer consumption in irrigated rice systems of Asia. Symbols and error bars represent means ± 1 standard deviation of 1000 models runs. *Scenario 3: Focus on increase in N use in combination with high nutrient use efficiency.*

- **Fertilizer use:** The rate of increase in fertilizer N (2%/year) is greater than the required yield growth rate (1.5%/year). Increase in P and K and fertilizer consumption at rates of 1%/year and 5%/year, respectively. Decreasing N:K ratio.

- **Fertilizer recovery efficiency:** Increase in recovery efficiencies of applied N at a rate of 2%/yr; increase in recovery efficiency of P and K at a rate of 1-1.5%/yr due to improved N management.

- **Indigenous nutrient supply:** No change in indigenous N and K supply. Only slight increase in indigenous P supply (0.5%/yr) due to slightly positive P balance.
4. Site-specific nutrient management

*Precision farming in small rice fields?*

It has become clear that large variation in indigenous nutrient supply is one of the most sensitive factors determining the efficiency of nutrients at the farm level. Our observations suggest that the bulk of this variation is variation among individual fields or, at least, among different farms rather than variation within rice fields. Presumably, socioeconomic differences among farmers have driven their ability to manage soil fertility during the past 30 years of rapid intensification rather than differences in native soil characteristics [36]. The current situation presents serious biophysical limitations to the usefulness of blanket recommendations for fertilizer use, but how can we achieve the tremendous improvements in nutrient management required at the farm level?

The concept of changing spatial and temporal scales of land resource management forms the core of site-specific crop management (SSCM) or precision farming gaining much popularity in developed countries. A SSCM system is based on matching resource application and agronomic practices with soil attributes and crop requirements as they vary across a site. By definition, SSCM practiced in some developed countries focuses on managing spatial and temporal variability within a single and usually large field. In a broader sense, however, SSCM should be viewed as a farming philosophy and a system to implement that philosophy, aiming at replacing prophylactic application of agricultural inputs by demand-based application [45]. Because of this, SSCM is also relevant to rice farming in Asia.

Implementing SSCM in the intensive rice system with (whole) small fields as the basic production units is feasible. Conceptually, adjusting tillage, sowing, fertilizer or pesticide rates separately for many small fields or farms (< 1 ha .... <10 ha) in an Asian domain is similar to adjustment according to soil variation within a large field (>10 ha .... >100 ha) found in North America. An “Asian variant” of SSCM in the intensive rice system would probably include operations at different spatial scales and with very different information demand. We argue that SSCM in Asia can be built around much less sophisticated technology than implementing SSCM in large fields, where GPS, mapping systems, computer technology, and VRT are minimum requirements.

Integrated pest and nutrient management are probably priority issues to get SSCM in irrigated rice started, but their concepts and information requirements differ. The IPM concept focuses on improving farmers’ knowledge so that they develop a better “feel” for the real pest situation in a specific field. Training plays a vital role for IPM and field-specific decisions may be based on both qualitative and quantitative information. In any case, most of this information is “visible” or easily obtainable. Precision nutrient management in rice, on the other hand, requires more quantitative information such as soil tests, leaf N monitoring, and accurate measurements of yields and externally provided nutrient inputs [17]. Therefore, during the next two decades, it will probably focus on managing between-field spatial variability, temporal variability in plant N status occurring within one growing season, and temporal variation in soil N, P and K status from season to season. Other SSCM measures in irrigated rice may include selection of cropping systems, crop varieties, or sowing dates according to climatic characteristics and soil properties; or field-specific soil tillage and irrigation based on knowledge of soil texture, soil morphology, and rooting depth.
Framework for site-specific nutrient management in irrigated rice systems

As a major component of SSCM in irrigated rice, we have recently proposed a new framework for site-specific nutrient management (SSNM). A key assumption in this is that significant increases in nutrient use efficiency require quantitative information about indigenous nutrient supply and turnover of externally applied nutrients on a field- or farm-specific basis [17].

An iterative research and extension approach to achieve this capability is illustrated in Figure 7 through a succession of rice crops. This approach provides a Nutrient Decision Support System (NuDSS) that integrates the various data inputs and provides the user with more cost-effective fertilizer recommendations. Modules similar to the simulation model used in our global scenario analyses will allow the farmer to plan his nutrient management over short, medium and long terms. Fertilizer recommendation follows the approach suggested in the QUEFTS model [27].

The following steps are required: (i) estimation of INS, IPS, and IKS and diagnosis of other nutritional disorders in year one, (ii) recommendation for NPK use and alleviation of other nutritional problems based on the NuDSS, (iii) optimization of timing and amount of applied N, (iv) estimation of actual grain yield, stubble (straw) returned to the field, and actual amount of fertilizer used. The latter is then used to predict the change in indigenous supply during the first crop cycle (Fig. 7). The predicted INS, IPS and IKS values are then used to develop fertilizer recommendations for the second crop cycle, and this procedure is followed for a succession of crops.

Within each cropping season, timing and splitting of N applications are crucial decisions determining synchrony of N supply and crop N demand. This can be based on (1) 3-5 split applications following agronomic principles, (2) regular monitoring of plant N status up to flowering stage using tools such as the chlorophyll meter (perhaps done by a village technician) or green leaf color charts [42,50], or (3) prediction of N split applications using simplified simulation models such as Manage-N [51,52]. So far, many of these approaches have been developed independently and their performance has not been compared widely. Future research has to clarify where which method is most suited.

The entire iterative process may include several years during which soil testing or other methods for estimating indigenous nutrient supply would not be required, but plant N monitoring within each cropping season is recommended. The inputs needed for each crop (grain yield, stubble left, fertilizer use of previous crop) can be easily obtained from the farmers, provided they keep good records. We speculate the process may require about 10 rice cropping periods and could evolve to account for changes in crop management practices such as establishment method, tillage, pest control, and water management which would affect yield levels and soil nutrient supply.
**Practical implementation issues**

The scope for using qualitative soil information is probably limited. Most irrigated riceland is found on large floodplains or coastal plains. Due to lack of easily visible soil-landscape relationships good relationships between general soil properties and dynamic soil properties related to nutrient supply [36], quantitative measures of INS, IPS and IKS are required. We currently test various methods for obtaining routine estimates of indigenous nutrient supplies, including grain yield measured in nutrient omission plots [6,17,39], classical soil tests, and in situ soil testing using ion exchange resin capsules [15,22].

The high cropping intensity in tropical rice and the huge number of single management units (field, parcel) that must be handled may set limits to implementing SSNM. Two or more crops are grown per year and the total number of observations and decisions to be made would be large. Currently, it seems difficult to conduct certain SSNM measures such as soil testing or regular plant monitoring on a field-specific basis or, if done so, their costs per hectare may become too high. In most regions, the demand for service would easily exceed current facilities.

Due to differences in climate, yield potential, and nutrient use efficiency nutrient management and information demand for wet and dry season rice differ. Therefore, season-specific calibration data sets for the major relationships between potential nutrient supply, nutrient uptake, and grain yield have to be generated first for the major rice-growing regions.
Managing the organic phase in a SSNM approach remains uncertain. Organic matter quality seems to have more influence on soil N supply than organic matter content [6]. Decomposition and humus formation pathways are sensitive to the timing of incorporating organic materials and we need better means of accounting for this in a nutrient balance-oriented SSNM.

Availability of accurate but simple and user-friendly decision aids will determine adoption of a knowledge-intensive technology such as SSNM. Farmers themselves will need better means for accurate measurement of nutrient inputs and outputs (yield) on a per field basis. This also includes improvement of their recording practices toward establishing long-term farm databases.

In many countries of Asia, facilities for more sophisticated farmer support need to be built-up. Included among these are: soil testing laboratories and a soil testing program, perhaps with the involvement of the private sector, fertilizer recommendation services, objective information about new fertilizer products, use of mass media (radio, TV, newspapers) for extension of new technologies.

There are probably more unique problems but they should not discourage us. The important point is that many of the approaches and tools needed for SSNM in irrigated ricelands are already well known or in an advanced development stage. Too often they have been applied independently or technologies proposed by researchers have not found their way into the routine farm operations.

**The RTDP Mega Project**

The Mega Project on *Reversing Trends in Declining Productivity in Intensive, Irrigated Rice Systems* (RTDP) started in 1994 as a collaboration between IRRI, the Philippine Rice Research Institute, the Pathum Thani Rice Research Center (Thailand), the Cuu Long Delta Rice Research Institute (Vietnam), the Tamil Nadu Rice Research Institute (TNRRI), and the Research Institute for Rice (Indonesia). This project is a unique combination of biophysical and socioeconomic on-farm and on-station research following uniform methodologies. At each site, a long-term fertility experiment was established and on-farm experiments are being conducted in 25-30 farmers’ fields within a radius of 10 to 20 km around the station to capture variation in soils and socioeconomic farm status.

Research during phase I (1994-1996) focused on quantitative monitoring of soil quality and current farmers’ management practices to assess variation and trends in total and partial factor productivities of all major farm inputs. Particular emphasis was given to improving our understanding of INS and of the factors determining temporal and spatial variation in N use efficiency [39].

Phase 2 (1997-2000) continues this monitoring to answer the question whether there are trends of declining productivity or yields at the farm level. We will test the SSNM approach proposed over a period of 4 years in about 220 farmers’ fields at eight sites in six countries. Three new sites with rice-wheat (North India), hybrid rice (Zhejiang, China) and rice-rice-maize systems (Red River Delta, Vietnam) were added. Other activities in this project include fundamental research on soil organic matter quality and microbial processes involved in nutrient cycling.
This rigorous field testing will allow to generate large sets of input data needed for further development of the whole SSNM concept. At the same time, we practice field management itself and hope to be able to use this experience for developing a validated technology that will be ready for broad-scale use. During the final project stage, research will focus on how such SSNM can be linked with integrated pest management by taking into account the interactions between nutrients and pests.

5. Conclusions

Currently, nutrient use efficiency in most farmers’ fields is well below achievable levels. Continuing such practice will not allow to produce enough rice in Asia, even if fertilizer consumption becomes very high. Our simulations indicate how fertilizer use and the quality of nutrient management will have to change. Without simultaneous improvements of the N:P:K ratio and of the agronomic and recovery efficiencies of N, P and K it will not be possible to keep pace with the rice demand beyond 2000, despite the progress that will be made through breeding.

We hope to be able to reverse many of the negative effects of rice farming on the soil resource base that have occurred during the past 30 years by a more resource-oriented approach such as SSNM. This will require the combined efforts of public and private sector. What should the fertilizer industry contribute to research and improvement of nutrient use at the farm level?

Many fundamental research questions remain unanswered [9,21]. Given the current constraints due to declining public sector funding for agricultural research, new models for a partnership between public and private sector institutions at both national and international levels are required. Specifically, more strategic research linked with farmer participatory research (as the work done in the RTDP project) should be conducted. Generating the knowledge needed for practical farm management has to include primary research in farmers’ fields beyond demonstration trials. This is more complicated, associated with more risk, and often more expensive, but it is the only way for capturing the vast variety of biophysical and socioeconomic conditions occurring. If our primary databases are limited, our recommendations given to farmers will be limited as well. Such research requires long-term commitments, also from the side of the fertilizer industry.

Currently, private sector activities focus on product development and raising public awareness through mass media, workshops and fertilizer demonstration trials. There is no doubt that these activities are extremely useful and need to continue. In most rice-growing countries, there is, however, very little direct support given to farmers. Considering the limitations of many government-based extension systems, we think that the industry has to play a major role in establishing better customer support service that really reaches the small rice farmer in Asia.

The next 30 years will be a period of major changes occurring in the rice systems of Asia. It will probably mark the introduction and adoption of a new generation of modern rice varieties with a yield potential of 13 t ha\(^{-1}\) or even more. Parallel to this, we hope to see a major change in the farming philosophy toward farming by soil and crop needs. Both new rice varieties and improved nutrient management have the potential to create another Green Revolution in Asia.
References

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FERTILISER USE IN RAINFED UPLAND CONDITIONS
IN TROPICAL ASIA

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Abstract

Fertiliser consumption and food grains production in the Asia have increased considerably during the last 3 decades. However, in tropical Asia, crop yields in general are far too low. The population in tropical Asia is growing at a fast rate resulting in higher need of food, fibre, fodder and fuel. The region houses a large number of the poor who suffer from the serious problem of food shortage and mal-nutrition. There is, therefore, an urgent need to increase food grain production in the region. Among the various means available, proper use of fertilisers can help in achieving the goal. The paper discusses the fertiliser use in rainfed upland conditions of the tropical Asian region. The constraints to increased use of fertilisers are listed.

Asia has 1264.7 million hectares of agricultural land out of a global total of 4846.1 m. ha. Likewise, the arable land and land under perennial crops in the Asia cover 472.5 m. ha out of a total of 1450.8 m. ha in the world. About 12.6% of the agricultural area in the Asia is irrigated and that is much higher than in other continents. Therefore, the percentage of rainfed area to agricultural area in the Asia is 87.4, whereas this percentage is 98.8, 95.3, 98.4 and 92.3 in Africa, North & Central America, South America, respectively. The fertiliser consumption in 1995 in Asia is estimated as 61.1 million tonne nutrient (n.m.t.) accounting for about 50% of the world total. There has been remarkable growth in cereal production in the Asia from 211.2 m. t. in 1961 to 929 m. t. in 1995, an increase of 340%. The use of high yielding varieties of crops requiring high levels of inputs coupled with irrigation and other modern agro-technologies have been responsible for increased crop production in the Asia.

The rainfed lands are not only thirsty but they are hungry as well. Though fertiliser is the key to increasing land productivity, its use in dry land crops is highly restricted. Further, the productivity of un-irrigated crops is low essentially due to abnormal and unpredictable availability of water during crop growth and low fertility of these soils. The fertiliser use in such soils is far below the recommended or satisfactory levels due to risk attached with rainfed farming. The nutrient imbalances are also more wide-spread in dry land regions. The productivity of rainfed crops can be improved by increasing input of fertilisers, manures and adoption of practices of removing deficiencies of nutrients. This paper deals with land resource including farm size, crop yields and production, nutrient deficiencies, nutrients and balanced use, nutrients mining, population and poverty, responses to applied nutrients, integrated plant nutrient supply and sustainability in food production under rain-fed upland conditions in the tropical Asia.

Land Resources

Of a total of 13381.6 m. ha of land area in the world, Asia accounts for 2757.6 m. ha, amounting to about 20.6%. Comparing the areas of potentially arable land and percentage of land being cropped in the Asia and other regions of the world (Table 1), it is seen that land is much more intensively used in the Asia than in Africa or South America. The distribution of total geographical area, agricultural area, arable land and land under permanent crops in selected countries of the tropical Asia are shown in Table 2.

Table 1: Agricultural, arable and rainfed area, 1994 ('000 hectares)

1 Paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997
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<td>92.3</td>
</tr>
<tr>
<td>Oceania</td>
<td>480812</td>
<td>52210</td>
<td>2428</td>
<td>99.5</td>
</tr>
<tr>
<td>World</td>
<td>4846095</td>
<td>1450838</td>
<td>249549</td>
<td>94.9</td>
</tr>
</tbody>
</table>

Source: FAO Production Year Book Vol. 49, 1995, FAO, Rome

### Table 2: Land use and irrigation in selected countries of tropical Asia, 1994 ('000 hectares)

<table>
<thead>
<tr>
<th>Country</th>
<th>Geographical area</th>
<th>Arable land</th>
<th>Land under perennial crops</th>
<th>Total agric. area</th>
<th>Irrigated area</th>
<th>Rainfed area to total agr. area (%)</th>
<th>Average size of agric. holding (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangladesh</td>
<td>14400</td>
<td>9450</td>
<td>244</td>
<td>10294</td>
<td>3288</td>
<td>68.1</td>
<td>1.3</td>
</tr>
<tr>
<td>Myanmar</td>
<td>67658</td>
<td>9534</td>
<td>542</td>
<td>10421</td>
<td>1336</td>
<td>87.2</td>
<td>2.4</td>
</tr>
<tr>
<td>India</td>
<td>328759</td>
<td>166100</td>
<td>3550</td>
<td>181050</td>
<td>48000</td>
<td>73.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Indonesia</td>
<td>190457</td>
<td>17126</td>
<td>13045</td>
<td>41971</td>
<td>4581</td>
<td>89.1</td>
<td>6.0</td>
</tr>
<tr>
<td>Malaysia</td>
<td>32975</td>
<td>1822</td>
<td>5782</td>
<td>7885</td>
<td>346</td>
<td>95.7</td>
<td></td>
</tr>
<tr>
<td>Nepal</td>
<td>14080</td>
<td>2325</td>
<td>29</td>
<td>4354</td>
<td>850</td>
<td>80.5</td>
<td>0.9</td>
</tr>
<tr>
<td>Pakistan</td>
<td>79610</td>
<td>20800</td>
<td>550</td>
<td>26350</td>
<td>17150</td>
<td>34.9</td>
<td>3.8</td>
</tr>
<tr>
<td>Philippines</td>
<td>30000</td>
<td>5520</td>
<td>3670</td>
<td>10470</td>
<td>1580</td>
<td>84.9</td>
<td>2.9</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>6561</td>
<td>908</td>
<td>975</td>
<td>2323</td>
<td>550</td>
<td>76.3</td>
<td>1.1</td>
</tr>
<tr>
<td>Thailand</td>
<td>51312</td>
<td>17600</td>
<td>3200</td>
<td>21600</td>
<td>4800</td>
<td>77.8</td>
<td>3.6</td>
</tr>
<tr>
<td>Vietnam</td>
<td>33169</td>
<td>5900</td>
<td>1085</td>
<td>7313</td>
<td>1860</td>
<td>74.6</td>
<td></td>
</tr>
</tbody>
</table>


The continent-wise break-up for suitability of rainfed agricultural potential land (Table 3) indicates that only 21.7% of total rainfed agricultural potential area in the Asia is suitable and the rest is marginal and unsuitable. The extent of such suitable lands in Africa, South America and Central America is 27.4, 46.3, 10.9%, respectively. The share of rainfed area to total agricultural area in selected countries of the tropical Asia (Table 2) varies greatly ranging from as low as 68.1% in Bangladesh to as high as 95.7% in Malaysia.

### Table 3: Continent-wise rainfed agricultural potential (m.ha)

<table>
<thead>
<tr>
<th>Country</th>
<th>Suitable</th>
<th>Marginal</th>
<th>Unsuitable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>789</td>
<td>231</td>
<td>1858</td>
</tr>
<tr>
<td>S. America</td>
<td>819</td>
<td>147</td>
<td>804</td>
</tr>
<tr>
<td>Central America</td>
<td>24</td>
<td>15</td>
<td>182</td>
</tr>
<tr>
<td>S.E. Asia</td>
<td>294</td>
<td>226</td>
<td>378</td>
</tr>
<tr>
<td>S.W. Asia</td>
<td>48</td>
<td>16</td>
<td>613</td>
</tr>
</tbody>
</table>

Source: FAO Land Food and People (1984). Economic and Social Development (Series 30)

In India, 56% of total land is suitable for crop production. Here, out of 185.5 m. ha of gross sown area, 119.3 m. ha are rainfed (64.3%). In distribution of area according to annual rainfall, only 8%
of the area receives assured rainfall (more than 2000 mm.), 30% receives annual rainfall of less than 750 mm. categorised as dry and the rest 62% between 750-2000 mm., grouped as medium. Indian agriculture is predominantly rain-dependent. The extent of un-irrigated area under different crops as percent of the net sown area in India is shown in Table 4.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Cropped area (m.ha)</th>
<th>Rainfed (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>42</td>
<td>54</td>
</tr>
<tr>
<td>Wheat</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td>Sorghum</td>
<td>13</td>
<td>94</td>
</tr>
<tr>
<td>Pearl millet</td>
<td>10</td>
<td>94</td>
</tr>
<tr>
<td>Maize</td>
<td>6</td>
<td>78</td>
</tr>
<tr>
<td>Pulses</td>
<td>22</td>
<td>89</td>
</tr>
<tr>
<td>Oilseeds</td>
<td>27</td>
<td>76</td>
</tr>
<tr>
<td>Cotton</td>
<td>7</td>
<td>67</td>
</tr>
<tr>
<td>All crops</td>
<td>141</td>
<td>66</td>
</tr>
</tbody>
</table>

Source: Directorate of Economics & Statistics. Ministry of Agriculture, Govt. of India

Farm Size

Most of the farms in the tropical Asia are small producing barely enough food to sustain the occupying farming families. The available land per capita in the Asia was 0.24 ha in early sixties which has reduced to 0.137 ha in early nineties and is expected to fall further to 0.084 ha by year 2010. The average size of agricultural holdings in selected countries in the tropical Asia is shown in Table 2.

In 1983, almost half of Indonesia’s farm household had a land holding of less than 0.5 ha and only about 6% of farm households possessed more than 3.0 ha. Over 63% of the farms households with less than 0.5 ha resided in the densely populated island of Java which has 60% of the country’s inhabitants and is one of the densest rural populations in the world. Indonesia’s Basic Agrarian Law imposes a limit in size of agricultural land holdings with a minimum and maximum of 2 and 20 ha, respectively.

The average farm size in Thailand is about 4.5 ha. The farm size in Bangladesh is expected to be diminished to less than 0.4 ha by year 2000. In India, farm size is less than 0.4 ha in over 50% of the farms. Here, the limit of holdings is 21.85 ha for rainfed and 4.05-10.93 ha for irrigated areas. The available cultivable land (including forest trees) per capita in India was 0.48 ha in 1951 and this will decrease to 0.15 ha in year 2000.

The predominance of small farm size influences the manner in which fertilisers are applied at the farm, marketed and distributed. The farmers are poor and use far low levels of fertiliser. They have to go a long distance to buy fertilisers. There is even difficulty in transfer of fertilisers from retailer to farms which is by means of bicycle, human or animal drawn conveyances or small trucks.
Crop Yield and Production

The crop yields obtained in the Asia are far below than in other continents except in Africa and South America where the yields are lower than even in the Asia (Table 5). The crop yields in different countries of the tropical Asia are shown in Table 6. The yields show large variations from one country to the next. Indonesia, Malaysia and Vietnam harvest higher yields than other countries in the region.

Table 5: Yield of crops in different continents, 1995 (kg/ha)

<table>
<thead>
<tr>
<th>Continent</th>
<th>Paddy</th>
<th>Wheat</th>
<th>Maize</th>
<th>Cereals</th>
<th>Pulses</th>
<th>Soybean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>2093</td>
<td>1675</td>
<td>1402</td>
<td>1110</td>
<td>574</td>
<td>1256</td>
</tr>
<tr>
<td>N&amp;C America</td>
<td>5386</td>
<td>2405</td>
<td>5781</td>
<td>3909</td>
<td>1138</td>
<td>2358</td>
</tr>
<tr>
<td>South America</td>
<td>3007</td>
<td>1949</td>
<td>2771</td>
<td>2606</td>
<td>636</td>
<td>2166</td>
</tr>
<tr>
<td>Asia</td>
<td>3776</td>
<td>2587</td>
<td>3634</td>
<td>3026</td>
<td>707</td>
<td>1350</td>
</tr>
<tr>
<td>Europe</td>
<td>5628</td>
<td>4689</td>
<td>5130</td>
<td>4312</td>
<td>2440</td>
<td>2618</td>
</tr>
<tr>
<td>Oceania</td>
<td>8597</td>
<td>1706</td>
<td>5612</td>
<td>1809</td>
<td>1183</td>
<td>2000</td>
</tr>
<tr>
<td>World</td>
<td>3689</td>
<td>2453</td>
<td>3776</td>
<td>2729</td>
<td>796</td>
<td>2022</td>
</tr>
</tbody>
</table>

Source: FAO Production Year Book 49, 1995, FAO, Rome

Table 6: Yield of different crops in selected countries in tropical Asia (kg/hectare), 1995

<table>
<thead>
<tr>
<th>Country</th>
<th>Paddy</th>
<th>Wheat</th>
<th>Maize</th>
<th>Pulses (Total)</th>
<th>Soybean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangladesh</td>
<td>2478</td>
<td>1846</td>
<td>903</td>
<td>750</td>
<td>-</td>
</tr>
<tr>
<td>India</td>
<td>2879</td>
<td>2482</td>
<td>1633</td>
<td>595</td>
<td>920</td>
</tr>
<tr>
<td>Indonesia</td>
<td>4343</td>
<td>-</td>
<td>2255</td>
<td>892</td>
<td>1124</td>
</tr>
<tr>
<td>Malaysia</td>
<td>3122</td>
<td>-</td>
<td>1792</td>
<td>-</td>
<td>333</td>
</tr>
<tr>
<td>Myanmar</td>
<td>3106</td>
<td>1374</td>
<td>1663</td>
<td>659</td>
<td>833</td>
</tr>
<tr>
<td>Nepal</td>
<td>2124</td>
<td>1508</td>
<td>1688</td>
<td>609</td>
<td>654</td>
</tr>
<tr>
<td>Pakistan</td>
<td>2733</td>
<td>2081</td>
<td>1428</td>
<td>513</td>
<td>556</td>
</tr>
<tr>
<td>Philippines</td>
<td>2654</td>
<td>-</td>
<td>1540</td>
<td>786</td>
<td>1332</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>2993</td>
<td>-</td>
<td>1003</td>
<td>781</td>
<td>1000</td>
</tr>
<tr>
<td>Thailand</td>
<td>2343</td>
<td>700</td>
<td>2807</td>
<td>811</td>
<td>1353</td>
</tr>
<tr>
<td>Vietnam</td>
<td>3636</td>
<td>-</td>
<td>2181</td>
<td>671</td>
<td>1038</td>
</tr>
<tr>
<td>World</td>
<td>3689</td>
<td>2453</td>
<td>3776</td>
<td>796</td>
<td>2022</td>
</tr>
</tbody>
</table>

Source: FAO Production Year Book, Vol. 49, 1995, FAO, Rome

In tropical Asia, amongst cereals, rice is the dominant crop. It covers 96.7, 41.8, 35.6, 27.4 and 23.5% of total agricultural area in Bangladesh, Thailand, Philippines, Indonesia and India, respectively. The wheat crop occupies 14.0% of agricultural area in India and 6.3% in Bangladesh. The area under cereals and pulses and their production in selected countries of the tropical Asia are shown in Table 7.
Table 7: Area and production of cereals and pulses in selected countries in tropical Asia, 1995

<table>
<thead>
<tr>
<th>Country</th>
<th>Area (000 ha)</th>
<th>Production (000 t)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cereals</td>
<td>Pulses</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>10699</td>
<td>727</td>
</tr>
<tr>
<td>India</td>
<td>100680</td>
<td>24925</td>
</tr>
<tr>
<td>Indonesia</td>
<td>15126</td>
<td>348</td>
</tr>
<tr>
<td>Malaysia</td>
<td>705</td>
<td>-</td>
</tr>
<tr>
<td>Nepal</td>
<td>3031</td>
<td>309</td>
</tr>
<tr>
<td>Pakistan</td>
<td>12187</td>
<td>1524</td>
</tr>
<tr>
<td>Philippines</td>
<td>6848</td>
<td>47</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>938</td>
<td>52</td>
</tr>
<tr>
<td>Thailand</td>
<td>10630</td>
<td>450</td>
</tr>
<tr>
<td>Vietnam</td>
<td>7154</td>
<td>321</td>
</tr>
</tbody>
</table>

Source: FAO Production Year Book 49, 1995, FAO, Rome

The yields of rainfed crops in India continue to be low (Table 8). This is ascribed to subnormal and unpredictable availability of water during crop growth, low inherent productivity of soils and low use of fertilisers. The productivity of rainfed crops varies in agro-ecoregions as well as in different locations in an agro-ecoregion. Agro-climatically, sub-humid regions suit well for rice but variation in rice productivity can be due to micro-climatic differences particularly with respect to soil properties.

Table 8: Yield of some rainfed crops in India 1990-91 (kg/ha)

<table>
<thead>
<tr>
<th>Crop</th>
<th>East</th>
<th>North</th>
<th>South</th>
<th>West</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>1097</td>
<td>2025</td>
<td>1750</td>
<td>1098</td>
</tr>
<tr>
<td>Wheat</td>
<td>1317</td>
<td>1914</td>
<td>371</td>
<td>829</td>
</tr>
<tr>
<td>Sorghum</td>
<td>-</td>
<td>143</td>
<td>714</td>
<td>653</td>
</tr>
<tr>
<td>Pearl millet</td>
<td>-</td>
<td>673</td>
<td>679</td>
<td>662</td>
</tr>
<tr>
<td>Maize</td>
<td>-</td>
<td>1304</td>
<td>2395</td>
<td>1402</td>
</tr>
<tr>
<td>Groundnut</td>
<td>-</td>
<td>547</td>
<td>833</td>
<td>740</td>
</tr>
<tr>
<td>Cotton (lint)</td>
<td>-</td>
<td>-</td>
<td>179</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: Directorate of Economics & Statistics, Ministry of Agriculture, Govt. of India, New Delhi

Table 9 shows the differences in productivity of rice in two similar agro-ecoregions representing sub-humid red loam soil in India (Das and Itnal, 1994).
Table 9: Productivity of rice (q ha\(^{-1}\)) in two similar agro-ecoregions in India

<table>
<thead>
<tr>
<th>Year</th>
<th>Ecoregion: Sub-humid with red loamy soils</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ranchi</td>
<td>Bhubaneswar</td>
</tr>
<tr>
<td>1</td>
<td>25.0</td>
<td>18.5</td>
</tr>
<tr>
<td>2</td>
<td>24.4</td>
<td>12.8</td>
</tr>
<tr>
<td>3</td>
<td>22.2</td>
<td>11.5</td>
</tr>
<tr>
<td>4</td>
<td>24.2</td>
<td>11.7</td>
</tr>
<tr>
<td>5</td>
<td>19.4</td>
<td>10.3</td>
</tr>
<tr>
<td>6</td>
<td>15.6</td>
<td>12.3</td>
</tr>
<tr>
<td>7</td>
<td>19.4</td>
<td>26.6</td>
</tr>
<tr>
<td>8</td>
<td>27.6</td>
<td>28.3</td>
</tr>
<tr>
<td>9</td>
<td>21.2</td>
<td>21.7</td>
</tr>
<tr>
<td>10</td>
<td>21.3</td>
<td>7.1</td>
</tr>
<tr>
<td>Mean</td>
<td>22.0</td>
<td>16.1</td>
</tr>
<tr>
<td>SD</td>
<td>3.3</td>
<td>6.9</td>
</tr>
</tbody>
</table>

*Source: Das and Itmal (1994)*

**Nutrient Deficiencies**

The rainfed lands are low in inherent fertility and show deficiencies of different nutrients. They are:

**Nitrogen:** Its deficiency is almost universal in rainfed soils and therefore its application becomes a necessity for growing satisfactory crops. Use of nitrogen (N) fertilisers alone has accentuated the removal of other nutrient leading to nutrient imbalances in many cases.

**Phosphorus:** Phosphorus (P) deficiency is next to N in importance. Since many of the rainfed agricultural soils in the Asia are low in total and available P, therefore the crop production is restricted by insufficient available soil P in many Asian countries. Ninety percent of soils in important agricultural areas of Vietnam are either very low or low in available P. Inadequate levels of available P are found in 80% of Pakistan crop land. Crop production is restricted by insufficient available soil P in many other tropical Asian countries including Philippines, Nepal and Sri Lanka. Ninety eight percent of soils in India are either low or medium in soil test P (Hasan, 1994) and its deficiency is often cited a limitation to high productivity.

**Potassium:** Potassium (K) deficiency is generally not as critical as that of N and P. However, due to intensive cultivation and multiple cropping with high yielding varieties of crops, its deficiency in soils is increasing. Potassium deficiency may be a problem in coarse textured soils or where K applications have been ignored continuously.

Potassium deficiency is being increasingly reported in many soils in Bangladesh and it is considered to be the third most serious nutrient deficiency following N and sulphur. Inadequate levels of available soil K restricts crop production in Indonesia and Philippines also. Crop responses to added K in Pakistan are not as wide spread as those to N and P. In India, generalised K status of some dry land areas show possibility of sub-optional K availability in 8 districts out of 144 districts (Tandon, 1993). The extent of N, P, K deficiencies in typical (predominantly sorghum growing) rain-fed districts in India is shown in Table 10.
Table 10: Extent (%) of NPK deficiency in some typical (predominantly sorghum growing) rainfed districts in India

<table>
<thead>
<tr>
<th>Nutrient status</th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>77</td>
<td>47</td>
<td>01</td>
</tr>
<tr>
<td>Medium</td>
<td>23</td>
<td>51</td>
<td>57</td>
</tr>
<tr>
<td>High</td>
<td>0</td>
<td>2</td>
<td>42</td>
</tr>
</tbody>
</table>


Sulphur: Sulphur (S) is now acknowledged to be Asia’s fourth major nutrient and its deficiency is on the increase in a number of countries in the tropical Asia. In Bangladesh, S deficiency is next to N in importance and occurs on up to 80% of the nation’s cropland. In India, S deficiency has been reported in the vast majority of un-irrigated soils and in the country as a whole, 25% of the districts are reported to be lacking S. Sulphur is of importance in different crops including high S requiring oilseeds and pulses which are essentially concentrated in rainfed regions (Biswas and Tewatia, 1991). The problem of S deficiency is wide-spread in Indonesia, Thailand and Vietnam.

Other nutrients: An assessment of deficiencies of nutrients other than N, P, K in soils of a number of countries in the tropical Asia is shown in Table 11.

Table 11. Deficiency of nutrients other than NPK in soils of some countries in tropical Asia

<table>
<thead>
<tr>
<th>Country</th>
<th>S</th>
<th>Mg</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>Cu</th>
<th>Mo</th>
<th>B</th>
<th>Cl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangladesh</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>India</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Indonesia</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4**</td>
<td>***</td>
</tr>
<tr>
<td>Malaysia</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4**</td>
<td>***</td>
</tr>
<tr>
<td>Pakistan</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Philippines</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2**</td>
</tr>
<tr>
<td>Thailand</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

Data Source: Dibb & Dev (1996)

Scale of occurrence of deficiency qualitative: 5= common, extensive; 4= common enough to be of concern; 3= localized, sometimes; 2= rare; 1= none reported

** very common in oil palm
*** chloride deficiency important for oil palm in Indonesia, Malaysia and for coconut in Philippines

Plant Nutrient Use

The fertiliser nutrients consumption in Asia has increased from 3.12 m. t. in 1961 to 61.1 m. t. in 1995, recording an increase of 1858%. The share of fertiliser consumption in the Asia was about 11% of the world’s consumption in 1961 and this has increased to 50% in 1995. The fertiliser nutrients consumption in selected countries of the tropical Asia are shown in Table 12. India is the world’s third largest fertiliser user, while in the tropical Asia, it is the largest user of fertiliser.

Table 12: NPK consumption, total and per ha of arable land & land under permanent crops and use ratio in some selected countries in tropical Asia, 1994-95
The nutrients use per unit of agricultural land in different countries of the tropical Asia varies greatly. It is 108.1 kg in Bangladesh, 79.9 in India and 65.5 kg in Philippines (Table 12).

In a survey in 4 villages in Andhra Pradesh (India), the change in crop-wise fertiliser use under rainfed conditions showed that after a span of 15 years, both N and P use increased in all the crops (Table 13). However, comparing with the recommended levels of nutrients for dry land crops (Table 14), the use is far low.

Table 13: Progress in crop-wise fertiliser use in rainfed crops in Andhra Pradesh in India (kg ha\(^{-1}\))

<table>
<thead>
<tr>
<th>Crop</th>
<th>1977-78</th>
<th>1991-92</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P(_2)O(_5)</td>
</tr>
<tr>
<td>Sorghum</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Castor</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Rice (kharif)</td>
<td>15</td>
<td>21</td>
</tr>
<tr>
<td>Rice (rabi)</td>
<td>14</td>
<td>25</td>
</tr>
</tbody>
</table>

*No potassic fertilisers are used in the survey villages

Source: CRIDA, unpublished report
<table>
<thead>
<tr>
<th>Crop</th>
<th>Average annual rainfall</th>
<th>Moisture storage (mm)</th>
<th>Native fertility status</th>
<th>Fertiliser recommendations (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>N</td>
<td>P</td>
</tr>
<tr>
<td><strong>Rainy season crops</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearl millet</td>
<td>300-400</td>
<td>80-90/90 cm</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>600-700</td>
<td>80-90/90 cm</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>135-145/45 cm</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Sorghum</td>
<td>600-800</td>
<td>40-70/45 cm</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>800-1000</td>
<td>135-145/45 cm</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>140-270/90 cm</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Finger millet</td>
<td>800-1000</td>
<td>180-200/90 cm</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>1400-1600</td>
<td>180-200/90 cm</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Maize</td>
<td>800-1000</td>
<td>180-200/90 cm</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>1000-1200</td>
<td>90-100/ m</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td></td>
<td>110-140/ m</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Upland rice</td>
<td>1000-1200</td>
<td>145-270/90 cm</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>1400-1600</td>
<td>180-200/90 cm</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Clusterbean/mothbean</td>
<td>300-400</td>
<td>80-90/90 cm</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Horsegram/blackgram/cowpea/pigeonpea</td>
<td>400-600</td>
<td>145-270/90 cm</td>
<td>Low</td>
<td>Low to Medium</td>
</tr>
<tr>
<td><strong>Post rainy season crops</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rabi sorghum</td>
<td>150-200</td>
<td>135-145/45 cm</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Wheat</td>
<td>40-80</td>
<td>110-140/ m</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>100-150</td>
<td>90-100/ m</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>150-200</td>
<td>110-180/ m</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>200-250</td>
<td>140-180/ m</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Barley</td>
<td>50-100</td>
<td>110-140/ m</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>100-250</td>
<td>140-180/ m</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Chickpea</td>
<td>60-70</td>
<td>110-140/ m</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>100-150</td>
<td>145-270/90 cm</td>
<td>Low</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Balanced Nutrients Use

Balanced nutrient use refers to the application of essential plant nutrients, particularly major nutrients - nitrogen, phosphorus and potassium not only in right proportion but also in optimum quantities through correct methods and timing of application suited for a specific soil-crop-climate situation. Balanced fertilisation of crops is profit maximising not only in intensive irrigated farming but is of equal importance in rainfed farming as well where both high yield and yield stability are of interest. Balanced and adequate fertilisation are key to increasing agricultural production by enhancing land productivity.

Since nearly all soils in the Asia are low in N fertility status, the fertiliser N consumption increased dramatically with adoption of modern science-based agriculture system involving fertiliser responsive high yielding varieties, intensive cultivation and multiple cropping. The consumption of P and K did not keep pace with very large increases in N use, resulting in NPK imbalance. Table 12 shows the NPK use ratio in different countries in the tropical Asia. It is seen that NPK use ratio varies widely in these countries.

The nutrients use ratio may be a useful guide as to whether a country with diversified crops and soils is using balanced fertilisation programme but gives no indication whether adequate amounts of nutrients are being used. The NPK ratio can serve the general purpose for comparing countries but may not give the correct picture for fertiliser use on different crops.

The NPK use ratio of 4:2:1 is often cited as appropriate for cereal based systems in developing agriculture. However, this ratio can also be narrower. Different crops need or remove nutrients from soil in other proportions. For example, legumes may need nutrients ratio of 0:1:2, 1:2:2 or 1:2:3, root crops and some grain crops a ratio of 2:1:2.

The nutrient balance must be considered beyond N, P and K. The deficiency of secondary and/or micro nutrients also limits yield. Ignoring these deficiencies will result in significant losses in yield and inefficiency of applied NPK.

Nutrient Mining

The crop harvest removes nutrients from the soil reserves and thus the total nutrients removal is directly dependent upon the level of crop production obtained. The nutrients removal in irrigated crops far exceeds that under rainfed conditions essentially due to higher crop production in the former case. The nutrient balance with cropping depends on the amounts of nutrients removed from the soil by crop harvest and those added to the soil through fertilisers or other sources. The depletion of soil nutrients is wide-spread, including in Asia’s agriculture. This is not healthy. As an example, in India, in case of rainfed sorghum, one tonne of grain (and associated stover) involves uptake of 9.3 kg N, 3.2 kg P₂O₅ and 15.4 kg K₂O/ha (FAI, 1996). Sorghum receives in general 8 kg N and 14 kg P₂O₅ /ha. The calculations on these basis for the nutrients removal, addition and deficit (Table 15) show that by sorghum crop alone in India, there is deficit of both N and K. Likewise, nutrients deficits occur with other rainfed crops, though in different magnitudes.
Table 15: Nutrient removal, addition and deficit (000 t/annum) with sorghum (total production: 9.2 m.t.; rainfed 94%) in India, 1994-95

<table>
<thead>
<tr>
<th></th>
<th>Removal</th>
<th>Addition*</th>
<th>Deficit</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>81</td>
<td>70</td>
<td>11</td>
</tr>
<tr>
<td>P\sub{2}O\sub{5}</td>
<td>28</td>
<td>122</td>
<td>(+) 94</td>
</tr>
<tr>
<td>K\sub{2}O</td>
<td>134</td>
<td>0</td>
<td>134</td>
</tr>
</tbody>
</table>

* Calculations based upon the nutrient use at 8 kg N and 14 kg P\sub{2}O\sub{5} ha\(^{-1}\)

Sources: Directorate of Economics and Statistic, Ministry of Agriculture, Govt. of India. Statistical abstracts, FAI, 1996

In order to prevent this depletion or an even more serious state of exhaustion from the soil, attempts must be made to replace plant nutrients removed by cropping from outside sources. The rainfed crops receive far less fertilisers than irrigated crops resulting in more depletion of nutrients from soil reserves. The use of N fertilisers alone in rainfed crops has also accelerated the removal of other essential nutrients, leading to nutrient imbalances.

Population and Poverty

The Asia currently accounts for nearly 60% of global population but has only one-fourth of the world’s arable land. The population in the Asia has increased from 1.02 billion in 1961 to 3.39 billion in 1995 (232% increase). The projected share of the Asia vis-a-vis other continents of Latin America and Africa in world population during year 2000 and 2020 is shown in Table 16. It is estimated that at least 90% of all future growth in the world’s population will occur in developing countries with the Asia accounting for nearly 60% of the increase. The greatest population pressure is in the Asia where the number of people per arable ha of land is around 8. This is expected to reach 9.7 by year 2000, 12.0 by 2010 and 17.7 by 2030 (Fig. 1).

Figure 1: Human population per hectare of arable land in different regions
(not included)
Table 16: Projected share of Asia, Latin America and Africa in world population

<table>
<thead>
<tr>
<th>Annual growth rate (%)</th>
<th>year 2000</th>
<th>year 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Million</td>
<td>% of total</td>
</tr>
<tr>
<td>1. Asia</td>
<td>1.8</td>
<td>3611</td>
</tr>
<tr>
<td>2. Latin America</td>
<td>2.2</td>
<td>537</td>
</tr>
<tr>
<td>3. Africa</td>
<td>2.9</td>
<td>886</td>
</tr>
<tr>
<td>4. 1+2+3</td>
<td>1.7</td>
<td>5034</td>
</tr>
<tr>
<td>5. World</td>
<td></td>
<td>6178</td>
</tr>
</tbody>
</table>

Based on data of Population Reference Bureau.

In the tropical Asia, India with an annual increase of 18 million people is the second most populous country in the world (China, being the first). It is expected that India’s population will increase to 1 billion by year 2000. Indonesia is the world’s fourth most populated country with over 188 million people.

The number of people as % of total population below poverty line in developing continents are given in Table 17. It is seen that much higher proportions of people are below poverty line in the Asia. A major concern is that most of the population increase will occur in developing countries where the food deficit already exists and bigger proportion of people are below poverty line not having much resources for investment in rainfed farming.

Table 17: Poverty in the developing world, 1985-2000

<table>
<thead>
<tr>
<th>% of population below poverty line</th>
<th>1985</th>
<th>1990</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>All developing countries</td>
<td>30.5</td>
<td>29.7</td>
<td>24.1</td>
</tr>
<tr>
<td>South Asia</td>
<td>51.8</td>
<td>49.0</td>
<td>36.9</td>
</tr>
<tr>
<td>East Asia</td>
<td>13.2</td>
<td>11.3</td>
<td>4.2</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>47.6</td>
<td>47.8</td>
<td>49.7</td>
</tr>
<tr>
<td>Middle East &amp; North Africa</td>
<td>30.6</td>
<td>33.1</td>
<td>30.6</td>
</tr>
<tr>
<td>Eastern Europe</td>
<td>7.1</td>
<td>7.1</td>
<td>5.8</td>
</tr>
<tr>
<td>Latin America &amp; Caribbean</td>
<td>22.4</td>
<td>25.5</td>
<td>24.9</td>
</tr>
</tbody>
</table>

Note: The poverty line used here US $370 annual income per capita purchasing power parity dollars.

Response of Rainfed Crops to Applied Nutrients in India

Exhaustive reviews have been published on responses to applied nutrients in rain-fed coarse cereals, pulse and oil seed crops. They includes information like dose, time and method of fertiliser application. The summary of salient findings as enunciated by Katyal and Reddy (1996) is given below:
Nitrogen: Since nitrogen is universally deficient in rainfed soils, marked responses to applied N in majority of crops have been recorded. The results obtained under All India Co-ordinated Research Project on Dry land Agriculture (Table 18) show that each kg of fertiliser N produced additional grain yield varying from 4 to 38 kg in a variety of crops grown under different rainfall environments and variable soil types. In these cases, the more often response ranged from 12 to 25 kg grain per kg N.

Table 18: Variation in response of crops to N application in different agro-climatic conditions in India

<table>
<thead>
<tr>
<th>Crop</th>
<th>Location</th>
<th>Annual average rainfall (mm)</th>
<th>Response (kg grain kg N(^{-1}))</th>
<th>N applied (kg ha(^{-1}))</th>
<th>No. of seasons averaged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rice</td>
<td>Rewa</td>
<td>987</td>
<td>118</td>
<td>19.0</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Ranchi</td>
<td>1178</td>
<td>218</td>
<td>21.2</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Bhubaneswar</td>
<td>16.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sorghum</td>
<td>Akola</td>
<td>687</td>
<td>80</td>
<td>38.0</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Hyderabad</td>
<td>602</td>
<td>128</td>
<td>25.0</td>
<td>40</td>
</tr>
<tr>
<td>Pearl millet</td>
<td>Jodhpur</td>
<td>334</td>
<td>19</td>
<td>16.5</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Solapur</td>
<td>568</td>
<td>133</td>
<td>20.4</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Hyderabad</td>
<td>602</td>
<td>128</td>
<td>25.0</td>
<td>40</td>
</tr>
<tr>
<td>Rabi sorghum</td>
<td>Solapur</td>
<td>568</td>
<td>133</td>
<td>16.7</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Bellary</td>
<td>284</td>
<td>164</td>
<td>12.0</td>
<td>30</td>
</tr>
<tr>
<td>Wheat</td>
<td>Rewa</td>
<td>987</td>
<td>118</td>
<td>14.5</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Ludhiana</td>
<td>564</td>
<td>151</td>
<td>28.5</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Varanasi</td>
<td>934</td>
<td>131</td>
<td>13.0</td>
<td>40</td>
</tr>
<tr>
<td>Safflower</td>
<td>Solapur</td>
<td>568</td>
<td>133</td>
<td>16.0</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Indore</td>
<td>868</td>
<td>67</td>
<td>7.5</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Agra</td>
<td>633</td>
<td>66</td>
<td>14.3</td>
<td>60</td>
</tr>
<tr>
<td>Mustard</td>
<td>Ludhiana</td>
<td>564</td>
<td>151</td>
<td>7.0</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Agra</td>
<td>633</td>
<td>66</td>
<td>4.3</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Varanasi</td>
<td>934</td>
<td>11</td>
<td>11.5</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 19 shows the agronomic efficiency of applied urea N in sorghum as influenced by N rate, rainfall and depth and nature of the soil. As expected, the agronomic efficiency was higher at lower level of N application and it decreased with increase in applied N levels. Further, the agronomic efficiency was low in shallow depth Alfisols than in deep Vertisols due to differences in amount of water stored. The influence of rainfall varied with the nature of soil.
Table 19: Agronomic efficiency of urea N as influenced by N rate, rainfall and depth of soil in sorghum (kg grain kg\(^{-1}\) N) in India

<table>
<thead>
<tr>
<th>Soil</th>
<th>Seasonal rainfall (mm)</th>
<th>Control yield (kg ha(^{-1}))</th>
<th>Agronomic efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>30-40 kg N ha(^{-1})</td>
<td>60-80 kg N ha(^{-1})</td>
</tr>
<tr>
<td>Deep Vertisol</td>
<td>913</td>
<td>1500</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>322</td>
<td>3270</td>
<td>33</td>
</tr>
<tr>
<td>Shallow Vertisol</td>
<td>913</td>
<td>670</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>322</td>
<td>3390</td>
<td>30</td>
</tr>
<tr>
<td>Deep Alfisol</td>
<td>907</td>
<td>1590</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>322</td>
<td>1490</td>
<td>15</td>
</tr>
<tr>
<td>Shallow Alfisol</td>
<td>485</td>
<td>1440</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>322</td>
<td>2120</td>
<td>19</td>
</tr>
</tbody>
</table>

*Source: IFDC-ICRISAT Collaborative Research Project, Hyderabad*

Timing and method of N application, moisture in soil, time of rain received, cropping season and crop type are factors which determine the response to applied fertiliser. The results given in Table 20 reveal the value of N placement vs. broadcast on grain yield of sorghum and pearl millet. The kharif crops responded more to fertiliser N than rabi crops. For post rainy season crops, N fertilisation could be decided dependent upon the amount of soil stored moisture.

Table 20: Placement versus broadcast - grain yield gains

<table>
<thead>
<tr>
<th>Crop</th>
<th>Yield gain (kg/ha)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearl millet</td>
<td>668</td>
<td>Sandy loam (774 mm)</td>
</tr>
<tr>
<td>Sorghum</td>
<td>1,130</td>
<td>Mean of five experiments</td>
</tr>
<tr>
<td>Sorghum</td>
<td>1,100</td>
<td>Vertisol (786 mm)</td>
</tr>
<tr>
<td>Sorghum</td>
<td>1,500</td>
<td>Alfisol (766 mm)</td>
</tr>
<tr>
<td>Sorghum</td>
<td>660</td>
<td>Vertisol (512 mm)</td>
</tr>
<tr>
<td>Sorghum</td>
<td>340</td>
<td>Shallow Vertisol (397 mm)</td>
</tr>
</tbody>
</table>

*Figures in parentheses indicate seasonal rainfall*

*Source: Hong et al., (1992)*

**Phosphorus:** Unlike nitrogen, the response to applied P in rainfed crops has been variable among crops. Sorghum has been found to be the most responsive to applied P (Kanwar and Rego, 1983). The usefulness of P application in pulses and oilseed crops has been repeatedly documented. Katyal et al. (1987) opined that response of rainfed crops to P will continue to remain small and marginal as long as currently poor yields of rainfed crops are not uplifted through efficient rain water management and by giving more attention to balanced nutrition.
In India, while N will continue to be the kingpin, increased use of phosphate fertilisers is increasingly important for sustainability of rainfed agriculture. In order to keep the cost of phosphatic fertilisers within reasonable limits, partial acidulation of natively exploitable phosphate deposits or its conjunctive use with FYM and other bulky manures or with green manures especially for acid soils deserve merit for both research and development initiatives.

**Other nutrients:** As under irrigated conditions, applied K produced no distinct response in rainfed cereals, though positive role of K in enhancing oil content in oilseed crops has been obtained.

Applied S has been found to excel all other nutrients in increasing yield and quality in oilseed and pulse crops. The rainfed groundnut has shown advantage with applied calcium (Ca), S and K. Among micro nutrients, applied Fe produced significant response in rainfed crops like chickpea and groundnut.

For efficient fertiliser use under rainfed conditions, two points of importance are (i) nutrients levels needed for rainfed crops are lower as compared to those required for irrigated crops. In case of macro nutrients, it is usually one-half. (ii) the time and method of fertiliser application are critical. It is generally accepted that at the soil moisture level which is enough for germination of seeds of planted crop is sufficient for making applied fertiliser efficient for crop growth. In those cases, the preferred method of fertiliser application especially P is placement or banding in soil zone which has enough moisture.

**Integrated Plant Nutrition System (IPNS)**

The Food and Agriculture Organisation of the United Nations with its involvement in sustainable agriculture and environment encourages integrated plant nutrition system which uses both organic and mineral sources of plant nutrients according to local availability. Where supplies of organic materials are inadequate, there must be greater use of mineral fertilisers and biological sources of N and vice versa.

The IPNS is of great relevance in rainfed agriculture, since organics are locally available with the farmers for use. Their resource base is poor to afford costly fertiliser and there is hardly any risk involved in use of organic and bio-fertilisers. The use of organics has additional advantages that it improves physical, chemical and biological properties of the soil, besides improving water holding capacity which is so vital a factor for rainfed crops. The organic manures and bio-fertilisers are valuable natural resources that can augment nutrient supply in rain-fed crops.

The results of a study from India on integrated use of FYM with fertilisers in rainfed finger millet over 17 years period is shown in Table 21. It is seen that yield increased by 1530 kg/ha with optimum NPK use. High yield stability was obtained when recommended NPK levels were applied in combination with 10 t FYM/ha. This treatment produced 3 t grains/ha or more in 14 out of 17 years (Hegde and Gajanan, 1996).
Table 21: Effect of continuous application of fertilisers and FYM on the productivity and stability of dry land finger millet for 17 years in a red loam soil in India

<table>
<thead>
<tr>
<th>Application (annual)</th>
<th>Mean grain yield (kg/ha) (1978-1994)</th>
<th>No. of years when yield (t/ha) was</th>
<th>&lt;1</th>
<th>1-2</th>
<th>2-3</th>
<th>3-4</th>
<th>&gt;4</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>1060</td>
<td>5</td>
<td>11</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>FYM 10 t/ha</td>
<td>2448</td>
<td>0</td>
<td>2</td>
<td>12</td>
<td>3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Fertilisers (50-25-25)</td>
<td>2542</td>
<td>0</td>
<td>3</td>
<td>9</td>
<td>5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>FYM + NPK (25-12.5-12.5)</td>
<td>2875</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>7</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>FYM + NPK (50-25-25)</td>
<td>3456</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>11</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Source: Hegde and Gajanan, 1996.

A number of studies in India have demonstrated the usefulness of green manuring in combination with fertiliser N in rainfed crops. The results in Table 22 show that green manuring not only improved efficiency of fertiliser N but it could also overcome N immobilisation related adverse effect of wide C-N ratio of sorghum stover. Application of sorghum stover produced yield which was less than even in control.

Table 22: Integrated use of fertiliser and organic N for rabi sorghum at Solapur, India

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grain yield (kg/ha)</th>
<th>N uptake (kg/ha)</th>
<th>Organic carbon at harvest (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>834</td>
<td>24.3</td>
<td>0.28</td>
</tr>
<tr>
<td>25 kg N/ha through urea</td>
<td>912</td>
<td>26.9</td>
<td>0.33</td>
</tr>
<tr>
<td>50 kg N/ha through urea</td>
<td>1013</td>
<td>27.6</td>
<td>0.35</td>
</tr>
<tr>
<td>25 kg N/ha through sorghum stover</td>
<td>781</td>
<td>18.7</td>
<td>0.43</td>
</tr>
<tr>
<td>25 kg N/ha through FYM</td>
<td>1184</td>
<td>35.1</td>
<td>0.43</td>
</tr>
<tr>
<td>25 kg N/ha through sorghum stover + 25 kg N/ha through urea</td>
<td>873</td>
<td>25.6</td>
<td>0.46</td>
</tr>
<tr>
<td>25 kg N/ha through FYM + 25 kg N/ha through urea</td>
<td>1174</td>
<td>36.5</td>
<td>0.54</td>
</tr>
<tr>
<td>25 kg N/ha through sorghum stover + 25 kg N/ha through leucaena</td>
<td>1305</td>
<td>39.1</td>
<td>0.51</td>
</tr>
<tr>
<td>CD (P = 0.05) = 225</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Katyal and Das, (1993)

Modern technology for increased agricultural production does not mean that F.Y.M, green manures, bio-fertilisers, organic residues, compost and other organic materials should be ignored. They are a valuable resource which can augment nutrient supply in rainfed agriculture. However there are limitations. The cattle dung is available in large quantities in the Indian sub-continent, but a large portion, as much as 50% of it is used for domestic fuel. In India and Bangladesh, the fuel shortage is acute that the farmers gather crop stubble and roots and use them as fuel.
The IPNS calls for encouraging combined use of available organic and mineral sources. However, mineral fertilisers will have to be the dominant contributor for meeting nutrient requirements of crops for increasing agricultural production, including in rainfed areas.

**Sustainable Agriculture**

Sustainability is the most compelling issue in agricultural production today. This is of equal importance in rainfed farming as well. Food is a human right and therefore every individual must have access to it, irrespective of his place of living or financial capability. Feeding the ever growing population is the concern of all the nations. This responsibility is more with the Governments in the Asia where the population growth rate outstrips all other growth rates. Food supply must be adequate, affordable and sustainable.

No fully satisfactory method is available for numerically measuring sustainability. The results of a study from India measuring sustainability yield index (SYI) - a quantitative measure to assess sustainability with fertiliser use under rainfed conditions are shown in Table 23 (Singh et al, 1990). It is found that fertiliser use improved sustainability index markedly in all situations evaluated.

**Table 23: Influence of fertiliser use on sustainable yield index (SYI)**

<table>
<thead>
<tr>
<th>Soil</th>
<th>Rainfall (mm)</th>
<th>Crop</th>
<th>SYI No Fertiliser</th>
<th>SYI Fertiliser</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertisol</td>
<td>730</td>
<td>Sorghum</td>
<td>0.05</td>
<td>0.48</td>
</tr>
<tr>
<td>Aridisol</td>
<td>400</td>
<td>Pearl millet</td>
<td>0.45</td>
<td>0.72</td>
</tr>
<tr>
<td>Alfisol</td>
<td>590</td>
<td>Pearl millet</td>
<td>0.06</td>
<td>0.24</td>
</tr>
<tr>
<td>Inceptisol</td>
<td>710</td>
<td>Pearl millet</td>
<td>0.21</td>
<td>0.48</td>
</tr>
<tr>
<td>Vertisol</td>
<td>1080</td>
<td>Rice</td>
<td>0.21</td>
<td>0.68</td>
</tr>
</tbody>
</table>

*Source: Singh et al., (1990)*

The essentials in sustainability are to optimise the use of all available resources with emphasis on recycling them wherever possible. In the context of fertiliser use, their supply in optimum levels and application in balanced proportion are the key components in sustainability.

**Constraints**

Many factors contribute to increased use of fertilisers in rainfed crops and they can be grouped as agronomic, economic, physical and institutional. However there are also many constraints. Different constraints to adequate and balanced fertiliser use in rainfed upland areas in the Asia can be listed as:

- Low land holdings and pattern of land tenancy,
- Poor enterprising ability of rainfed farmers
- Shortage of credit for fertiliser purchase
- Lack of knowledge among farmers
- Risk associated with rainfall distribution
- Lack of fertilisers available, locally
- Low level of extension services
- Lack of knowledge about proper fertilisation practices
- Inadequate research and education programmes.
Rainfed uplands are susceptible to climatic, edaphic, biotic, technological and socio-economic variations. The low level agricultural production in rainfed uplands is attributed to erratic and inadequate rainfall and in season drought. This is compounded by small and scattered holdings and lack of cash resources with the farmers to invest in agriculture. Absence of irrigation water compels many a farmers to keep the land fallow after harvesting wet season crops even though in many cases, the land and climatic conditions may be suitable for raising the second crop even without irrigation. The low fertility status of rainfed soils limits their productivity and fertiliser use is rainfed farming is far below the recommended rates. The increased fertiliser use can contribute to raise productivity of rainfed crops. Improved productivity in rainfed areas as well as diversification must form a part and parcel of any strategy for rainfed areas to move to higher growth rates that are sustainable.

References

PRECISION AGRICULTURE:
EUROPEAN CONCEPTS AND REALITIES

by

H. Auernhammer
Institute of Agricultural Engineering, Germany
Summary

In Europe, farming is dominated by family-owned businesses. Due to the increasing use of machines on an extra-operational basis, especially for harvesting, farmers lose valuable and formerly available local information. Such a loss of information may be compensated with GPS and a yield-measuring sensory system, a technology which also provides the basis for more selective soil testing. The data so obtained may be used for the purpose of drawing up target-oriented local application maps, which, if both growth rates and water content of the soil are taken into account, will allow a demand-oriented real-time N-fertilization. Considering currently available techniques for obtaining yield data, such systems may be able to assert themselves in European agriculture on a larger scale at the turn of the millennium.

1. Introduction

In European agriculture, the majority of businesses is family-owned (Table 1). As a rule, the surfaces cultivated are rather small (Table 2), with livestock being raised at the same time. The working of relatively small surfaces compels farmers to aim at the highest yields possible. With a generous supply of P and K nutrients available at the operational level, stable yield figures are usually secured through proportionate applications of nitrogen fertilizers.

<table>
<thead>
<tr>
<th>Table 1: Total Number and rel. Shares of Workers in European Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of workers</td>
</tr>
<tr>
<td>Family workers 14 038 300 93.6%</td>
</tr>
<tr>
<td>hired workers 962 200 6.4%</td>
</tr>
<tr>
<td>Workers total 15 000 500 100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2: Distribution and rel. Shares of Holdings in European Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distribution of holdings</td>
</tr>
<tr>
<td>rel share</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>holdings</td>
</tr>
<tr>
<td>rel. share</td>
</tr>
<tr>
<td>rel. share of holdings D</td>
</tr>
<tr>
<td>E</td>
</tr>
<tr>
<td>share of area D</td>
</tr>
<tr>
<td>E</td>
</tr>
</tbody>
</table>

1 Paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997
Family businesses all over Europe increasingly make use of extra-operational machinery (machinery rings, contractors) in order to lower operating costs. Generally, this practice first concerns grain harvests, with extra-operational harvesting of maize silage and sugar-beets soon to follow.

In comparison to situations where all accumulating work is being done by members of the family, this method considerably reduces workload and working time of all people involved. However, as a result the cycle of information - formerly intact within the operation - is broken: In the past, a farmer was bound to experience the successes and failures of work invested and actions taken throughout the year directly at the site - i.e. on every square meter of the land he owned:

- If more fertilizer resulted in more yield, his fertilization strategy was correct.
- If the yield remained unchanged in spite of higher amounts of fertilizer but plants came laid, the dosage applied was clearly too high.
- If the yield did not meet expectations, it was evident that past fertilization strategies were not optimal.

Such information is usually lost if the harvest is carried out by third parties, whose objective generally is not the collecting and documenting of information, but an optimal degree of efficiency in the work process and the running to capacity of the machinery used. As a rule, extra-operational use of machinery therefore leads to a discontinuation of now customary local fertilization strategies and a more uniform output of nutrients. The consequences are over-fertilization of certain areas on the one hand and a lack of fertilization in some areas on the other.

Thus, the situation on family-owned farms slowly approaches that of operations working with outside labor. In such enterprises, a closed cycle of information never existed since

- operations employing hired workers are usually much larger,
- individual workers are only responsible for partial tasks within a cultivation period,
- as a rule, employees do not work with the same commitment as family members,
- locally adjusted soil treatment is hardly feasible due to the sheer size of surface area and a lack of information about site-specific requirements.

2. Precision Farming

"Precision Farming", also called "Spatially Variable Plant Production" ("Teilschlagtechnik") is meant as a cure for these problems. The term originated from two different underlying concepts:

2.1 Spatial Variability

The term "spatial variability" first appeared in English. It denoted the description - and thus the recording - of spatial heterogeneity. In connection with extra-operational harvesting, the concept lead to yield measuring devices in combine harvesters across Europe, (after first experiments in the U.S. by SCHUELLER & SEARCY in 1987):

- by 1989, YIELD-O-METER in Great Britain and then at CLAAS
- from 1990 to 1992, large-scale yield measuring experiments with combine harvesters using GPS and DGPS in Germany (Weihenstephan)

- starting in 1990, yield measuring experiments with forage harvesters, trailers and round balers in Germany (Weihenstephan)

- in 1992, market introduction of local yield measurement devices in the combine harvester made by DRONNINGBORGBORG, Denmark

- by 1993, local yield measuring of silage maize with forage harvesters in Germany (Weihenstephan)

- by 1995, local yield measuring with sugar-beet harvesters (Weihenstephan and Utah) and potato harvesters (Utah)

The recording of local information necessitated a standardized communication system within Europe (in Germany, starting in 1986 at LAV). The objectives were:

- an open system
- suited for the device-specific electronic set-up of many, often small suppliers of machinery
- central controls at the drivers seat
- integration into management structures.

2.2 Site Specific Treatment

Unlike in Europe, in the U.S. greater yields are achieved on greater surface areas by operations with sufficient quantities of land available. At first, yield reserves are activated through an optimal supply of basic nutrients. To keep analysis costs low, a so-called "grid farming" concept was developed. Available nutrients are calculated by grid (starting at about 1.5 hectares or 3.6 acres) with fertilization according to the principle of "site-specific treatment" and additional measures to follow:

- by 1985, grid sampling to determine nutrient supply of soil (CONCORDE USA),

- by 1987, development of multi-bin fertilizer spreading systems (Lorant USA with 8 bins, at the same time as a 3-component-system at Weihenstephan).

2.3 Commercial Use

The availability of GPS, a reliable, universally accessible satellite positioning system, allowed attempts at site-specific soil treatment to be used commercially. In 1995, the term "Precision Farming" was coined. The goal is a closed cycle of three steps, related mainly to fertilizing:

1. gathering of local information
   - determination of local yield
   - determination of local available nutrients

2. analysis and forecast
   - decision support systems
   - experiences of farmers

3. site specific treatment
   - local adjustment of seed rates (density)
   - local fertilization
There are, however, two areas of "Precision Agriculture" which are largely neglected:

- The problem of an accurate completion of respective tasks as a necessary condition for any system of the above kind (Research findings in Germany show that with fertilization especially, considerable differences between actual and ideal values exist. The same findings also indicate large discrepancies with respect to vehicle pathways.)

- The cycle of information and subsequent actions with respect to plant protection (in Germany, picture analysis for weed identification, in the U.S., genetical engineering, resulting plant changes and use of appropriate herbicides)

At the moment, there seems to be a lack of interest on the manufacturers side in supplying techniques resulting in an improved degree of precision in the completion of tasks. The use of picture analysis is yet too expensive, genetical engineering is a controversial topic within the population.

Rather, the market currently seems to support systems which prescribe "exact amounts of fertilizer". However, the expectation of a drop in fertilizer costs and, at the same time, a decrease in the strain introduced to the environment ought to be convincing arguments in favor of a rapid realization and exploitation of such systems.

3. Concepts of "Precision Agriculture"

As mentioned above, the term "Precision Agriculture" was coined in the U.S.A. It is based on two different approaches. Hence, there are two different concepts discernable today:

3.1 Map-based Systems (U.S. Concept)

With "low yields", soil influence on yield is high. Three important conceptual approaches are to be considered here (Figure 1):

- An optimization of basic nutrients by means of local soil testing and local output of fertilizer supplements containing P, K and Ca

- A simulation of expected plant growth taking into account a limited number of climatic factors. Subsequent generation of application maps that allow the specification of yield objectives through:
  
  optimal seed density  
  appropriate N-fertilization

- Local yield measurement as a feedback for actions taken
Figure 1: Map-based System for Site Specific Fertilizing

(not included)

⇒ from the past to current situation
  ■ low yield production level
  ■ constant weather conditions
  ■ grain crop rotation

With this concept, the precision values required are quite low. The influence of seed density on yield is higher than that of N-fertilization, since, as a rule, water constitutes the delimiting variable. Respective growth models are based on these factors, drawing information from years of climatological records including modest year-to-year aberrations. For this concept, such models are absolutely indispensable.

3.2 Real-time Systems and Real-time Systems with Map-Overlay (European Concepts)

Here, the point of departure is high-yield soil which is well-supplied with P and K as well as sufficient rainfall during the growth period. The influence of the soil on reliable yield stability stems mainly from N-mineralization, a factor which is determined to a higher degree by actual weather conditions than by long-standing climatological factors. Without ecological and economical restrictions nitrogen applications will depend only from the current growth situation. Online measurement of actual plant growth (and water availability) allows "on-the-go" N-fertilization (Figure 2). Areas with less fertility may be overfertilized and harm the environment where on the other side areas with high fertility could produce higher yields and reduce possible economical benefits.
An improved "Precision Farming" concept (Figure 3) takes both facts into account and entails the following steps:

- by current plant growth
  - high yield production level
  - high weather variation
  - complex crop rotations

Figure 3: Real-Time System with Map-overlay for Site Specific Fertilizing

(not included)
- Determination of local yield over a time of several years in order to define areas of equal yield
- Soil testing for the availability of yield-promoting nitrogen within areas of equal yield
- Specification of potential yield objectives taking into account ecological delimitations such as soil type and water content of soil (yield structures)
- Adjustment of seed density for plants with high water requirements
- Online recording of data about actual plant growth and nutrient situation as well as available water resources (possibly indirectly at the plant itself) and local "on-the-go" N-fertilization within the scope of yield objectives and ecological delimitations

The precision values required are relatively high. In regions with less precipitation, selected types of plants and a change in seed density may result in an improved contribution to "Precision Agriculture". The value and importance of soil testing and the use of growth models play a less important role. In this system, yield objectives and ecological delimitations are indispensable.

4. The Reality

In Europe, we currently find a wide range of soil cultivation systems in various stages of development. With respect to the implementation of "Precision Farming", the following directions may be discerned:

4.1 Large Scale Farming with Simplified Crop Rotation (Grain Production)

In large scale operations, recognizable attempts at "Precision Farming" are currently being made in three EU countries:

GREAT BRITAIN

The largest efforts within Europe may be observed on bigger operations in England, especially on the very large grain farms in the eastern part of this country. Attempts adopt the European concept using

- local yield determination
- geo-referenced soil testing
- use of decision support systems
- site-specific nitrogen fertilization (of late in the form of dual systems at the front and back of the tractor)

Nevertheless, results have been rather modest. Only one manufacturer of combine harvesters was successful in turning the advantages of a state-wide available reference service (DCI) into results measured by numbers of items sold. In 1996, 80% of the newly sold machines in this line were equipped with DGPS and yield measuring devices. Other manufacturers currently have to rely on suppliers for a lack of own solutions. From a scientific point of view, the interpretation of yield data is plagued by considerable shortcomings.

Geo-referenced soil testing is on the rise. Scientific research shows that available nutrients are being scattered over a surprisingly wide area.

The implementation of site-specific fertilization depends largely on the experiences of the management of individual operations, with site-specific information being used as guidelines. Definite results about a decrease in costs and/or higher yields are not available yet.
GERMANY

Most large-scale operations are in the eastern part of Germany. Despite favorable agrarian conditions, "Precision Farming" has not taken hold yet. Major obstacles are:

- A state-wide reference service for GPS correction signals is not available so far.
- The operations work on rather limited budgets.

Altogether, there are about 50 combine harvesters in use today. Information about respective site-specific fertilization data is not yet available. Nevertheless, experiments on a large operation at Oderbruch show that site-specific treatment considerably improves nitrogen exploitation.

DENMARK

Despite their relatively small size, Danish farmers have increasingly turned to local yield determination with grain harvesting. There are two important reasons for this development:

- In 1992, the Danish combine harvester manufacturer DRONNINGBORGBORG was the first to offer a marketable device for local yield measurement. Products of this manufacturer largely dominate the Danish market.
- Since the country is largely composed of islands, DGPS reference signals are available state-wide via coastal radio.

A scientific analysis of strip-farming experiments show that site-specific fertilization reduces the amount of N-fertilizer required by about 7.5%.

All other countries must currently to be considered "blank pages", although interest seems to be growing in France and Spain.

4.2 Small-scale Farming with Complex Crop Rotation

With the exception of the few areas with large-scale operations producing mainly grain, the majority of European farmers own smaller scale operations with a rather differentiated crop rotation system. A first step towards "Precision Farming" ought to be local yield determination. Yet, this is exactly where basic requirements are still missing:

- The market leader in combine harvesters did not offer an affordable yield measuring system until today.
- The availability of DGPS reference signals varies greatly within Europe. State-wide services exist only in the Northern European states, the Benelux and Great Britain. Users fees are relatively high.
- There are no yield measuring systems offered for any other harvesting machines than combine harvesters.
- Soil testing is done with traditional methods. In almost all countries, soil samples are taken from a site at random and then mixed. Of this mixture, a representative sample is analyzed. Naturally, the result is only suited for homogenous fertilization measures.
4.3 Organisatorial Limitations

Aside from limitations due to the lack of available DGPS correction signals that are affordable, safe and precise, technical shortcomings of yield determination systems play a large role. The main problem is restrictions with respect to the use of systems based on radiometric sensors. At the moment, such sensors are

- legal without restrictions in Denmark and Sweden,
- legal with some restrictions in Germany, Great Britain and Benelux,
- not legal in France.

The use of local yield determination poses yet another problem. As mentioned above, the bulk of the harvesting is done with extra-operational machinery. New technologies are used only if they are justified by greater efficiency or if they save a considerable amount of working time. Both is not the case with local yield determination. Rather, it requires additional investments, the use of which could at the most be seen in greater customer dependency. Fears with respect to the use of a great deal of electronic equipment in a sector formerly dominated by mechanical technology should also not be overlooked.

These reservations apply to farm machinery cooperatives as well as to contractors. As far as contractors are concerned, a change in thinking currently seems to be underway, which will soon lead to an increased use of such new technology.

5. Conclusions

A careful, objective evaluation of the future development of "Precision Farming" in Europe would read as follows:

- In Europe, the point of departure is local yield determination. After the introduction of state-wide availability of DGPS correction signals in all European countries and yield measurement sensors by the market leader for combine harvesters, this technology may become standard within the following three years.
- With respect to soil testing, the second basic variable, a transition to geo-referenced sample-taking is already in progress. After yield measuring devices become generally available in combine harvesters, this technique could become standard use for large areas at the turn of the millenium.
- Due to the rather humid conditions characterizing soil cultivation in great parts of Europe, local data about growth and available water content in the soil is a prerequisite for the implementation of site-specific fertilization. First approaches towards an online recording of growth data exist and could be turned into practice on a larger scale by the turn of the millenium.
- By then, marketable yield determination systems for other crops should also be available.

All in all, the introduction of "Precision Farming" (i.e. site-specific planting and fertilization) in Europe appears to be forthcoming with the beginning of the next millenium. Proceeding from large-scale operations, the development will soon affect family-owned businesses and thus improve their traditionally high output. As a consequence, such operations will be able to supply any by then required documentation and recording of all specific factors involved in plant production without any additional effort.
6. Literature


SITUATION IN AGRICULTURE AND PERSPECTIVES OF SUSTAINABLE AGRICULTURE IN RUSSIA

by

N.M. Andreyeva

IMEMO, Russia
Russia is a large agricultural power, taking into consideration its production potential: large agricultural areas, rich soils, plentiful precipitation, rather favourable climate. All these factors could ensure high and stable crop production. Nevertheless, Russian agriculture continues to be low productive and inefficient. Its production and yields of agricultural crops varied highly by years. In 1996, farm output in Russia decreased by 6% against the 1995 level, in 1997 can expect another fall by 7%. In 1996, 69.3 Mt of grain were harvested, up 9.3% from previous year, but 33.5% lower than in 1986-1990. The area planted to grain was 53.4 M.ha, down 2.4% from 1995 and 15.4% lower than in 1990. Grain yields averaged 1300 kg/ha (weight after cleaning), 12% higher than in 1995 but 18.2% lower than in 1986-1990. The situation on the grain market in Russia appears to be tense in 1996/97, taking into account the low level of grain reserves and shortage of financial resources to pay for grain imports. Sugarbeet production was down in 1996 by about 16%, to reach 16.1 Mt. The major fall was recorded in sunflower production (about 36%). The decrease in output was caused mainly by the fall of average yields against the 1995 level: sunflower by 31% to 100 kg/ha, sugarbeet by 13.7% to 15200 kg/ha. Potato and vegetable production decreased by only 3.5% and 5.3% respectively; acreages planted and yields remained at the 1995 level. (See Appendix 1).

A lot of factors affect the agricultural production and efficiency. We focus on fertilizer production and consumption. Fertilizer production in Russia in 1996 totaled 9.1 Mt nutrients (including joint-ventures). It is down by 5.2% from the previous year and by 47.4% lower than ten years ago (See Appendix 3). The production capacities of fertilizer plants are being used at a rate of only 40-50%. The domestic market receives no more than 25% of total fertilizer produced (variations by years: 1990 -16%, 1993 -43%, 1994 -25%). In 1996, 1.84 Mt of urea were produced, 1.72 Mt. or 93% were exported. As to potash fertilizers, 2.62 Mt. were produced in 1996, of which 1.78 or 68% went to foreign market.

As to fertilizer consumption, the situation remains very difficult. In 1996 deliveries of mineral fertilizers totaled 1.73 Mt total nutrients, which is only 13% of 1986-1990 level. The deliveries of mineral fertilizers for the main agricultural crops were down considerably compared with 1986-1990: grain - 7.3 times, sugarbeet - 5 times, sunflower - 9.6 times, potatoes - 10.4 times, vegetables - 6.4 times. Application rates (kg/ha) declined also: grain -5.5 times, sugarbeet - 3.5 times, sunflower - 10.2 times, potatoes - 2.4 times, vegetables - 2.7 times (See Appendix 2).

Some constraints hindering the use of fertilizer are:

- shortage of financial resources in agriculture,
- poor equipment and technical know-how for fertilizer application,
- lack of a distribution system suited to local conditions.

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1 Poster paper presented at the IFA Agro-Economics Committee Conference, Tours, France, on 23-25 June 1997
Three types of agricultural producers prevail currently in Russia: large agricultural enterprises; domestic plots; private individual farms. Each has a different legal status, organization, size, specialization, and each plays a different role in production and marketing. Large agricultural enterprises produce most of grain, sugar beet and sunflower. Their share is 95%, 96% and 87% respectively. As to the legal status, these producers are former collective and state farms, which were re-registered since 1992 into corporations, cooperatives, associations, etc.

One of the main positive changes in the Russian agriculture during the last 5 years (the transition to a market economy began in 1992) has been the increasing role of the private sector. This sector comprises the domestic plots, orchards and gardens, private individual farms. In 1996 the domestic plots produced 90% of potatoes, 75% of vegetables, 75% of fruits and berries, 49% of meat, 42% of milk and 30% of table eggs. From 1992 to 1996 the share of the private sector has increased two times in grain production, 1.8 times in sugar beet production and two times in sunflower production. Though the position of large agricultural enterprises continues to be strong due to their large size and because they have large agricultural resources, they are losing their power in production and marketing. From 1970 to 1996 their share of agricultural production decreased from 69 to 54% (in crop production from 73 to 46%). Meanwhile, the share of the private sector increased from 30% in 1970 to 46% in 1996 (in crop production from 27 to 54%, in livestock production from 34 to 37%).

At present the key problems of Russian agriculture are the following:

- Financial resources and possibilities to receive cheap credit are limited.
- Land reform has not been completed.
- The price disparity between agricultural and industrial commodities is large.
- There is no systematic government support to agricultural producers.

THE ENVIRONMENTAL IMPACT OF AGRICULTURE

Russian agriculture is facing an environmental crisis. Massive soil degradation and land loss caused by erosion, salivation, soil compaction, humus loss, water pollution by chemicals and run-off from livestock production, increasing levels of harmful industrial chemicals in soil, surface and ground water, food contamination by residues of pesticides, etc. are the indicators of this crisis.

According to the estimates of the specialists, water and wind erosion affect about two thirds of Russian arable land. Water erosion is probably the most serious threat to soil fertility in important agricultural regions. Each year, the acreage of eroded land increases by 0.4-0.5 M.ha, and the annual losses of fertile top soil, including considerable quantities of humus, attain 1.5 billion tons. Undiscriminate expansion of arable land and intensified use of pasture are the main causes of the increasing erosion problem. The erosion process is particularly serious in the Blacksoil, Volga and Northern Caucasus regions, and in a number oblasts of the Urals and Siberia. In the Blacksoil region, row crops such as sugar beet and sunflower are cultivated on sloping fields, causing extensive water erosion. In the dry land west of Volga where a monoculture of spring wheat is only interrupted by fallow, serious wind erosion developed in the 1960s. Since then new agricultural practices have improved the situation to some extent.

The formation of gullies is a severe consequence of water erosion. About 400,000 gullies covering more than 500,000 ha are found in Russia. In the Blacksoil region 11 gullies are found per thousand ha of agricultural land.
As in the West, soil compaction is a problem. The frequent use of heavy machinery, especially under bad weather conditions, is the major cause. Soil compaction is widely distributed in the Non-Blacksoil and Northern Caucasus regions. Yield decreases of 10-15% are frequent.

The most fertile soils in the South of Russia are frequently contaminated by pesticides, even if in general Russia uses less pesticides per acreage than most OECD countries. The quality of pesticides is low and that the spectrum of pesticides used is more toxic than in the West. In the beginning of 1990s, 20% of chlorinated insecticides are frequently found in the soils. The most severe contamination is found in Irkutsk and Volgograd oblasts and in the Krasnodar krai. In these regions 64-90% of the soil samples exhibited higher than maximum allowable concentration of various pesticides.

Acres of highly acid soil, at present 4.9 M.ha, are increasing. Acid soils is a problem of the humid north and west. Although industrial pollution and the use of some fertilizers are to some extent responsible, natural factors explain most of tendency to acidification. The rates of liming, the remedy for acid agricultural land, are at present decreasing as centrally financed programmes cease to exist.

A continuation of these processes may result in very serious problems in a majority of agricultural regions of Russia within the next two decades, resulting in decreasing soil fertility and yields of crops. The decrease of soil fertility is particularly dramatic in the Blacksoil, Volga-Vyatka and Eastern Siberian regions. In the first of these regions, the blacksoil of the Russian plains has lost a third of its humus and the fertile soil layer has decreased by 10-15 cm over the last 30-40 years. The decrease of soil fertility has been estimated to correspond to an annual average yield loss at about 1 ton of grain per hectare. With original levels of soil fertility production per acreage would be 50-60% higher. The rate of soil degradation is increasing. From 1970 the acreage of eroded, salinated and acid soils approximately doubled. Losses of organic matter are only compensated for to 50%.

Agriculture is an important source of water pollution. At the end of the 1980s, about 15 cbmk of waste water ended up in surface of water reservoirs. However, a major part of the pollution comes from 143 cbkm of surface run-off from agricultural land where high quantities of pollutants are found. Pesticide contamination of water reservoirs in the Samara oblast exceeds the maximum allowable concentration (MAC, according to Russian regulations) by 10-15 times. In Novgorod, Ryazan and Moscow oblasts the content of ammonium and nitrate nitrogen in the water occasionally exceeds the maximum allowable concentrations by 10-25 times.

The incorrect use and storage of mineral fertilizers, manure and pesticides is a major cause of this pollution. Equipment for pesticide application is of low quality. Reglemented storage facilities for fertilizers and pesticides in the farms are only available at 10% of the estimated needs. Only 50 and 30% of needed spreaders for fertilizers and pesticides are available.
Low standards for handling pesticides add to the problems. Recommended doses are being exceeded, the number and timing of applications are frequently wrong; applications are made massively instead selectively; environmentally dangerous, low-quality preparations are used. It should be noted that the Russian agricultural producers refuse often to purchase pesticides manufactured in Russia because their bad quality. A big problem is the utilization of surpluses. One can consider that one third of these pesticides may be used in the building materials industry after special processing, the rest of pesticides must be burn in the special stoves.

Animal production is an important source of soil, surface and ground water pollution. Only about 30% of the huge quality of manure produced per year is returned to the soil. The rest becomes waste, causing severe water pollution problems. Very large facilities for livestock production are found in the regions with the high density population such as Krasnodar krai, the Moscow, Belgorod and Samara oblasts, St. Petersburg region. Many of these facilities are not equipped with installation for spreading or treating the manure. The greatest ecological risk is caused by industrial swine factories designed for feeding 54, 108 and 216 thousand swines. One of these factories for 108 thousand swines yield 300 tons of liquid manure per day or more than 1 Mt. per year. A similar situation is found in the poultry production. In summary, we need to admit that the "impact" of Russia in the global pollution exceed its impact in the world industrial and agricultural production.

To improve the ecological situation in Russia there is required the monitoring of it in different regions, the creation of information infrastructure, revision of list of main pollutants, development of sustainable agriculture, use mainly biological methods of pest control, improved varieties of crops, etc.

SUSTAINABLE AGRICULTURE IN RUSSIA

It is known that annual losses of agricultural production from pests, diseases and weeds exceed 40%. And though in the Western countries the chemical methods of pest control continue to prevail, more and more attention is given to the nonchemical methods, particularly to the biological methods. The biological methods ensure to minimize the pollution and to diminish the residues of pesticides in products. The fields of their use are greenhouses, fruit and vegetable production, especially for fresh consumption. They may also successfully be applied to sugarbeet, cotton and sunflower production.

The biological methods of pest control were widespread in the former USSR, mainly because of the shortage of pesticides. One must admit that the former USSR was the leader in the world by the scale of use of this technology. The biological methods were very popular in the Ukraine, Moldavia, Kazakhstan, Turkmenistan, Tadjikistan where the land was very plowed up and where there was a little of forests. In the central regions of Russia, where forests occupy large acreages and where the losses of yields caused by pests and deseases were not high, the biological methods were used not very often. They are used mostly in sugarbeet, cotton and corn production. Import of natural pests has been practicized very often. As usual, the principle of incompatibility was used.

In 1993 in Russia the biological methods were used on the acreage of 3.8 M.ha. Its share account for about 20.5% in the crop production, and 60% in the vegetable (greenhouses) and fruit production. It is expected, that to the end of the 1990s its share in the vegetable production in greenhouses will reach 90%, and in the fruit and potato production about 40-50%.
In modern Russia there are several types of biopreparations' producers. Among them the factories of microbiological industry (6 types of biopreparations), the agricultural enterprises (16 bacteria and fungus preparations and 17 useful pests). The service of the crop control consists of 74 biolaboratories, 10 biofabrics, 4 shops, 174 interstate laboratories, 9 scientific-production societies, joint-stock companies etc.

Major factors that are restricting the development of sustainable agriculture in commercial sector and the use of biological methods are:

- low quality of domestic pesticides which are non-competitive in comparison with imported ones;
- the government does not support the use of the biological methods of pests control in agriculture;
- the domestic preparations are very expensive because they are produced mainly at the small factories;
- the lack of professional microbiologists is a severe problem;
- the weakness of the technological base of the microbiological industry;
- low level of ecological culture; the agricultural producers are not prepared to use biological preparations instead of chemicals ones.

Opposite to Russia, the American government promotes to the use of biological methods and support an alternative agriculture, though most of American farmers use the chemical methods of pest control. The USA has been worked out a complex national programme of the use of the biological methods in agriculture, in which 73 scientific centers and laboratories are involved.

In the former USSR the environmental problem was not a priority. The deterioration of ecological situation in the 1980s compelled the authorities to change their attitude to this problem. Since then several legislative acts and regulations have been adopted ("The Law on Environment", 1991; "On Ecological Examination", 1995 and others). In June 1994 has been adopted the Decree of the Government of the RF "On Measures to Increase the Production and Application of Biological Methods of Pest Control in Agriculture". According to the opinions of Russian specialists, the future belong to the biological methods of pest control. According to their estimates, at the beginning of the next century more than 50% preparations used in agriculture will be produced in the microbiological industry.

Therefore, there are two main types of agricultural producers in modern Russian agriculture - large agricultural enterprises and private sector which includes domestic plots, orchards and gardens, and private individual farms. The private sector produces the majority of potatoes, vegetables, fruits and berries. Practically these farms do not use pesticides and chemical fertilizers due to lack of financial resources. Organic materials, particularly manure, are mainly used for fruit, berries and vegetable production.

Thus, due to financial shortage and low quality domestic pesticides Russia can be considered as a country with widespread sustainable agriculture.
### Appendix 1

**RUSSIA: CROP PRODUCTION, mln.t**

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<tbody>
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<td>2.8</td>
<td>2.5</td>
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<td>11.3</td>
<td>10.7</td>
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### Appendix 2

**RUSSIA: MINERAL FERTILIZER DELIVERIES AND APPLICATION**

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<td>4295</td>
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<td>1473</td>
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<td>grain</td>
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<td>72</td>
<td>22</td>
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<td>5</td>
<td>4</td>
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<td>Applications rate, kg/ha</td>
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<td>88</td>
<td>46</td>
<td>24</td>
<td>17</td>
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<td></td>
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</tr>
<tr>
<td>grain</td>
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<td>81</td>
<td>44</td>
<td>23</td>
<td>16</td>
<td>17</td>
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<tr>
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<td>431</td>
<td>247</td>
<td>150</td>
<td>120</td>
<td>127</td>
</tr>
<tr>
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<td>85</td>
<td>27</td>
<td>9</td>
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<td>5</td>
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<td>120</td>
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<td>74</td>
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<td>265</td>
<td>176</td>
<td>119</td>
<td>113</td>
<td>105</td>
</tr>
<tr>
<td>feed crops, total</td>
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<td>78</td>
<td>37</td>
<td>19</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>flax</td>
<td>186</td>
<td>172</td>
<td>86</td>
<td>46</td>
<td>29</td>
<td>27</td>
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</tbody>
</table>

### Appendix 3

**RUSSIA: FERTILIZER PRODUCTION Mt nut**

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<tr>
<td>Mineral fertilizers, total</td>
<td>11.8</td>
<td>17.3</td>
<td>16.0</td>
<td>15.0</td>
<td>12.3</td>
<td>9.9</td>
<td>8.3</td>
<td>9.6</td>
<td>9.1</td>
</tr>
<tr>
<td>of which:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Nitrogen</td>
<td>5.4</td>
<td>8.0</td>
<td>7.2</td>
<td>6.7</td>
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<td>4.8</td>
<td>4.1</td>
<td>4.9</td>
<td>4.9</td>
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<td>Phosphate</td>
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<td>2.5</td>
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<td>1.6</td>
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<tr>
<td>Potash</td>
<td>3.5</td>
<td>4.9</td>
<td>3.8</td>
<td>4.1</td>
<td>3.5</td>
<td>2.6</td>
<td>2.5</td>
<td>2.8</td>
<td>2.6</td>
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BALANCED NUTRITION AND CROP QUALITY IN SUGAR BEET

by

J. Wiebel and K. Orlovius
Kali und Salz GmbH, Germany
ABSTRACT

Soil mining of the potassium reserves has become a common feature in recent years also in Germany. Even application rates theoretically matching nutrient removal by the harvested crops are leading to declining soil contents in major sugar beet growing areas. Particularly in potassium demanding crops such as sugar beet, yield and quality characteristics are severely affected by sub-optimal potash supply, especially since a new formula for calculating extractable sugar has been adopted by the German sugar industry. Declining K soil contents are a matter of concern since low contents of exchangeable potassium in the soil can not be fully compensated by higher potassium application rates.

INTRODUCTION

In Germany potassium fertilisation has been decreasing since 1975/76 (1.8 Mio t K₂O), stabilising only in recent years at a level of about 650.000 t. Today potash consumption is with approximately 40 kg K₂O/ha cultivated land on a similar level as 50 years ago. The N:K₂O-ratio has deteriorated from 100 : 95 in 1975/76 to 100 : 37 in 1995/96. In times of decreasing profits, farmers are taking advantage of the potassium reserves in the soil and potassium soil mining - a practice particularly common in countries with no indigenous potash deposits and soils originally rich in potash - is now also widespread in Germany. Consequently the content of exchangeable potassium in the soil is decreasing on a large scale.

Furthermore, critical limits for potassium (very low - low - adequate - high - very high), have been lowered by the concerned state authorities. At adequate soil levels, potash is recommended according to the quantity removed by the harvested crops ("fertilising according to nutrient removal"). This concept of balancing fertilisation has been established already in 1855 by Justus von Liebig: "Return to the soil the same quantity of nutrients which you have removed from it". After more than 150 years a critical examination of this concept might be worthwhile.

Particularly in sugar beet yield and quality characteristics, i.e. sugar content and extractable sugar content, are severely affected by sub-optimal potassium supply. Besides, sugar beet is still one of the most profitable field crops in German farming systems and often the economic backbone of arable farms. Furthermore, farmers get a prize premium for beet of good quality. Thus, soil fertility levels in farms growing sugar beet supposed to be adjusted according to its requirements.

In the light of potassium "soil mining" and "fertilisation according to nutrient removal" answering the following questions may contribute to sustain productivity in sugar beet:

1. In soils well supplied with potassium: can an optimum sugar yield be achieved and soil K levels maintained by simply replacing the removed potassium in sugar beet based cropping systems?
2. In soils having experienced a significant decrease in exchangeable potassium content: can a single K application, well above the quantity removed by sugar beet, make up for the lower soil K content?

3. Does the new formula, used for calculating the extraction rate of sugar since 1996, affect the role of potassium in producing beet of best quality and thus optimum sugar yield?

**FERTILISATION ACCORDING TO "NUTRIENT REMOVAL"**

In Germany 13 locations in typical sugar beet growing areas with adequate potassium soil contents were selected for this long term experiment. Crop rotation was typically sugar beet - winter wheat - winter barley. Four levels of potash fertilisation (4 treatments and 4 replicates in a randomised block design) were chosen based on the estimated yield and net removal:

\[
\begin{align*}
K_0 &= \text{control (no potash application)} \\
K_{net} &= \text{potash application according to net removal (typically 120-50-50 kg K}_2\text{O/ha for sugar beet, wheat and barley, respectively)} \\
K_{med} &= \text{potash application approx. 2-times higher than net removal (typically 240-100-100 kg K}_2\text{O/ha for sugar beet, wheat and barley, respectively)} \\
K_{high} &= \text{potash application approx. 3-times higher than net removal (typically 360-150-150 kg K}_2\text{O/ha for sugar beet, wheat and barley, respectively)}
\end{align*}
\]

N.B.: removal was calculated using average values for K in grain (0.5 % K) and sugar (1.17 % K); crop residuals (straw and sugar beet tops and leaves) remained on the field.

The optimum potash application rate (in terms of money) and the incremental increase in profit due to optimum potash application was calculated with the help of quadratic production functions, taking average prices for K-fertiliser, sugar, wheat and barley into account while omitting EU subsidies for cereals.
Table 1: Optimum annual K-application rates, initial soil K content, final soil K content and increase in net profitability in a sugar beet - wheat - barley crop rotation (based on Orlovius, 1996a)

<table>
<thead>
<tr>
<th>loc.</th>
<th>clay/silt content</th>
<th>optimum K kg K₂O/ha/year</th>
<th>x-times removal</th>
<th>soil K content in mg K₂O/100g (CAL)¹</th>
<th>Δ profit K₀pt DM/ha/year</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>initial</td>
<td>final K₂O</td>
</tr>
<tr>
<td>1</td>
<td>14/46</td>
<td>223</td>
<td>2.4</td>
<td>22</td>
<td>15</td>
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<td>27</td>
<td>16</td>
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<tr>
<td>3</td>
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<td>222</td>
<td>0.9</td>
<td>29</td>
<td>16</td>
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<td>4</td>
<td>19/78</td>
<td>250</td>
<td>2.7</td>
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<td>19</td>
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<td>30</td>
<td>19</td>
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<td>6</td>
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<td>195</td>
<td>0.8</td>
<td>13</td>
<td>6</td>
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<td>21/74</td>
<td>204</td>
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<td>8</td>
<td>23/75</td>
<td>0 (108)³</td>
<td>0 (0.9)³</td>
<td>22</td>
<td>17</td>
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<tr>
<td>9</td>
<td>27/69</td>
<td>0 (120)³</td>
<td>0 (1.2)³</td>
<td>22</td>
<td>16</td>
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<td>11</td>
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<td>0 (171)³</td>
<td>0 (1.2)³</td>
<td>17</td>
<td>9</td>
</tr>
<tr>
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<td>34/55</td>
<td>0 (111)³</td>
<td>0 (1.4)³</td>
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<td>3.3</td>
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<tr>
<td>ave.</td>
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<td>150</td>
<td>1.4</td>
<td>22</td>
<td>15</td>
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¹ values of CAL extraction in mg K₂O/100 g are commonly in a similar range as values obtained by NH₄Ac extraction in mg K / 100 g
² final values are averages of the last three experimental years
³ figures in brackets indicate the calculated values; since yield increase due to potash application was statistically not significant, optimum potash application is 0 kg K₂O/ha
⁴ final K values at optimum K-application rate were obtained by interpolation

The calculated optimum K-application rate, averaged over all 13 locations, was 150 kg K₂O per ha and year - well above (1.4-times) the official recommendation of 107 kg K₂O/ha and year (i.e. fertilisation according to nutrient removal) for soils adequately supplied with potash (Table 1). Net profit, on average, would have been up by 147 DM (approx. 90 US $) per ha and year if optimum quantities of potash (Kopt) would have been applied.

The average K soil content decreased significantly if potash application was omitted. Surprisingly, even at an application rate theoretically matching the removal (Kₙet), soil K contents decreased. Since soil potassium is not subjected to leaching, potassium fixation is the most likely cause for the observed decrease.

The variability of the results suggests that other factors, such as reserves of non-exchangeable K, soil texture, clay content/mineralogy, soil structure, organic matter content, effective rooting depth, characteristics of the sub-soil, water availability, yield potential, etc., need to be taken into account in order to improve the meaningfulness of exchangeable soil K values - a fact which has been stressed by a number of authors (e.g. Schlichting, 1986; Andres, 1990). However, if such information is not available or purposely omitted due to practical reasons, critical limits are more error-prone and thus require additional safety margins. In case of sugar beet based cropping systems in Germany a K soil content of 15 - 30 g K₂O / 100 g (CAL) is considered to be adequate in medium textured soils. Our results confirm this range with a strong tendency towards the upper limit. The same holds true for all cropping systems comprising "leafy crops" such as potato, oil seed rape, and maize.
SUGAR YIELD IN SOILS WITH OPTIMUM AND HIGH K CONTENT

For this long term experiment locations well supplied with potassium ("adequate" exchangeable K content, i.e. > 20 mg K₂O / 100 g - CAL extraction) in four major German sugar beet growing areas were selected. Part of the trial area was heavily fertilised with potash in order to increase the exchangeable K content significantly ("high" exchangeable K content, i.e. > 30 mg K₂O / 100 g, CAL). Subsequently sugar beet were grown every third year and fertilised with four different potash application rates, i.e. 0, 120, 240 and 360 kg K₂O/ha.

Results (Figure 1), averaging 4 locations and three sugar beet harvesting seasons, indicate that sugar yield was always higher in soils with "high" K content, even at a potash application rate of 360 kg K₂O/ha. The increase in sugar yield was caused mainly by higher beet yield, higher sugar content and, to some extend, by the improved content of extractable sugar (Figure 2).

Figure 1: Beet yield and sugar yield of sugar beet grown in soils with "adequate" and "high" potassium content (average of 4 locations and 3 harvesting seasons); (Orlovius, 1996b; Orlovius, pers. comm.)

THE NEW FORMULA FOR EXTRACTABLE SUGAR

Since alkalinity of the sugar beet juice has consistently been declining in the past, the sugar industry in Germany adopted in 1996 a new formula to calculate the percentage of extractable sugar:

Old: \[
\text{extract. sugar } = [0.343 \times (K+Na) + 0.094 \times N + 0.29]
\]

New: \[
\text{extract. sugar } = [0.120 \times (K+Na) + 0.240 \times N + 1.08]
\]
In the past potash commonly exhibited a clear influence on beet yield and sugar yield. However, extractable sugar was often not affected or in some cases even depressed, particularly at very high potash application rates. Now, the positive influence of potassium on quality is clearly reflected, as shown in Figure 2, using the experimental data base described for Figure 1. At the highest rate (360 kg K\textsubscript{2}O/ha) sugar content as well as extractable sugar content was 0.26 and 0.21 points, respectively, higher than the control (0 kg K\textsubscript{2}O/ha). In comparison, extractable sugar would have increased only by 0.10 points if the "old" formula, previously used by the German sugar industry, would have been applied.

**Figure 2:** Influence of the new formula on sugar percentage and extractable sugar in a long term experiment (average of 4 locations, 3 harvesting seasons and 2 levels of soil potassium; in retrospect)

![Figure 2](image)

**CONCLUSIONS**

- Under the prevailing conditions in Germany fertilising according to nutrient removal is causing a decrease in exchangeable K content in sugar beet growing areas.

- For sugar beet based cropping systems application rates should be on average 1.4 times higher than the quantity removed by the harvested products in order to keep soil levels constant and produce sugar yield.

- In potash demanding crops such as sugar beet, yield can only be achieved in soils having to "high" potassium soil content. Higher application rates can not fully compensate for lower K status of soils.

- Applying the new formula of the German sugar industry for calculating the extractable sugar content, the positive influence of potassium is now clearly and equally reflected in beet yield, sugar content and extractable sugar content.
REFERENCES