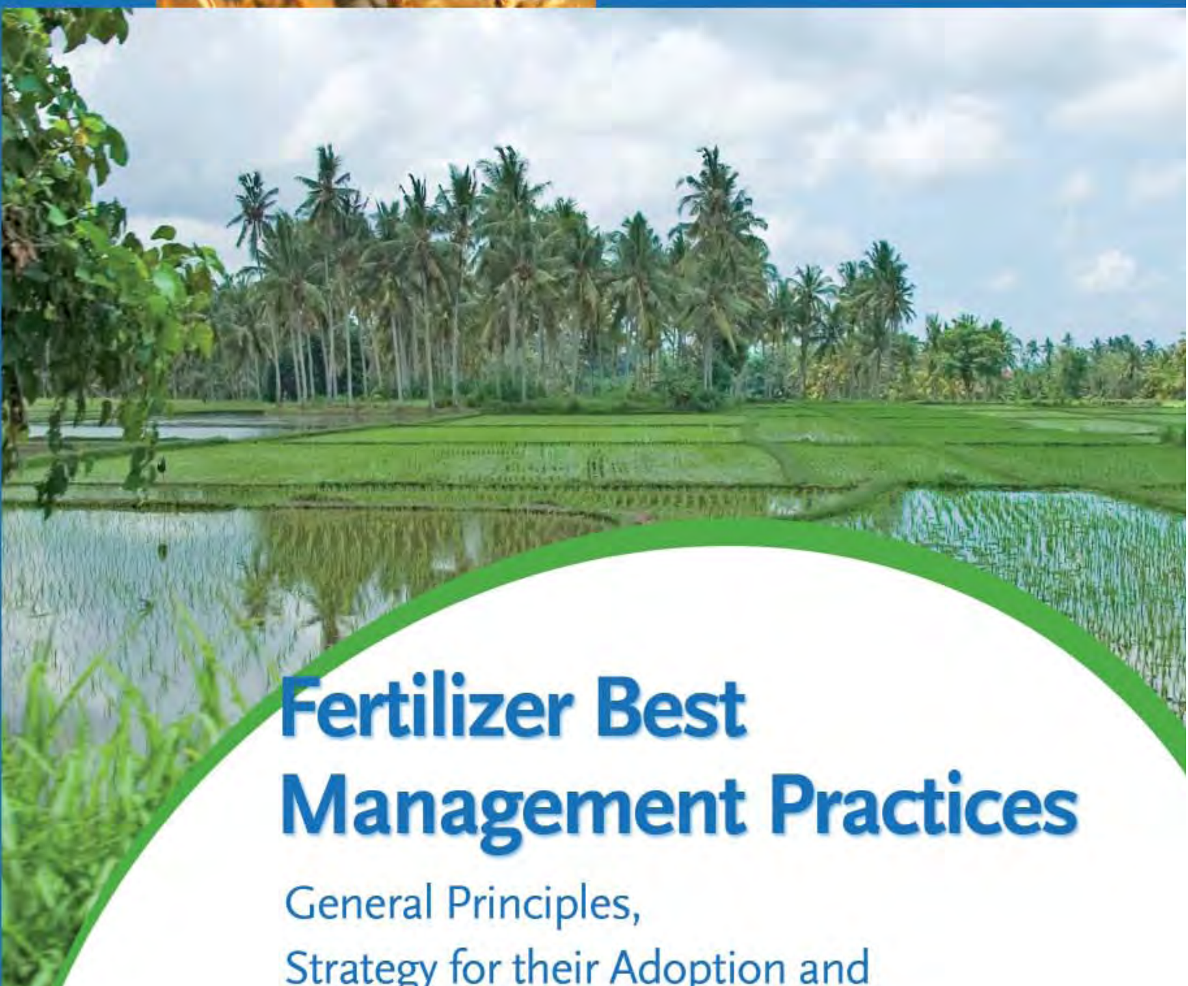
International Fertilizer Industry Association



Fertilizer Best Management Practices

General Principles,
Strategy for their Adoption and
Voluntary Initiatives vs Regulations

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Papers presented at the IFA International Workshop
on Fertilizer Best Management Practices
7-9 March 2007, Brussels, Belgium

International Fertilizer Industry Association
Paris, France, 2007

Fertilizer Best Management Practices
First edition, IFA, Paris, France, August 2007

ISBN 2-9523139-2-X

The publication can be downloaded from IFA's web site.
To obtain paper copies, contact IFA.

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Acknowledgements

The IFA Executive Committee decided in 2006 to launch an initiative on fertilizer best management practices (FBMPs). One component of that initiative was the organization of an International Workshop on Fertilizer Best Management Practices, which took place from 7 to 9 March 2007 in Brussels, Belgium. The workshop gathered some 40 participants from all continents and relevant stakeholder categories. It was aimed at (i) defining the general principles of FBMPs and the strategy for their wider adoption; (ii) defining the role of the fertilizer industry in developing and promoting FBMPs and listing priority areas for action; (iii) exchanging information on experiences; (iv) reviewing achievements and identifying gaps; and (v) understanding the actors and identifying the key partners. The workshop was conducted under the leadership of the Convenor of the IFA Task Force on Fertilizer Best Management Practices, Mr. R. Sinha from DSCL, India.

This book is a collection of all the papers submitted by the speakers. In addition to this book, all the papers and slides presented at the workshop are available in PDF format on IFA's website at www.fertilizer.org/ifa/publicat/bap/2007_brussels_fbmp.asp. No paper has been received for three contributions presented at the workshop, but the corresponding slides can be downloaded online.

The papers published in this book have been reviewed and edited by A. Krauss, K. Isherwood and P. Heffer. Many thanks to C. Aholou-Pütz and H. Ginet for the layout of the book and of the graphics in preparation for printing.

Nutrient use efficiency – measurement and management

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Nutrients in the global scheme

Mineral fertilizers have sustained world agriculture and thus global population and wealth growth for more than 100 years (Smil, 2001; Stewart *et al.*, 2005). Their contribution to increasing crop yields has spared millions of hectares of natural ecosystems that otherwise would have been converted to agriculture (Balmford *et al.*, 2005). However, lacking, imbalanced, inappropriate or excessive use of nutrients in agricultural systems remains a concern. Nutrient mining is a major cause for low crop yields in parts of the developing world, particularly Africa. In other situations, nutrients such as nitrogen (N) and phosphorus (P) often move beyond the bounds of the agricultural field because the management practices used fail to achieve good congruence between nutrient supply and crop nutrient demand (van Noordwijk and Cadisch, 2002). If left unchecked, such losses may bear significant costs to society (Mosier *et al.*, 2001). Hence, increasing nutrient use efficiency continues to be a major challenge for world agriculture.

This paper tries to summarize how the use efficiency of N, P and potassium (K) from mineral fertilizer is commonly defined and measured, what needs to be considered for interpreting such values, and how it can be improved through soil, crop and fertilizer management. It focuses on cereal systems because those consume the bulk of the world's fertilizer, but the principles discussed are similar in all agricultural crops. Where possible, attempts are made to discuss differences between developed and developing countries. Two key messages emerge: (i) Nutrient use efficiencies measured under practical farming conditions are mostly lower than those reported from research experiments, but information on current levels of fertilizer use and nutrient use efficiency by different crops, cropping systems and world regions remains insufficient; (ii) Numerous technologies for increasing nutrient use efficiency exist. They have been evaluated thoroughly, but adoption by farmers is lagging behind.

Measuring nutrient use efficiency

Agronomic indices for short-term assessment of nutrient use efficiency

Table 1 summarizes a set of simple indices that are frequently used in agronomic research to assess the efficiency of applied fertilizer (Novoa and Loomis, 1981; Cassman *et al.*, 2002), mainly for assessing the short-term crop response to a nutrient. A practical example is illustrated in Figure 1. Other indices are sometimes used (Gourley *et al.*, 1993; Huggins and Pan, 1993), but they have no additional advantages for understanding fertilizer best management practices (FBMPs). More detailed studies on the fate

Table 1. Indices of nutrient use efficiency, their calculation using the difference method, and their interpretation.

Index	Calculation	Interpretation	Nitrogen in cereals
RE = Apparent crop recovery efficiency of applied nutrient (kg increase in N uptake per kg N applied)	$RE=(U-U_0)/F$	• RE depends on the congruence between plant demand and nutrient release from fertilizer. • RE is affected by the application method (amount, timing, placement, N form) and factors that determine the size of the crop nutrient sink (genotype, climate, plant density, abiotic/biotic stresses).	0.30–0.50 kg/kg; 0.50–0.80 kg/kg in well-managed systems, at low levels of N use, or at low soil N supply
PE = Physiological efficiency of applied N (kg yield increase per kg increase in N uptake from fertilizer)	$PE=(Y-Y_0)/(U-U_0)$	• Ability of a plant to transform nutrients acquired from fertilizer into economic yield (grain). • Depends on genotype, environment and management. • Low PE suggests sub-optimal growth (nutrient deficiencies, drought stress, heat stress, mineral toxicities, pests).	40–60 kg/kg; >50 kg/kg in well-managed systems, at low levels of N use, or at low soil N supply
IE = Internal utilization efficiency of a nutrient (kg yield per kg nutrient uptake)	$IE=Y/U$	• Ability of a plant to transform nutrients acquired from all sources (soil, fertilizer) into economic yield (grain). • Depends on genotype, environment and management. • A very high IE suggests deficiency of that nutrient. • Low IE suggests poor internal nutrient conversion due to other stresses (nutrient deficiencies, drought stress, heat stress, mineral toxicities, pests).	30–90 kg/kg; 55-65 kg/kg is the optimal range for balanced nutrition at high yield levels

AE = Agronomic efficiency of applied nutrient (kg yield increase per kg nutrient applied)	$AE=(Y - Y_0)/F$ or $AE=RE \times PE$	• Product of nutrient recovery from mineral or organic fertilizer (RE) and the efficiency with which the plant uses each additional unit of nutrient (PE). • AE depends on management practices that affect RE and PE.	10–30 kg/kg; >25 kg/kg in well-managed systems, at low levels of N use, or at low soil N supply
PFP = Partial factor productivity of applied nutrient (kg harvested product per kg nutrient applied)	$PFP=Y/F$ or $PFP=(Yo/F) + AE$	• Most important for farmers because it integrates the use efficiency of both indigenous and applied nutrients. • High indigenous soil nutrient supply (Y_0) and high AE are equally important for PFP.	40–80 kg/kg; >60 kg/kg in well-managed systems, at low levels of N use, or at low soil N supply

F – amount of (fertilizer) nutrient applied (kg/ha)
Y – crop yield with applied nutrients (kg/ha)
Y_0 – crop yield (kg/ha) in a control treatment with no N
U – total plant nutrient uptake in aboveground biomass at maturity (kg/ha) in a plot that received fertilizer
U – total nutrient uptake in aboveground biomass at maturity (kg/ha) in a plot that received no fertilizer

of nutrients in agro-ecosystems often involve isotopes, which are particularly useful for understanding loss, immobilization, fixation and release mechanisms.

In field studies, nutrient use efficiencies are either calculated based on differences in crop yield and/or nutrient uptake between fertilized plots and an unfertilized control ('difference method', Table 1), or by using isotope-labeled fertilizers to estimate crop and soil recovery of applied nutrients. Time scale is usually one cropping season. Spatial scale for measurement is mostly a field or plot. For the same soil and cropping conditions, nutrient use efficiency generally decreases with increasing nutrient amount added (Figure 1). Crop yield (Y) and plant nutrient accumulation/uptake (U) typically increase with increasing nutrient addition (F) and gradually approach a ceiling (Figures 1a and 1c). The level of this ceiling is determined by the climatic-genetic yield potential. At low levels of nutrient supply, rates of increase in yield and nutrient uptake are large because the nutrient of interest is the primary factor limiting growth (de Wit, 1992). As nutrient supply increases, incremental yield gains become smaller because yield determinants other than that nutrient become more limiting as the yield potential is approached.

Because each of the indices in Table 1 has a different interpretation value, fertilizer research should include measurements of *several* indices to understand the factors governing nutrient uptake and fertilizer efficiency, to compare short-term nutrient use efficiency in different environments, and to evaluate different management strategies. The

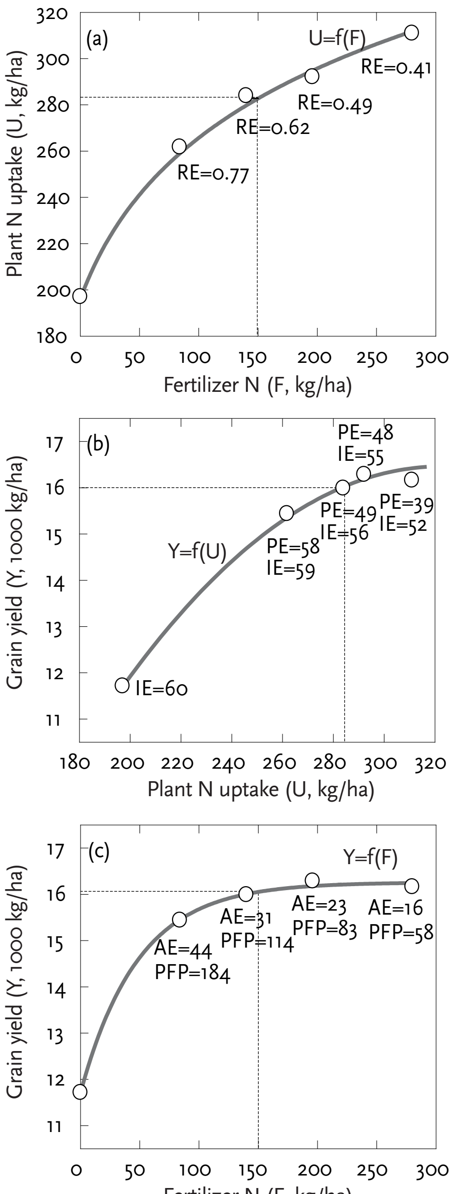

Figure 1. Response of irrigated maize to N application at Clay Center, Nebraska, USA: (a) relationship between plant N uptake (U) and N rate and the recovery efficiency of fertilizer N at four N rates; (b) relationship between grain yield (Y) and plant N uptake (U) and the physiological (PE) and internal efficiency (IE) of fertilizer N; (c) relationship between grain yield (Y) and N rate (F) and the agronomic efficiency (AE) and partial factor productivity (PFP) of applied N. Dashed lines indicate maximum profit (Dobermann and Cassman, 2004).

'difference method' is simple and cost-efficient, which makes it particularly suitable for on-farm research. However, sampling and measurement must be done with great care.

Interpretation must also consider potentially confounding factors. For example, agronomic efficiency (AE) and apparent recovery efficiency (RE) are not appropriate indices of nutrient use efficiency when comparing cropping practices such as crop establishment methods or different water management regimes when the crop yield in control treatments (Y_0) differs significantly because of these management practices. In these instances, partial factor productivity (the ratio of grain yield/nutrient amount applied, PFP) is a more appropriate index for making comparisons. Likewise, comparisons of RE and physiological efficiency (PE) among genotypes should use agronomically fit varieties and avoid comparison with 'inferior germplasm' not adapted to the particular growth conditions. Caution is required when using AE, RE or PE for assessing trends in nutrient use efficiency in long-term experiments because depletion of indigenous soil nutrient resources in permanent nutrient omission plots (0-N, 0-P or 0-K plots) will lead to overestimation of the true nutrient use efficiency in fertilized plots. For nitrogen, results obtained with the 'difference method' may also be confounded by added-N interactions, i.e. differences in N mineralization rates from soil organic matter and crop residues between +N and 0-N plots.

Agronomic indices only provide accurate assessment of nutrient use efficiency for systems that are at relatively steady-state with regard to soil nutrient content and where differences in root systems between unfertilized and fertilized crops are relatively small. For example, nitrogen in roots as well as any net accumulation of N from fertilizer in soil organic matter and its effect on the indigenous soil N supply for subsequently grown crops cannot be easily accounted for. This may lead to an underestimation of the overall *system level efficiency* of applied N inputs. In the example shown in Table 2, the average PFP of applied N suggested that the recommended management system was more N-efficient than the intensively managed system because it produced 70 kg grain/kg N applied (or 0.88 kg grain N/kg N applied) as opposed to 50 kg grain/kg N (or 0.65 kg grain N/kg N applied) in the intensive system. However, when the net change in soil N was included, both systems had nearly the same *system level* N use efficiency (0.92-1.01) because fertilizer-N contributed to build-up of soil organic matter in the intensive system. Over time, this will increase soil N supply, reduce the need for fertilizer, and increase PFP_N. Nutrient budgeting and isotope methods should be used to assess the fate of nutrients in the entire soil-crop-atmosphere system over different time periods and at different scales.

Nutrient budgets for medium- to long-term assessment

Nutrient budgeting approaches are used to evaluate system-level nutrient use efficiency and to understand nutrient cycling by estimating input, storage and export processes by mass balance. A surplus or deficit is a measure of the net depletion (output > input) or enrichment (output < input) of the system, or simply of the 'unaccounted for' nutrient. This approach is used in studies on the fate of nutrients, for medium- to long-term assessment of FBMPs, nutrient flows and their respective impact on soil and the environment in managed or natural ecosystems, and for regulatory purposes in industrialized countries.

Table 2. Nitrogen use efficiency in a long-term experiment with irrigated continuous maize systems (CC) managed at recommended (-rec) and intensive (-int) levels of plant density and fertilizer inputs. Total amounts for a five-year period (2000-2005) at Lincoln, Nebraska, USA.

2000-2005	CC-rec	CC-int
Average maize yield (t/ha/yr)	14.0	15.0
Fertilizer-N input (kg N/ha)	1005	1495
Nitrogen removal with grain (kg N/ha)	880	970
Measured change in total soil N (kg/ha)	139	404
N unaccounted for (kg/ha)	14	121
NUE 1: partial factor productivity (kg grain/kg N applied)	70	50
NUE 2: kg grain N/kg N applied	0.88	0.65
NUE 3: kg grain N + change in soil N/kg N applied	1.01	0.92

Nutrient budgets can be constructed for different time periods at any scale, ranging from small fields to whole countries or the globe. Budgets constructed for the purpose of guiding and regulating agricultural management or for policy decisions often consist of simple mass balances. For proper interpretation, methodologies must be clearly described and budgets should include statements about scales and uncertainties associated with the estimates (Oenema *et al.*, 2003). General methodologies for this have been proposed in recent years (Smaling and Fresco, 1993; Roy *et al.*, 2004), but the degree of detail depends on the purpose of budgeting and on the resources available to collect the information. Generally speaking, nutrient budgets for larger regions are often highly uncertain because of imprecise available information on key processes such as fertilizer input by different crops and cropping systems, N input from atmospheric deposition and biological N fixation, and gaseous, leaching and runoff losses.

Most common are partial budgets that do not include all inputs or outputs or make assumptions about those that are difficult to quantify at the scale of interest. For a correct interpretation, nutrient budgets must be compared with the nutrient stock in the soil and its availability. A negative nutrient balance on a soil that has excessive levels of that nutrient is not necessarily bad. Likewise, a neutral nutrient balance indicates that the total stock in the soil does not change, but the 'quality' of the stock, and hence soil fertility, may still alter. Hence, a differentiation between 'available' and 'not-immediately available' nutrients is useful in nutrient balance studies, but has only been attempted occasionally (Janssen, 1999; Hoa *et al.*, 2006). Table 3 shows different K balances for an irrigated rice system in South Vietnam. Partial K budgets resulted in K balance estimates that were too negative because of neglected K inputs via rain, irrigation water and sediments. Irrespective of fertilizer-K input, large annual K input from sediments resulted in a positive balance of total K, but most of this was not plant-available.

Table 3. Comparison of partial and complete K input-output budgets in two treatments of a long-term experiment with irrigated double-cropping of rice at Omon, Vietnam. NP: no K fertilizer; NPK: 150 kg K/ha/yr (Hoa *et al.*, 2006).

K budget (kg K/ha/yr)	NP	NPK
Balance of soluble K (partial budget)	-92	22
Balance of soluble K (complete budget)	-69	44
Balance of labile K (NH_4-acetate K, complete budget)	-66	47
Balance of non-labile K (NaTPB-K, complete budget)	-58	55
Balance of total K (complete budget)	251	364

Partial budget: Inputs: fertilizer; Outputs: crop K removal with grain and straw
Complete budget: Inputs: fertilizer, rain water, irrigation water, sediments from annual flood; Outputs: crop K removal with grain and straw, leaching, runoff, sediment removal

Current status of nutrient use efficiency

Nitrogen

World consumption of N fertilizers has averaged 83-85 million metric tonnes (Mt) in recent years, with nearly 60% of that amount applied to cereal crops (Table 4). At a global scale, cereal production (slope = 31 Mt/year), cereal yields (slope = 45 kg/year), and fertilizer N consumption (slope = 2 Mt/year) have all increased in a near-linear fashion during the past 40 years. However, significant differences exist among world regions with regard to N use efficiency (Table 4). At global or regional scales, PFP_N (Table 1) is the only index of N use efficiency that can be estimated more easily, although not very precisely because of uncertainties about the actual N use by different crops and about crop production statistics. Because PFP is a ratio, it always declines from large values at small N application rates to smaller values at high N application rates. Thus, differences in the average cereal PFP_N among world regions depend on which cereal crops are grown, their attainable yield potential, soil quality, amount and form of N application, and the overall timeliness and quality of other crop management operations.

Globally, PFP_N in cereal production has decreased from 245 kg grain/kg N applied in 1961/65, to 52 kg/kg in 1981/85, and is currently about 44 kg/kg. This decrease in PFP_N occurs as farmers move yields higher along a fixed response function unless offsetting factors, such as improved management that remove constraints on yield, shift the response function up. In other words, an initial decline in PFP_N is an expected consequence of the adoption of N fertilizers by farmers and not necessarily bad within a system context.

In many developed countries, cereal yields have continued to increase in the past 20 years without significant increases in N fertilizer use, or even with substantial declines in N use in some areas. This has resulted in steady increases of PFP_N in Western Europe (rainfed cereals systems), North America (rainfed and irrigated maize), Japan and South Korea (irrigated rice) since the mid 1980s (Dobermann and Cassman, 2005). At present, average cereal yields in these regions are 60 to 100% above the world average, even though the N rates applied are only 30 to 60% above world average rates (Table 4). High yields and high PFP_N in these regions result from a combination of fertile soils, favorable climate and excellent management practices. Investments in crop improvement (high yielding varieties with stress tolerance), new fertilizer products and application technologies, algorithms and support services for better fertilizer recommendations, better soil and crop management technologies, extension education, and local regulation of excessive N use by both the public and the private sector have contributed to the increase in N use efficiency (Cassman *et al.*, 2002; IFA, 2007). It is likely that this trend will continue.

In developing regions, N fertilizer use was small in the early 1960s and increased exponentially during the course of the Green Revolution. The large increase in N use since the 1960s resulted in a steep decrease in PFP_N in all developing regions. Regional N rates on cereals range from less than 10 kg N/ha in Africa to more than 150 kg N/ha in East Asia (Table 4) and, with the exception of Africa, PFP_N continues to decline in all developing regions at rates of –1 to –2%/year (Dobermann and Cassman, 2005). The very high PFP_N in Africa (122 kg/kg N applied) and Eastern Europe/Central Asia (84 kg/kg) are indicative of unsustainable soil N mining due to low N rates used at present. In some countries, e.g. India, PFP_N seems to have leveled off in recent years, but in many other developing countries it continues to decline because public and private sector investments in better technologies, services and extension education are far below those made in developed countries. Except for research and limited on-farm demonstrations, there are no documented cases for country-scale increase in N use efficiency in a developing country that could be ascribed to adoption of better N management technologies.

How does this compare with more detailed field-level measurements of N use efficiency? A clear distinction must be made between field experiments conducted under more controlled conditions in research stations and values measured on-farm, under practical farming conditions (Table 5). The latter are scarce in the literature, but from the few available studies it is clear that actual N use efficiency is substantially lower in most farms than what is achieved in research experiments. For example, in the worldwide research trials summarized by Ladha *et al.* (2005), the average RE_N in research plots was 46% in rice, 57% in wheat and 65% in maize, with a 'global' mean of 55% (Table 5). This is even higher than Smil's (1999) estimate, who suggested that, on a global scale, about half of all anthropogenic N inputs on croplands are taken up by harvested crops and their residues. In contrast, the few available on-farm studies suggest that average RE_N values are more commonly in the 30-40% range (Table 5). Similar differences between research trials and on-farm studies occur for other indices of N use efficiency (Table 5). Notably, average PFP_N in on-farm studies conducted in developing countries ranged from 44 to 49 kg/kg N, which is close to the estimated 'global' average of 44 kg/kg N (Table 4).

Lower N use efficiency in farmers' fields is usually explained by a lower level of management quality under practical farming conditions and greater spatial variability of factors controlling RE_N, PE_N and PFP_N (Cassman *et al.*, 2002). This is further supported

Table 4. Cereal production, N fertilizer use on cereals, and cereal N use efficiency by world regions. Annual means for 1999 to 2002/03 (Dobermann and Cassman, 2005).

	Developed					Transitional/Developing						World
	North America	NE Asia	West Europe	E Europe C Asia	Oceania	Africa	W Asia NE Africa	South Asia	SE Asia	East Asia	Latin America	
Cereal prod. (Mt)	377	19	208	216	34	98	81	307	141	447	144	2072
Cereal yield (t/ha)	5.1	6.1	5.5	2.1	1.9	1.1	2.3	2.4	3.2	4.8	2.9	3.1
Total N use (Mt)[1]	12.5	0.9	9.5	4.9	1.3	1.4	4.2	14.6	4.0	24.9	5.1	83.2
Cereal share N (%)[2]	66	32	45	51	67	56	56	50	71	58	53	57
N use cereals (Mt)	8.3	0.3	4.3	2.5	0.9	0.8	2.4	7.3	2.8	14.5	2.7	46.7
N rate (kg N/ha)[3]	112	89	113	25	48	9	68	58	65	155	55	70
PFP_N (kg/kg)[4]	45	68	49	84	40	122	34	41	49	31	53	44
Relative PFP[5]	1.0	1.6	1.4	2.1	1.1	2.8	0.8	1.0	1.2	0.7	1.3	1.0

[1] Total fertilizer N consumption by all crops (FAO, 2004)
[2] Estimated share of cereal N use of total N consumption, calculated as weighted average of country-specific estimates of fertilizer use by crops (IFA, 2002). Weights were proportional to N use by countries
[3] Estimated average N application rate on all cereal crops
[4] Average partial factor productivity of applied N = kg grain yield per kg N applied
[5] PFP_N relative to world average (World = 1)

by the fact that in the on-farm studies cited (Table 5), N use efficiency varied widely among farmers in the domains sampled, with good farmers already achieving RE_N in the 50-80% range. For example, in widespread on-farm research on irrigated rice in Asia, average RE_N by farmers was only 31% (Table 5), but the top 25% of farmers exceeded RE_N levels of 42%. When a site-specific management was used in the same fields, average RE_N increased to 40% and the top quartile exceeded 53% (Dobermann *et al.*, 2002).

Considering this, N use efficiency achieved in research trials may serve as a reasonable indicator of what can be targeted with good management. It should be noted, however, that this holds only true for short-term field trials that represent N carry-over situations similar to those in farmers' fields, where fertilizer is commonly applied. In long-term experiments with stationary treatment plots, soil N depletion in control plots leads to bias in estimating N use efficiency by the difference method (Table 1), i.e. where soil N is gradually depleted the calculated N use efficiency will steadily rise over time. This methodological problem can only be overcome by using experimental designs with non-stationary treatment plots or by occasionally embedding 0-N microplots within N treatment plots and using those for estimating N use efficiency. This is not common yet. Hence, it is likely that the higher N use efficiencies reported in the literature for research station trials (Ladha *et al.*, 2005) have at least been partially inflated by such bias.

In general, for systems that are near steady-state, ^{15}N methods tend to produce results that are well correlated with those obtained with the difference method (Cassman *et al.*, 2002). Overall, RE_N values obtained with ^{15}N are often somewhat lower than those estimated with the difference method because of confounding effects caused by pool substitution, i.e. immobilization of ^{15}N fertilizer in microbial biomass and initial release of microbial-derived ^{14}N. Ladha *et al.* (2005) estimated an average 'global' RE_N for cereal research trials of 55% measured with the difference method as compared to 44% measured with the ^{15}N method. However, their summary of literature data was not restricted to paired comparisons at the same sites. ^{15}N has the added advantage of allowing to also quantifying N recovery in subsequently grown crops. Typically, in addition to the first-crop RE_N, another 5-6% of the fertilizer-N applied is recovered over a period of five subsequent crops grown after harvesting the first crop (IAEA, 2003; Ladha *et al.*, 2005). Thus, total crop N recovery from a one-time application of N averages about 50 to 60% in research trials with cereals or 40-50% under most on-farm conditions. The remainder is mostly lost from the cropping system.

In summary, the shortage of information on farm-level N use efficiency in key cropping systems has hampered efforts on designing the right N management strategies for reducing reactive N loads and increasing farm-level profitability (Cassman *et al.*, 2002). It is reasonable to assume that, on a global scale, at least 50% of the fertilizer-N applied is lost from agricultural systems and most of these losses occur during the year of fertilizer application. However, it has also been demonstrated through research, the best farmers and commercial implementation of new N management technologies that 30 to 50% increases in N use efficiency can be achieved in many crops (Dobermann and Cassman, 2004; Giller e*t al.*, 2004).

Table 5. Average N use efficiency terms for cereals in different world regions: literature summary of field trials conducted at research stations and averages of selected on-farm studies.

Region/crop	N rate	RE_{15N}	RE_N	PE_N	AE_N	PFP_N
	(kg/ha)			(kg/kg)		
Research station trials (stationary treatment plots) [1]						
Africa	139	0.37	0.63	23	14	39
Europe	100	0.61	0.68	28	21	50
America	111	0.36	0.52	28	20	50
Asia	115	0.44	0.50	47	22	54
Average		*0.44*	*0.55*	*41*	*21*	*52*
Maize (rainfed & irrigated)	123	0.40	0.65	37	24	72
Rice (irrigated)	115	0.44	0.46	53	22	62
Wheat (rainfed & irrigated)	112	0.45	0.57	29	18	45
On-farm studies (non-stationary treatment plots)						
Maize, USA (rainfed & irrigated)[2]	158	-	0.36	33	12	61
Maize, USA (irrigated)[3]	142	-	0.57	41	23	94
Maize, Indonesia (rainfed & irrigated)[4]	200	-	0.37	46	17	46
Rice in S, E and SE Asia (irrigated)[5]	117	-	0.31	39	12	49
Rice in West Africa (irrigated)[6]	106	-	0.36	47	17	46
Wheat in North India (irrigated)[7]	134	-	0.34	32	11	44

RE_{15N} – average N recovery efficiency measured with the ^{15}N isotope dilution method.
All other N use efficiency terms – difference method, as described in Table 1

[1] Research station trials summarized by Ladha *et al.*, 2005. Most of those are multi-year or long-term trials with stationary treatment plots

[2] 52 sites in IL, KS, MI, MN, MO, NE and WI, 1995-1998 (Cassman *et al.*, 2002)

[3] 32 site-years in Nebraska, 2001-2004 (Dobermann *et al.*, 2006)

[4] 25 farms in Indonesia, 2004-2005, at N rate of 200 kg N/ha (Witt *et al.*, 2006)

[5] Farmers' fertilizer practice, 179 farms in China, India, Vietnam, Indonesia and the Philippines, 1997-1999 (Dobermann *et al.*, 2002)

[6] Farmers' fertilizer practice, 151 farms in West Africa (Wopereis *et al.*, 1999; Haefele *et al.*, 2001)

[7] Farmers' fertilizer practice, 23 farms in Uttar Pradesh, 1998-1999

Phosphorus

The global patterns of P supply, consumption and waste production have become decoupled from natural P cycles (Tiessen, 1995). Global mobilization of P has roughly tripled compared to its natural flows, and global food production is now highly dependent on the continuing use of phosphates (Smil, 2000). Although most crops use P efficiently, lost P that reaches aquatic ecosystems downstream from agricultural areas is a main cause of eutrophication. Phosphorus surpluses due to fertilizer use, livestock industry and imports of feed and food have become widespread in industrialized countries. In contrast, both P surpluses and deficits are found in developing countries, including a large area of P deficient soils (largely in the tropics) for which additions of P are the only way to increase agricultural productivity and income.

Global agricultural P budgets (inputs are fertilizers and manures and outputs are agricultural products and runoff) indicate that average P accumulation in agricultural areas of the world is approximately 8-9 Mt P/year (Bennett *et al.*, 2001). Although this annual P accumulation has remained unchanged since the 1980s and appears to decline in recent years, cumulative P accumulation resulting from agriculture has reached more than 300 Mt P since 1960 (Bennett *et al.*, 2001). Rates of P accumulation on agricultural land have started to decline in many developed countries, but are still rising in many developing countries. Forty years ago, developing countries were net exporters of P from agricultural land, but they now accumulate more P per year than developed countries, accounting for 5 of the 8 Mt P/year total global P accumulation on agricultural lands (Bennett et *al.*, 2001).

Great diversity exists in P budgets among countries, within a country, or even between fields in the same farm. Nutrients audits for China suggest average annual P losses of 5 kg P/ha agricultural land (Sheldrick *et al.*, 2003). Similarly, an annual P loss of 3 kg P/ha was estimated for 38 countries of Sub-Saharan Africa (Stoorvogel *et al.*, 1993). In contrast, on-farm studies conducted in China, India, Indonesia, Thailand and the Philippines showed an average annual P surplus of 12 kg P/ha under double-cropping of irrigated rice (Dobermann and Cassman, 2002).

About two thirds of the world's P fertilizer is applied to cereals, mostly to wheat, rice and maize (FAO, 2002), but, because of lacking on-farm studies, it is difficult to judge the 'global' efficiency of fertilizer P. On responsive soils, P applications typically result in cereal yield increases (AE_P) of 20 to more than 50 kg grain/kg P applied. Under favorable growth conditions, most agricultural crops recover 20 to 30% of applied P during their growth. Much of the remainder accumulates in the soil and is eventually recovered by subsequent crops over time, but even small amounts of losses as runoff (particulate and dissolved P) or leaching can cause secondary off-site impacts. Table 6 summarizes RE_P values for a large number of field studies on rice, wheat and maize in Asia, mostly on soils with low P fixation and under favorable climate and management. For all three crops, average RE_P was similar (0.22 to 0.27 kg/kg P applied). However, in each of these studies RE_P varied widely, from 0 to nearly 100% recovery. Most common RE_P values (50% of all data) ranged from 0.10 to 0.35 kg/kg, which probably applies to the majority of agricultural land in the world.

Potassium

Global potassium flows are widely unbalanced because recoverable natural K resources are concentrated at few locations (Sheldrick, 1985) and potash use varies. Roughly 96% of all potash is produced in North America, Western and Eastern Europe and the Middle East. There is virtually no production in Africa and Oceania and only small amounts are produced in South America and Asia. As a result, large amounts of potash fertilizers are shipped around the globe to satisfy the needs of crop production for this important macronutrient. Fortunately, potassium is environmentally benign and its major role is that of increasing crop productivity.

In most developed countries, particularly in Europe, K use has been historically large and sufficient to sustain soil fertility and crop production at high levels. However, K use has declined in recent years. As a result, average crop K removal rates approach or exceed K inputs in these areas and many farmers appear to take advantage of mining soil K that had been accumulated over time. In many developing countries, K input-output budgets in agriculture are highly negative. Nutrient audits have been conducted for several developing countries (Sheldrick *et al.*, 2002) and they mostly show a negative K balance. Although K use has increased on agricultural land in China during the past 20 years, its overall annual K budget remains highly negative at about minus 60 kg K/ha. Similar estimates for India and Indonesia suggest annual K losses of about 20 to 40 kg K/ha and those have been increasing steadily during the past 40 years. An average annual K loss of nearly 20 kg K/ha was estimated for the whole of Sub-Saharan Africa (Stoorvogel *et al.*, 1993).

Table 6 summarizes RE_K values for a large number of field studies on rice, wheat and maize in Asia. Average RE_K ranged from about 0.4 to 0.5 kg/kg K. On soil with low K-fixation potential, with good management (high yield) and at relatively low K rates, RE_K is often in the 0.5 to 0.6 kg/kg range. In general, on-farm estimates of K use efficiency are scarce.

Table 6. Average recovery efficiencies (kg/kg) of N, P and K from mineral fertilizers in field trials with rice, wheat and maize in Asia. Values shown refer to recommended fertilizer rates (rice, wheat and maize) or those currently applied by farmers (rice).

Data set	RE_N	RE_P	RE_K
Rice in S, E and SE Asia, farmers' practice	0.33	0.24	0.38
Rice in S, E and SE Asia, site-specific management	0.43	0.25	0.44
Wheat in India	0.58	0.27	0.51
Wheat in China	0.45	0.22	0.47
Maize in China	0.50	0.24	0.44

Rice: 179 farmers' fields in five countries, 1997-1998, N=314, (Witt and Dobermann, 2004)
Wheat in India: field trials at 22 sites, 1970-1998. 120-26-50 kg/ha NPK (Pathak *et al.*, 2003)
Wheat and maize in China: field trials across China, 1985-1995 (Liu *et al.*, 2006)

Management strategies for increasing nutrient use efficiency

Nitrogen

On a global scale, higher crop yields are likely to be achieved through a combination of increased N applications in regions with low N fertilizer use, such as Africa and parts of Asia and Latin America, and improved N fertilizer efficiency in countries where current N fertilizer use is already high. The global PFP_N in cereals needs to increase at a rate of 0.1 to 0.4%/year to meet cereal demand in 2025 at a modest pace of increased N consumption (Dobermann and Cassman, 2005). Such and far greater rates of increase have been achieved in several countries. In the UK, average cereal PFP_N rose from 36 kg/kg in 1981/85 to 44 kg/kg by 2001/02 (+23%, 1.1%/year). In the USA, annual surveys of cropping practices indicate that PFP_N in maize increased from 42 kg/kg in 1980 to 57 kg/kg in 2000 (+36%, 1.6%/year)(Dobermann and Cassman, 2002). In Japan, PFP_N of irrigated rice remained unchanged at about 57 kg/kg from 1961 to 1985, but it increased to more than 75 kg/kg (+32%, 1.8%/year) since then (Mishima, 2001).

Approaches for N management and increasing N use efficiency have been discussed in many recent publications (Schroeder *et al.*, 2000; Cassman *et al.*, 2002; Dobermann and Cassman, 2004; Giller *et al.*, 2004; Lemaire *et al.*, 2004; Ladha *et al.*, 2005; McNeill *et al.*, 2005; Lobell, 2007; IFA, 2007). The bullet points listed below re-iterate some of the major considerations.

- Knowing and managing the N supply from soil and other indigenous sources and maximizing the fertilizer efficiency ($AE_N = RE_N \times PE_N$) are equally important components for achieving high PFP_N. Because the relationship between yield and N uptake is tight and because losses of fertilizer-N are highest during the year of application, maximizing the first crop recovery of N from mineral fertilizer or organic amendments (RE_N) is of particular importance. In modern cereal production systems, management should aim to achieve AE_N of 20-35 kg grain/kg N applied. Typically, this requires an RE_N of 0.5-0.7 kg/kg.
- Achievable levels of RE_N depend on crop demand for N, supply of N from indigenous sources, fertilizer rate, timing, product and mode of application. Figure 2 illustrates these relationships by using a simple nutrient supply - demand index. With other factors held constant, RE_N declines with either increasing N rate, higher indigenous N supply or a smaller crop N sink. For any given level of the index, the range in RE_N between the minimum and maximum lines represents other factors, including those that can be controlled by better timing of N applications or other management factors. Changing only one component through a specific technology will not result in the maximum levels of RE_N and profit possible. Holistic management concepts are required that jointly optimize (1) the crop N sink for a specific environment and (2) the availability of soil and fertilizer-N for plant uptake at critical growth stages.
- Many technologies have synergistic effects on crop yield response to N. Hence, they must be applied in an integrated manner:
  1. **Optimize the crop N sink** and the internal plant N utilization: genetic improvements (yield potential and abiotic/biotic stress tolerance, N harvest index), understanding and exploiting the seasonal yield potential, removal of other constraints

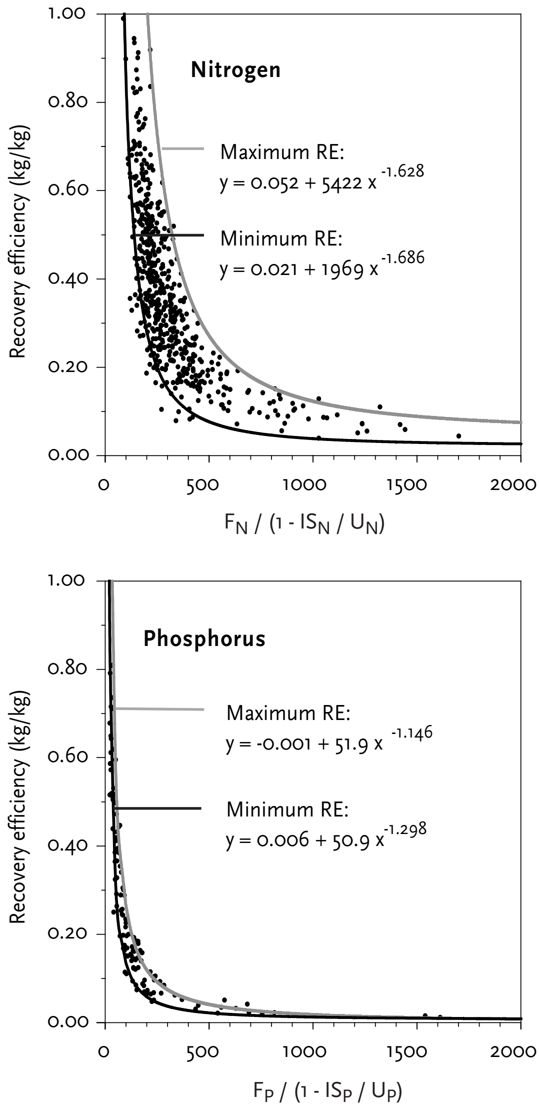

Figure 2. Influence of fertilizer rate (F, kg/ha), effective nutrient supply from indigenous sources such as soil, crop residues, manure or water (IS, kg/ha) and crop nutrient uptake (U, kg/ha) on the range of recovery efficiencies of N and P from applied fertilizer in irrigated rice. Values shown are based on on-farm studies conducted at 179 field sites in Asia during 1997-1998 (Witt and Dobermann, unpublished). F/(1-IS/U) represents a nutrient supply and demand index that determines how efficiently added nutrients are utilized.

for crop growth and internal N utilization (crop establishment, balanced nutrition, optimal water use, control weeds, insects and diseases).

2. **Manage soil and fertilizer-N** for better congruence with crop N uptake: better (site-specific) prescription algorithms, better timing of N applications according to phenological stages, more efficient N application methods, more efficient fertilizers (new N forms, modified fertilizers and inhibitors that lead to slow/controlled release), residue management for sustaining/increasing the indigenous soil N supply.

- Modern concepts for tactical N management should involve a combination of anticipatory (before planting) and responsive (during the growing season) decisions. Uncertainties in the prediction of the seasonal crop N demand require the use of N status indicators for fine-tuning of N rates and timing of N applications. This is of particular importance for high-yielding systems, but also for risk management in systems with relatively low N input. Crop-based approaches for in-season N management are now becoming widely available, ranging from simple tools such as a leaf color chart to crop simulation models or sophisticated on-the-go sensing and variable N rate application systems.
- Enhanced-efficiency N fertilizers have a theoretical advantage over other more knowledge-intensive forms of N management because the knowledge is 'embedded' in the product to be applied. As experience with seeds shows, embedded knowledge can lead to high adoption rates by farmers, provided that the benefit/cost ratio is high. Improved fertilizer products can thus play an important role in the global quest for increasing N use efficiency, but their relative importance will vary by regions and cropping systems.
- Managing N in organic farming systems is as challenging as managing N from mineral fertilizer sources and must follow the same principles.
- Increasing N use efficiency must be accomplished at the farm level through a combination of improved technologies and local policies that support the adoption of such technologies. New technologies must be profitable and robust, provide consistent and large enough gains in N use efficiency, and involve little extra time. If a new technology leads to at least a small, consistent increase in crop yield with the same amount or less N applied, the resulting increase in profit is usually attractive enough for a farmer. Where yield increases are more difficult to achieve, where increasing crop yield is of less priority, or where reducing reactive N is the top societal priority, adoption of new technologies that increase N use efficiency but have little effect on farm profit needs to be supported by appropriate incentives.

Phosphorus and potassium

Understanding and management of P and K in agriculture have advanced much. Much of the current knowledge has been captured in models and decision support systems for predicting soil and crop response to P and K (Wolf *et al.*, 1987; Janssen *et al.*, 1990; Greenwood and Karpinets, 1997; Chen *et al.*, 1997; Greenwood *et al.*, 2001; Karpinets *et al.*, 2004; Witt *et al.*, 2005; Smalberger *et al.*, 2006). Other models have been developed for simulating P and K in the rhizosphere of plants, predicting the fate of fertilizer in the soil, or predicting leaching and runoff losses. The main challenge for improving P and K use efficiency at the farm level is to apply the existing knowledge in a practical manner. Major considerations include:

- Cereals take up 2-3 kg P for each tonne of grain yield produced, 70-80% of which is removed from the field with the grain. In modern cereal production systems with no severe P fixation, management should aim to achieve AE_P of 30-50 kg grain/kg P applied. This requires an RE_P of 0.15-0.30 kg/kg. Because of its different physiological role, the relationship between crop yield and crop K uptake can vary widely, making it difficult to specify meaningful target values for K use efficiency. In cereals, AE_K of 10-20 kg grain/kg K applied and RE_K of 0.40-0.60 kg/kg are realistic targets on soils that do not have high available K reserves.
- On soils with low P or K status and/or high fixation capacity, capital investments are required to build-up soil nutrients to levels until the system becomes profitable and sustainable. This needs to be accompanied by other soil and crop improvement measures to ensure profitability. Adopted germplasm with improved P acquisition from more recalcitrant soil P pools and/or increased internal P utilization can be part of such an approach. Cumulative effects of repeated P additions on acid tropical soils are often more economical than single, large doses, primarily because of increasing RE_P and AE_P (Cassman *et al.*, 1993). Similar principles apply to the K management on K-fixing soils (Cassman *et al.*, 1989). The science for this is well understood, but, in the developing world, farmers require initial financial support for implementing such approaches.
- On soils with moderate P and K levels and little fixation, management must focus on balancing inputs and outputs at field and farm scales to maximize profit, avoid excessive accumulation, and minimize risk of P losses. This requires adequate prescription algorithms for calculating fertilizer requirements as a function of the effective soil supply, net crop removal, fertilizer recovery and the overall input-output balance. Replacement strategies are often most sustainable for such situations (Djodjic *et al.*, 2005), but they require accurate accounting of net P and K removal by crops and inputs of these nutrients from other sources, particularly manure (P) and water (K, Table 3). Soil testing is widely used in developed countries for guiding P and K management decisions by farmers. In the developing world, such services are rarely available, but alternative, crop-based approaches have been developed for site-specific P and K management under such conditions (Witt *et al.*, 2004a).
- Eliminate other factors that cause low P or K use efficiency – optimize crop management. Table 7 provides an example for this from a long-term experiment with rice in China. When no P was applied (NK treatment), rice had a high internal P efficiency (IE_P = 590 kg/kg), indicating P deficiency. Adding P but skipping K (NP treatment) alleviated the P deficiency (IE_P = 345 kg/kg), but, because the system was K-deficient, resulted in sub-optimal yield increase and an uneconomical soil P accumulation. With balanced fertilization (NPK), yield increased, primarily due to an increase in RE_P and hence AE_P and PFP_P.
- In developing countries, many P and K recommendations are based on field trials that emphasize short-term crop response to nutrient applications. Although the ini-

Table 7. Average rice yield (at 14% moisture), plant nutrient uptake, P use efficiencies and cumulative P mass balance of eight consecutive rice crops grown at Jinhua, China from 1997 to 2000 (Modified from Zhang *et al.*, 2006).

	Control	NK	NP	NPK
Grain yield (t/ha)	2.7d	4.2c	4.9b	5.7a
N uptake (kg/ha)	37d	75c	83b	89a
P uptake (kg/ha)	6d	8c	15b	17a
K uptake (kg/ha)	43d	78b	58c	93a
IE of P (kg grain/kg P)	497b	590a	345c	352c
RE of fertilizer-P (kg P/kg P applied)			0.28b	0.35a
PE of fertilizer-P (kg grain/kg P)			157a	171a
AE of fertilizer-P (kg grain/kg P)			44b	60a
PFP of fertilizer-P (kg grain/kg P)			196b	226a
P input-output budget (kg P/ha/year)	-12c	-16d	21a	17b

Within each row, means followed by the same letter are not significantly different at $P<0.05$ level.

tial yield response of cereals to P or K applications is often small, large cumulative yield increases can accrue over time. In the example shown in Figure 3, initial yield increases due to P or K application were not significant (<0.5 t/ha). However, yield increases were consistent and became larger over time as plant available soil P and K became exhausted. Neglecting P or K application caused a grain production loss of 16.5 or 11 t/ha, respectively.

- Most of the K taken up by plants is contained in vegetative plant parts. Improving the internal, on-farm and field recycling is the most important K management issue worldwide. Key components of this are better crop residue and organic waste management to avoid depletion of soils (developing countries) and a re-distribute nutrients from confined livestock operations back to agricultural land (Bijay-Singh *et al.*, 2004; Öborn *et al.*, 2005).
- As for N, the primary determinants for RE_P and RE_K are the size of the crop sink, soil supply and fertilizer rate (Figure 2). However, RE_P and RE_K also depend strongly on soil characteristics determining fixation of P or K in more recalcitrant soil fractions or losses by leaching or runoff. Hence, FBMPs for P and K must also consider the specific characteristics of crops, cropping systems, environments and soils. Examples include:
  - Site-specific measures for preventing runoff and erosion losses of P, e.g. no-till farming, terracing or buffer strips;
  - Band placement of P or K fertilizer in no-till systems to improve nutrient availability during early growth (Bordoli and Mallarino, 1998; Vyn and Janovicek, 2001);
  - Band placement of fluid P fertilizer on calcareous soils with high P fixation capacity;

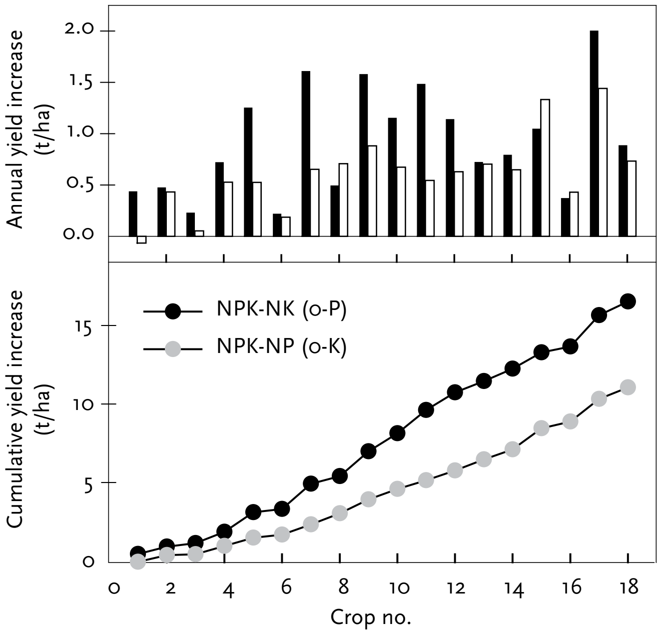

Figure 3. Annual and cumulative yield increases of irrigated rice due to P or K applied to each crop on a Vertisol at Maligaya, Philippines, 1968-76 (Witt *et al.*, 2004b).

- P management in rice-wheat: apply more P to wheat than rice to account for different P availability under aerobic and anaerobic conditions (Yadvinder-Singh *et al.*, 2000);
- Reduced K rates on soils with very high indigenous K supply from minerals or irrigation or for crops with high capability for mobilizing non-exchangeable K;
- Splitting of K applications to minimize leaching, increase stalk strength and resistance to diseases, and improve the quality of harvested products;
- Site-specific management of spatial variability in soil supply and/or crop removal (yield) through variable-rate application of P or K.

Summary and outlook

In North America and West Europe, future increases in fertilizer consumption will be slow or advanced technologies will even allow further reduction of N use without loss of crop production. Farm-level and regional nutrient budgeting are of particular importance in these regions. In many parts of Asia and South America, emphasis will be on improving N use efficiency and ensuring more balanced fertilization, particularly of K and micronutrients. In Sub-Saharan Africa, we hope to enter the beginning stages of a Green Revolution, including adoption of mineral fertilizers. This will require appropriate infrastructure and education.

Both agronomic indices (short-term) and nutrient budgets (medium- to long-term) are important tools for designing FBMPs that fulfill the needs of producers and those of the general public. Fertilizer management strategies should be balanced with regard to achieving high short-term efficiency as well as maximizing the cumulative crop yield response over time. Long-term benefits accruing from residual fertilizer availability (P, K) or increases in soil C and N storage should be included in assessing the *system level efficiency* of applied nutrients. Quantifying the true status of nutrient use efficiency in agriculture remains, however, difficult because reliable farm level data are not widely available. Data on fertilizer use by individual crops within countries and regions are notoriously difficult to obtain and we do not have reliable time series.

Experience from various developed countries has demonstrated that trends of declining N use efficiency can be reversed with the promotion of improved technologies. Research trials and the world's best farmers provide an indication of what levels of nutrient use efficiency can be achieved in both developed and developing countries. Particularly for nitrogen, the gap between achievable targets and current levels of fertilizer use efficiency is still large. Ample knowledge exists on what governs nutrient use efficiency. Public and private sector research and development have resulted in numerous technologies, tools and regulatory activities for increasing nutrient use efficiency under practical farming conditions, as illustrated by the examples shown in Table 8. Because the use efficiencies of all major nutrients are driven by a multitude of site-specific biophysical and socioeconomic factors, improvement is only possible by implementing FBMPs at the field and farm scales, through systematic, site-specific measures rather than promotion of general messages or 'blanket' solutions. The latter play an important role for raising awareness and providing basic education, but they need to be supported by suitable diagnostic tools and management approaches at the field level. Both public and private sector must jointly implement the broader adoption of FBMPs, including better support for 'greener fertilization technologies' that have recently become available.

Three new challenges are emerging for public and private sector research, the fertilizer industry and governments: climate change, bioenergy and micronutrient malnutrition. Global climate will have profound but still little understood influence on land use, crop yields, plant nutrition and a wide range of other abiotic and biotic factors affecting the response to fertilizers (Lynch and St.Clair, 2004; Pendall *et al.*, 2004; Garrett *et al.*, 2006; Long et al., 2006; Pielke *et al.*, 2007). It is largely unknown how it will affect soil nutrient supply and crop response to fertilizers and hence what impact this may have on regional as well as global fertilizer demand. One thing is clear: mitigation of greenhouse gas emission and global climate will be a slow process. In the near future, more emphasis will be placed on adaptation of crops, cropping systems and management practices to better cope with hotter, drier and generally more extreme climate. FBMPs will have to change along with this, but they are among the most cost-effective mechanisms for improving crop resilience to extreme weather and reducing greenhouse gas emissions (Stern, 2006).

Table 8. Recent public and private sector examples of new technologies, tools, support services or regulations for more balanced, efficient, and sustainable use of nutrients in agriculture.

Description	Web links
North America	
USA: Improved hybrids, better crop management practices and N technologies, detailed N algorithm, extension education and Nitrogen Management Zones in Nebraska. Steady increase in N use efficiency in maize since the mid 1980s.	http://soilfertility.unl.edu www.cpnrd.org
USA: InSite Information Management System® and InSite VRN® programs, Mosaic company. Precision agriculture solutions for fertilizer dealers and farmers, including variable rate nutrients.	www.mosaicco.com
USA & Canada: Commercialization of ESN Smart Nitrogen (controlled-release urea) for the commodity crop market, Agrium.	www.agrium.com/ESN/index.jsp
Mexico: Conservation agriculture and site-specific N management in the Yaqui Valley, Mexico, CIMMYT & Stanford University.	http://yaquivalley.stanford.edu
Europe	
Germany: Yara N-sensor® and N-sensor ALS® for site-specific N management and associated services for farmers; about 500 units in operation (half in Germany).	www.sensoroffice.com
Netherlands: Manure policy and MINAS farm accounting system for nitrogen and phosphorous, since 1998. Fees for surpluses.	
Denmark: Nitrogen quotas for farms – 10% below agronomic optimum.	
France: "Agriculture Raisonnée" scheme; whole farm auditing and certification program, including 18 obligations for soil and nutrient management, since 2004.	www.agriculture.gouv.fr
Africa	
Eastern and Central Africa Maize and Wheat (ECAMAW) Network, Quality Protein Maize Development (QPMD) project, IFDC and CIMMYT; crop improvement and nutrient management.	www.ifdc.org
Millenium Villages Project (MVP, The Earth Institute, Columbia University). Multi-sectoral approach with improving seed and fertilizer supply at villages scale as key entry point.	www.earthinstitute.columbia.edu/mvp

Fertilizer micro-packaging for smallholders in Sub-Saharan Africa, TSBF institute of CIAT in collaboration with private sector.	ww.ciat.cgiar.org/tsbf_institute
Asia	
Site-specific nutrient management for rice. 10 years of research and extension sponsored by public and private sector. Bangladesh, India, China, Myanmar, Vietnam, Philippines, Indonesia.	www.irri.org/irrc/ssnm
IPNI SE Asia program and partners: best management practices for oil palm management, including Oil palm Management Program (OMP) software for plantations.	www.eseap.org
IFDC program on Adapting Nutrient Management Technologies in south and southeast Asia: balanced fertilization and deep placement of urea briquettes in rice (Bangladesh, Cambodia, Vietnam).	www.ifdc.org
Oceania	
Australia: SoilMate, software & service for soil testing and fertilizer recommendations that integrates a large amount of public sector research and models, Nutrient Management Systems.	www2.nutrientms.com.au
Australia: Fertcare® program; national training and accreditation initiative for industry businesses and staff, Australian Fertiliser Services Association & Fertilizer Industry Federation of Australia.	www.fifa.asn.au
New Zealand: FBMPs for N and P and Code of Practice for Fertiliser Use, FertResearch, since 1998.	www.fertresearch.org.nz

Rapidly rising use of agricultural crops for biofuel production will have tremendous impact on land use at local to global scales (Cassman *et al.*, 2006; Hazell, 2006), but the consequences for nutrient management may vary widely. In general, demand for biofuels will provide incentives to (i) convert more land to agriculture and (ii) increase crop yields, both of which will lead to increased fertilizer consumption. In addition, a number of more regional or local developments will likely occur. Where land is converted from less fertilizer-intensive crops (e.g. soybean) to crops that require large amounts of nutrients (e.g. maize) N consumption will rise. Where competition for grain drives up grain prices, farmers will have more incentive for use high N rates to achieve high yields, which can lead to negative environmental impact. Where large amounts of crop biomass are removed from the field for ethanol production (sugarcane, sweet sorghum, C4 grasses or straw for cellulosic ethanol), soil organic matter levels may decline and nutrient balances will become negative, particularly for K. Where land is converted to oil palm plantations for biodiesel production, demand for nutrients such as K and Mg will rise rapidly. The fertilizer industry needs to address these issues now and support activities on FBMPs for integrated crop – livestock – biofuel systems in different parts of the world.

Malnutrition is one of the most pressing Millennium Development Goals, particularly in Sub-Saharan Africa and South Asia. The new framework (Graham *et al.*, 2007) calls for attention first to balancing crop nutrition to increase crop productivity, allowing sufficient staple to be produced on less land so that the remaining land can be devoted to more nutrient-dense and nutrient-balancing crops. Once this is achieved, the additional requirements of humans and animals for vitamins, selenium and iodine can be addressed. Hence, improving nutrition through a combination of diversified diets, enrichment of processed food and water supplies, and enrichment of crops with pro-vitamin A and micronutrients through biofortification (breeding) or better soil and fertilizer management is feasible. The fertilizer industry will have a significant future role in the quest for improving micronutrient nutrition in the developing world. Various options for micronutrient enrichment of fertilizers ('fertification') already exist (IFA, 2005), but more work is needed. Public policies must be established to favor the use of enriched fertilizers in specific target regions. Little is known about best management practices for growing biofortified crops. Many of those will only reach their full genetic enrichment potential with appropriate FBMPs, including a minimum level of micronutrient supply.

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Right product, right rate, right time and right place … the foundation of best management practices for fertilizer

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The concept of agricultural best management practices (BMPs) is not a new one. First introduced almost 20 years ago, scientists at the Potash & Phosphate Institute (PPI) defined BMPs as those practices which have been proven in research and tested through farmer implementation to give optimum production potential, input efficiency and environmental protection (PPI, 1989; Griffith and Murphy, 1991). Today, the emphasis appears to be more on environmental protection than optimal production potential as current definitions suggest BMPs are practical management practices or systems designed to reduce soil loss and mitigate adverse environmental effects on water quality caused by nutrients, animal wastes and sediments. Common BMPs directed towards mitigation include strip cropping, terracing, contour stripping, grass waterways, special manure handling, animal waste structures, ponds, minimal tillage, grass filter strips and nutrient application. Agronomic BMPs leading towards optimizing production potential include: variety, planting date, hybrid maturity, row-spacing, seeding rates, plant population, integrated pest management, weed control, disease control and nutrient management.

Both soil conservation and agronomic-based BMPs can work together to meet objectives of optimal production potential and mitigation of adverse nutrient-caused environmental effects on water quality. While BMPs may differ depending on objective, to be used by farmers they must also be economic … the practices and management they employ must be profitable and sustainable. Nutrient management deserves special attention because it is critical to both optimizing production potential and to environmental stewardship.

One of the challenges faced in the fertilizer industry is that much of society does not trust it. Many believe that fertilizers are applied indiscriminately, that the industry is only interested in increased profits … through unwarranted fertilizer sales … and that farmers are willing recipients who unnecessarily over-apply nutrients to ensure high yield crops resulting in excessive levels of plant nutrients to the detriment of the environment. This, of course, is not true, but the perception is there and that drives policymakers towards regulating nutrient management, water quality guidelines, total daily load limits and other policies or practices aimed at restricting or eliminating the use of fertilizer.

Part of the solution in gaining the public's confidence in our ability to manage nutrients responsibly is through encouraging the widespread adoption of fertilizer BMPs.

The fertilizer industry needs to be unified in the promotion of BMPs designed to improve nutrient use efficiency and therefore environmental protection, without sacrificing farmer profitability. The North American industry has been advocating management practices that foster the effective and responsible use of fertilizer nutrients with a goal to match nutrient supply with crop requirements and minimize nutrient losses from fields (Canadian Fertilizer Institute, The Fertilizer Institute). The approach is simple: apply the correct nutrient in the amount needed, timed and placed to meet crop demand — right product, right rate, right time and right place. These are the underpinning principles of fertilizer BMPs.

The following summarizes these guiding principles for fertilizer management. A more in-depth discussion is available in Roberts (2006).

- **Right product:** Match the fertilizer source and product to crop need and soil properties. Be aware of nutrient interactions and balance nitrogen, phosphorus, potassium and other nutrients according to soil analysis and crop needs. Balanced fertilization is one of the keys to increasing nutrient use efficiency.
- **Right rate:** Match the amount of fertilizer applied to the crop needs. Too much fertilizer leads to leaching and other losses to the environment and too little results in lower yields and crop quality and less residue to protect and build the soil. Realistic yield goals, soil testing, omission plots, crop nutrient budgets, tissue testing, plant analysis, applicator calibration, variable rate technology, crop scouting, record keeping and nutrient management planning are BMPs that will help determine the right rate of fertilizer to apply.
- **Right time:** Make nutrients available when the crop needs them. Nutrients are used most efficiently when their availability is synchronized with crop demand. Application timing (pre-plant or split applications), controlled release technologies, stabilizers, inhibitors and product choice are examples of BMPs that influence the timing of nutrient availability.
- **Right place:** Place and keep nutrients where crops can use them. Application method is critical for efficient fertilizer use. Crop, cropping system and soil properties dictate the most appropriate method of application, but incorporation is usually the best option to keep nutrients in place and increase their efficiency. Conservation tillage, buffer strips, cover crops and irrigation management are other BMPs that will help keep fertilizer nutrients where they were placed and accessible to growing crops.

There is not one set of universal fertilizer BMPs. By definition BMPs are site-specific and crop-specific; they vary from one region to the next and one farm to the next depending on soils, climatic conditions, crop and cropping history and management expertise. BMPs can be implemented in large, extensive farming operations and on small family farms. Right rate, right time and right place offer sufficient flexibility that these guiding principles can be applied to fertilizer management for rice production in Indonesia, banana production in Latin America, maize production in the U.S. Corn Belt, or any farming system used throughout the world.

Fertilizer BMPs should help ensure that fertilizer uptake and removal by target crops is optimized and fertilizer loss to the environment is minimized. Fertilizer BMPs should increase nutrient use efficiency, but maximum use efficiency is not the primary objective. The goal is to use fertilizers efficiently and effectively in providing adequate nutrition for crops.

If maximizing fertilizer efficiency was the goal, we just need to work lower on the yield response curve. For a typical yield response curve, the lower part of the curve is characterized by low yields since few nutrients are available or applied (Figure 1). Nutrient use efficiency is high at the bottom of the yield curve because any addition of a limiting nutrient gives a relatively large yield response as much of the applied nutrient is taken up by the nutrient-limited crop. If highest nutrient use efficiency were the only goal, it would be achieved here in the lower part of the yield curve and by applying the first increments of fertilizer. Lower rates of fertilizer appear better for the environment, because more nutrients are removed by the crop, leaving less in the soil for potential loss. But lower yielding crops produce less biomass and leave fewer residues to protect the land from wind and water erosion and less root growth to build soil organic matter. As one moves up the response curve, yields continue to increase, albeit at a slower rate, and nutrient use efficiency typically declines. However, the extent of the decline in nutrient use efficiency will be dictated by the BMPs employed as well as soil and climatic conditions.

Fertilizer nutrients are essential for modern agriculture to meet its crop yield and quality goals, but fertilizers must be used responsibly. Development and adoption of BMPs for fertilizer are necessary for the fertilizer industry to demonstrate its commitment to product and environmental stewardship, and to help the farmer produce sustained, profitable yields. Every farm and field is different. Fertilizer BMPs must be adap-

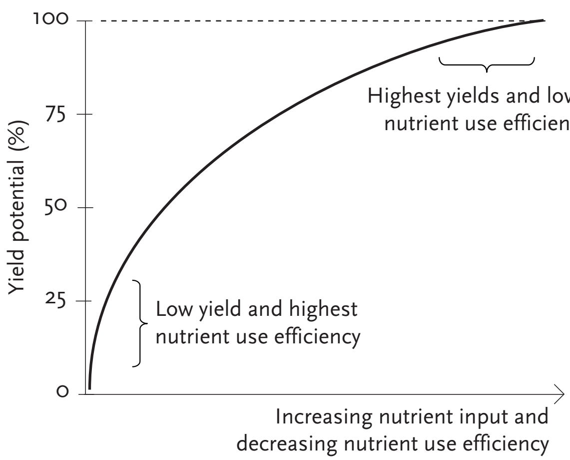

Figure 1. Relationship between yield response and nutrient use efficiency (Adapted from Dibb, 2000).

table to all farming systems … one size does not fit all. Right nutrient, right rate, right time and right place provide a framework for a farmer to select those BMPs best suited to the farm's soils, crops and climate and to the farmer's management capabilities.

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Balanced fertilization for sustainable use of plant nutrients

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Introduction

Fertilizer best management practices (FBMPs) are methods and conditions established for using fertilizers, mainly to assure optimum plant growth, contribute to a profitable farming business and minimize adverse environmental effects. Some FBMPs could apply to a wide range of situations and cropping systems throughout a country, a region or the whole world, whereas others are designed for specific circumstances, such as reducing nutrient loads to enriched soils, protecting a low level of the ground water table, or building up the nutrient content of poor or very deficient soils. So, the best set of management practices for a specific cropping situation will depend on individual circumstances; no single set of best management practices applies to all situations.

Balanced fertilization is the proper supply of all macronutrients and micronutrients in a balanced ratio throughout the growth of crops. It aims at providing optimum plant development, obtaining good yields, providing the farmer with optimum profit and limiting or preventing damage to the environment. In this respect, balanced fertilization is a key component of FBMPs.

This paper will stress the importance of using nutrients in a balanced way for productive and profitable crop production. In particular, it will outline the importance of balanced fertilization for increased crop yield and farm incomes, improved nutrient use efficiency and the improved quality of crop products.

Essential plant nutrients

Many scientist agree that sixteen elements are essential for the growth and development of higher green plants (Roy *et al.*, 2006). These elements are: Carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P) and sulphur (S), which are the elements out of which proteins and protoplasm are made, the living substance of all cells. In addition to these six, there are ten other elements that are essential to the growth of some plants: calcium (Ca), magnesium (Mg), potassium (K), iron (Fe), manganese (Mn), molybdenum (Mo), copper (Cu), boron (B), zinc (Zn) and chlorine (Cl). Sodium (Na), cobalt (Co), vanadium (V), silicon (Si) and nickel (Ni) are also required by some lower plants. Other elements may be found to be essential in the future.

These 16 elements or plant nutrients are essential since:

- a deficiency in one of them makes it impossible for the plant to complete the normal vegetative and reproductive stages of its life cycle;
- such a deficiency is specific and can be prevented or corrected only by supplying it;

- each element is involved directly in the nutrition of the plant, apart from its possible effects in correcting some deficiency of the soil or some other culture medium.

Plants up take plant nutrients in different amounts and forms. With the exception of carbon, hydrogen and oxygen, they all must be obtained from the soil. Six elements are required in relatively high amounts; their concentrations in the plant tissue represent up to a few percent of the fresh plant weight: they are the **macronutrients** (nitrogen, phosphorus, potassium, calcium, magnesium and sulphur). Eight other nutrients are required in much smaller amounts, with a magnitude of mg per kg of fresh plant weight: they are called **micronutrients** (molybdenum, nickel, copper, zinc, manganese, iron, boron and chlorine).

All of these nutrients fulfil specific functions in plants and cannot replace each other. Regardless of the amount required physiologically, all of them are equally important. This means that the lack of one single nutrient will limit crop growth even if all the other nutrients are fully available. In consequence, the supply of all these nutrients is essential for growing healthy crops that produce high yields of good quality. Figure 1 represents the general relationship between yield and the supply of nutrients.

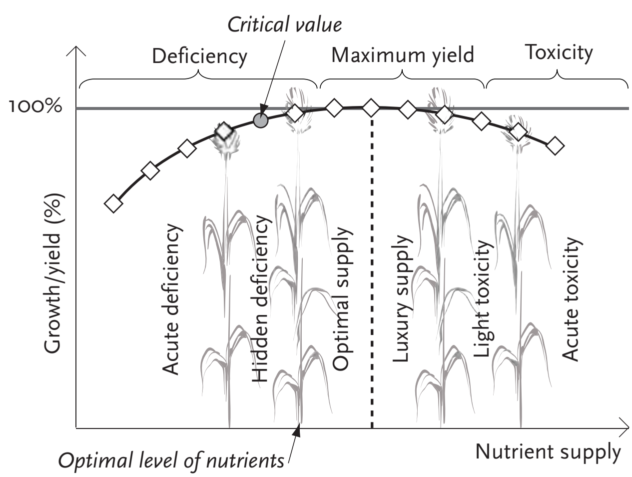

Figure 1. Plant growth and yield relationship with the supply of nutrients.

If one of these elements is in a short supply (i.e. is a limiting element) then the **Law of the Minimum** (Liebig's law, Figure 2) determines the plant's development and yield. In short, this law states that if one crop nutrient is missing or deficient, plant growth will be poor, even if the other elements are abundant. Therefore, a **limiting nutrient** is an element necessary for plant growth, but available in a concentration insufficient to support continued growth. Meanwhile, it is known that plants may take up many elements that play no vital role in their own nutrition. They can consume high levels of certain elements, some of which are essential and some of which are not. They may accumulate low levels of elements which play no beneficial role in the plants themselves but which are important in the diet of animals that eat these plants. Plants can even take up elements, such as heavy metals, which may be extremely toxic when their availability exceeds certain levels in the soil.

Figure 2. Law of the minimum (Liebig's Law).

Dealing with plant nutrition, whether it is addressed through balanced fertilization, integrated fertilizer or nutrient management practices or integrated plant nutrition, requires that all the nutrients necessary to achieve good yields and food quality should be taken into account. Therefore, identifying and assessing these needs and requirements are central to any approach that aims at obtaining good yields and food quality.

Defining balanced fertilization

Basically, the law of the minimum governs balanced fertilization. Balanced fertilization is the proper supply of all macronutrients and micronutrients throughout the growth of a crop. It is not the supply of a single or a couple of nutrients but rather the complete supply to a crop or a cropping system, with optimum and adequate quantities of the required nutrients at appropriate times to achieve a target yield, which is profitable and sustainable. All available knowledge about the crop and the environment in which it will be grown, including the economics of plant nutrient applications, must be combined to establish the right combination of nutrients to be applied. As both the total amount of nutrients (macro and micronutrients) required and the right nutrient ratios vary from one type of crop to another, balanced fertilization should be based on the specific requirements of the crop that is grown.

Balanced fertilization is soil and crop-specific

Balanced fertilization not only guarantees optimal crop production, better food quality and benefits for the growers, but is also the best solution for minimizing the risk of nutrient losses to the environment. If the balance of nutrients applied is not appropriate, the crop will not be able to grow properly and its overall uptake of nutrients will be limited. The supply of other nutrients will then be of no or limited use, and these will accumulate in the soil, leading to potential environmental problems.

The nutrient ratios in a balanced fertilization recommendation give only an indication of the fertilizer requirement of a given crop. Any recommendation to supply a crop with balanced fertilization must first take into account the amount of nutrients supplied from the soil or from other sources such as the irrigation water, green or animal manure, residues from preceding crops, etc. Since these sources are very rarely sufficient, mineral fertilizer must be added to satisfy the remaining nutrient needs of the crop.

The balanced use of fertilizers should be aimed mainly at: (1) increasing crop yield, (2) increasing crop quality, (3) increasing farm income, (4) correction of inherent soil nutrient deficiencies, (5) maintaining or improving lasting soil fertility, (6) avoiding damage to the environment, and (7) restoring fertility and productivity of the land that has been degraded by wrong and exploitative practices in the past.

Balanced fertilization is not a static but a dynamic concept that can pave the way to a sustainable agriculture and which will provide the world population with high quality food while minimizing the impact on the environment. **A well-balanced fertilization also optimises the nutrient use efficiency of crops.**

Table1 gives examples of nutrients required to ensure a balanced fertilization of the selected crops and cropping systems.

Table 1. Examples of nutrients required for the balanced fertilization of certain crops and cropping systems.

Crops/cropping systems	Balanced nutrients requirements
Intensively cropped irrigated areas	N, P, K, Zn and S or N, P, S and Zn
Areas under oilseeds	N, P, K and S or N, P, Zn and S
Legumes in acid soils	N, P, K, Ca and Mo
Fruit trees in alkaline, calcareous soils	N, P, K, Zn, Mn and Fe
Cabbage, cauliflower and other crucifers	N, P, K, S and B
High-yielding tea plantations	N, P, K, Mg, S and Zn
Coconut in light soils	N, P, K and Mg
Immature rubber plantations	N, P, K and Mg
Mature rubber plantation	N, P and K

In practice, there are many reasons for the unbalanced use of plant nutrients. Among these are:

- The relative prices at which fertilizers are sold to farmers, with in general N fertilizers having very low prices compared with other fertilizers, in particular P, K and S;
- The availability in time of needed quantities;
- The perception by the farmers of the benefit associated with fertilizers;
- The financial return.

At a time of economic pressures, farmers face the need to reduce production costs. In the case of fertilizers, they often tend to favor the use of N, particularly when their land tenure is insecure, which is the case of many countries of the developing world. But in many situations, the use of even appropriate levels of N fertilizer without adequate use or soil contents of P and K results in yield losses and inefficiency in the use of nitrogen, as illustrated in Figure 3.

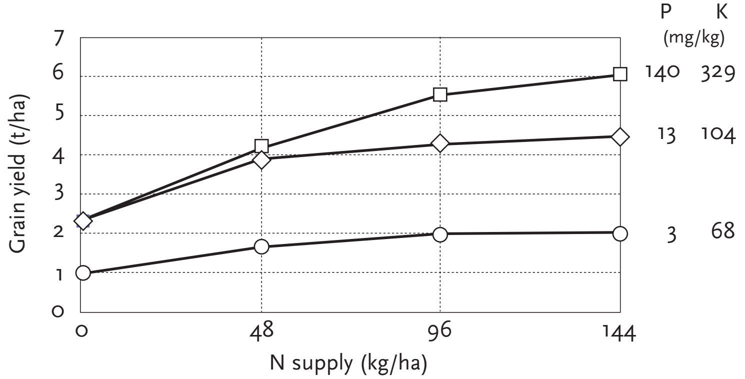

Figure 3. Spring barley responses to N on soil with different P and K contents, Rothamsted, UK.

Evolution of world fertilizer consumption and nutrient consumption ratios

World total fertilizer consumption increased from 27.4 million tonnes (Mt) nutrients in 1960 to 137.7 Mt and 151.4 Mt in 2000 and 2005 respectively. In 2015, world fertilizer consumption is projected to amount to 165.1 Mt nutrients.

Trends in fertilizer consumption show that, from 1960 to the early 1990s, developed countries accounted for more than half of world fertilizer use. In 1990, their fertilizer consumption was about 80 Mt nutrients. By 1992, fertilizer consumption in developing countries surpassed the consumption in developed countries. By the year 2020, it is forecast that fertilizer consumption in developing countries will be at least 40% higher than its level in developed countries.

Table 2 gives average nutrient consumption ratios of the world and in some of the major crop production regions.

Table 2. Nutrient consumption ratios (2002).

Region	N	P_2O_5	K_2O
World	1.0	0.4	0.2
Developed countries	1.0	0.4	0.3
Developing countries	1.0	0.4	0.2
Latin America & Caribbean	1.0	0.7	0.6
Africa	1.0	0.3	0.2
East & South-east Asia	1.0	0.3	0.3
South Asia	1.0	0.3	0.1
Europe	1.0	0.2	0.3

At the world level, the above table shows an unbalanced use of P and K with respect to N, in relation to a normal or generally accepted "balanced ratio" between N, P_2O_5 and K_2O of 1:0.5:0.5. It also shows a rather large variation between the selected regions, with Latin America and the Caribbean being the only region were P and K consumption, compared with N, is higher than the normal figure. This is not an indication of very high levels of P and K use compared with the needs of the crops grown, but rather a low level of N use that might limit the efficiency of the applied P and K fertilizers and the level of crop production. It also needs to be stressed that there are large areas of soybean and pastures planted with legumes that do not need high applications of N (Amar and Cissé, 2007).

In the other regions, from Africa through Europe and Asia, P and K applications are very unbalanced in relation to N. Data from countries of Asia, where the World Phosphate Institute (IMPHOS) is conducting several promotional activities on the balanced use of fertilizers, are presented below. NPK use ratios in India from 1980/81 to 2005/06 are given in Table 3.

Table 3. Ratios of N, P, K use in India.

Year	N	P_2O_5	K_2O
1980/81	1.0	0.3	0.1
1985/86	1.0	0.4	0.1
1990/91	1.0	0.4	0.2
1992/93	1.0	0.3	0.1
1993/94	1.0	0.3	0.1
2000/01	1.0	0.4	0.1
2005/06	1.0	0.4	0.2

In Pakistan, during the decade from 1996 to 2005, N, P and K consumption, while increasing substantially, in particular for N and P, was substantially unbalanced in the use of these three nutrients, as illustrated in Table 4 (Cissé , 2006a).

Table 4. Ratios of N, P, K use in Pakistan.

Year	N	P_2O_5	K_2O
1996/97	1.0	0.2	0.004
1997/98	1.0	0.3	0.01
1998/99	1.0	0.2	0.01
1999/2000	1.0	0.3	0.01
2000/01	1.0	0.3	0.01
2001/02	1.0	0.3	0.01
2002/03	1.0	0.3	0.01
2003/04	1.0	0.3	0.01
2004/05	1.0	0.3	0.01

Also in China, the use of NPK nutrients is very unbalanced. In 2002, the $N:P_2O_5:K_2O$ ratio was 1.0:0.4:0.2.

Among the many consequences that result from the unbalanced use of nutrients are:

- Decreased fertilizer use efficiency, in particular for N. In China, results from a study covering 5.7 million hectares show that, on average, fertilizer use efficiency had fallen by 8.2%;
- Yield reduction, which in the above example ranged from 0.4 to 1 t/ha;
- Reduction in the farmer's income;
- Soil mining, in certain areas (India) of P and K on a very large scale;
- Lower response ratios: in India from 10 in the 1970s to 6 at present on cereals;
- Increasing N losses to the environment by leaching and volatilization.

This paper will focus mainly on balanced fertilization for the purposes of:

- Increasing crop production and financial returns;
- Improving nutrient use efficiency and avoiding unnecessary nutrient losses to the environment;
- Improving food quality.

Balanced fertilization for increased crop yield and financial return

In Asia, there is generally an over-application of N compared with P. This is well documented, from China to Pakistan. In China, wheat and corn yields increased by 15 to 20% in recent years as a result of balanced fertilization.

As indicated above, balanced fertilization refers to the application of all plant nutrients required by a given crop grown on a given soil to achieve established agronomic, economic and environmental goals. Therefore, the application of micronutrients, where needed, is required in addition to the application of macronutrients. There are many documented cases that clearly show the need to apply nutrients other than N, P and K to satisfy plant growth and obtain higher yields and better crop quality.

On rice, results show increased yields from the application of Zn, ranging from 1.9% to 13.5%. On rapeseed, yield increases following Mn applications ranged from 8% to about 40%. On wheat, yield increases due to the application of micronutrients (a single application of Fe, Zn, Cu or B, or the application of all together) amounted to 4% with B application alone; to 11% when all four were applied. Zinc application alone gave the highest increase, of about 10% (Malakouti, 2006).

IMPHOS has launched several projects in Asia to promote the balanced use of fertilizer nutrients. In Pakistan, the project conducted by IMPHOS, the Food and Agriculture Organization of the United Nations (FAO) and the National Fertilizer Development Centre (NFDC) from 1986 to 2005 gave many significant results that clearly demonstrate the important role of balancing N with P to increase crop production. This case will be used to illustrate the impact on crop production that can result from more balanced fertilization practices (Amar and Cissé, 2007).

In Pakistan, fertilizer use is highly biased in favour of N. Micronutrient use is negligible compared to the actual requirements, and is limited to Zn on rice, potato and citrus; B on cotton, potato and rice (Figure 4).

Over the course of the project in Pakistan, 712 demonstration trials were conducted on seven crops, comprising 412 trials on wheat, 159 on rice, 57 on cotton, 54 on maize, 9 on sugarcane, 11 on oilseeds and 10 on onions. Region-wise, the four agricultural pro-

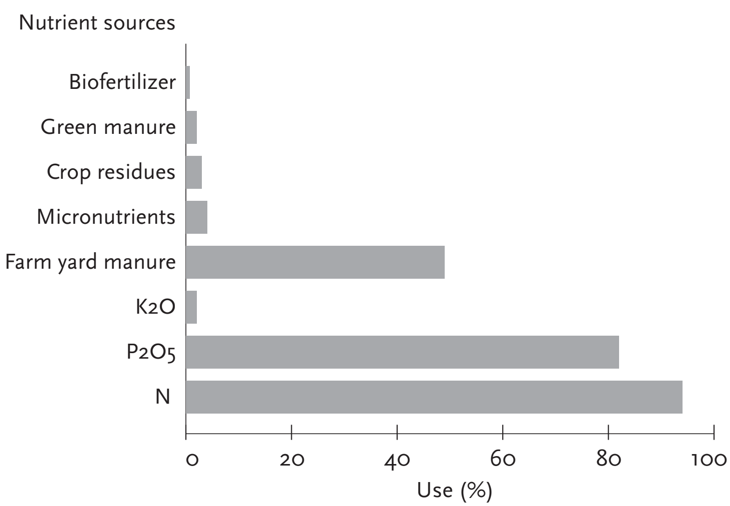

Figure 4. Source and level (%) of plant nutrient used by farmers in Pakistan, 2006.

vinces of Pakistan were covered, with 366 trials conducted in Punjab, 152 in Sindh, 137 in NWFP (North West Frontier Province) and 57 in Baluchistan. Trials were conducted under irrigated and rainfed conditions, using simple non-replicated treatments applied on large plots of 1000 m^2 each.

In all locations, in addition to the control treatment (0-0-0), farmers' practice on their own fields was recorded and the yield they obtained was used to assess the effect of the balanced application of NPK on the crop grown.

When comparing the balanced treatment with actual farmers' practices, which are very unbalanced in favour of N, and scaling up the results to the country level, the aggregated data show very substantial effects of the balanced use of N, P and K on the production of the selected crops.

For example, the average yield of wheat obtained in Punjab for the period of 1987 to 2005, was 1370 kg/ha on the control, 2168 kg/ha for N and 3284 kg/ha for NP (the N and P_2O_5 doses per hectare were respectively 120 and 90 kg/ha). The increase per unit of nutrient was 6.6 kg for N and 12.4 kg for P.

Overall crop yields obtained by farmers compared with those obtained with balanced fertilization on irrigated wheat, rainfed wheat, rice (IRRI variety), rice (Basmati), cotton and maize are presented in Figure 5.

The impact of a balanced use of P with respect to N is quite substantial for the production of all the crops. Table 5 shows that the additional production with a 50% adoption of a balanced use of P vis-à-vis N. It represents an average increase of 30% over the national output of the selected crops, amounting to about 11.7 Mt.

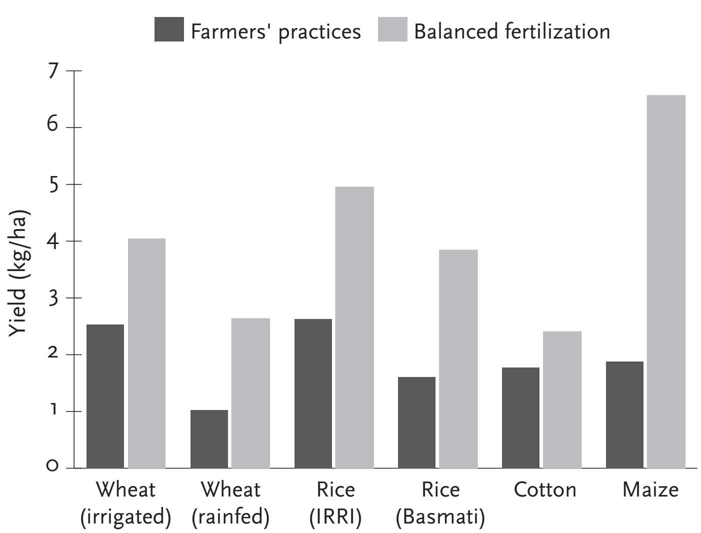

Figure 5. Average farmer's yields and yields obtained with balanced fertilization, Pakistan, 2006.

Table 5. Impact on the production of selected crops if balanced NP fertilization was adopted on 50% of the land planted to these crops in Pakistan.

	Wheat	Rice	Maize	Sugarcane	Total
Area (thousand ha)	7,333	2,156	335	206	10,030
Additional production (thousand tonnes)	4,422	2,895	350	4,014	11,681

The income associated with the adoption of balanced fertilization on 50% of the area planted to the above selected crops would amount to US$ 41.9 million per year.

Wheat is the staple food of the vast majority of Pakistanis; it is one of the most important crops of the country and production never matches the needs of the population. There is often a shortfall in wheat production, as was the case in 2005, with an 800 thousand tonne deficit. This deficit would have been covered by a 10% adoption of balanced NP fertilization in the country.

Since exports of cotton, rice and other products based on agricultural raw materials account for 80% of Pakistan's foreign exchange earnings, the impact of balanced fertilization on the country's balance of payment would be significant.

Balanced fertilization for improved nutrient use efficiency

Worldwide, at least one-third of the gain in cereal production has been attributed to increased fertilizer consumption and, in many countries, the figure is 50%. The application of mineral fertilizers needed to obtain higher yields should complement nutrients available from other sources and match the needs of individual crop varieties. The increased use of fertilizer is becoming even more crucial in view of other factors, such as the impact on soil fertility of more intensive cultivation practices and the shortening of fallow periods, and the growing concern about improved food quality. Fertilization should ensure not only high yields per unit area but also high quality of the produce.

Many studies that have assessed the relationship between food grain production and fertilizer consumption during the period 1961 to 2006 show that the partial factor productivity of fertilizers has been declining regularly. Available data increasingly indicate a reduction in crop response to fertilizer application, especially when balanced fertilization is not practiced.

When nutrients are properly used they are very beneficial, but applied in the wrong place, at the wrong time and with an inappropriate rate, they lose much of their positive effects. Farmers can achieve increased nutrient use efficiency by adopting improved and more precise management practices. It is expected that this trend towards increasing efficiency of nutrient use through better nutrient management, by improving the efficiency of nutrient balances and the timing and placement of fertilizers, will continue and accelerate in the future.

There are several causes of the declining or lower crop responses to applied fertilizers or efficiency of fertilizer applications in developing Asian countries. One major cause of this decline is the continuous nutrient mining of the soils (particularly P and K) resulting from unbalanced fertilization practices.

The data from on-farm trials conducted in India during 1999-2003 showed that the average response of cereals to fertilizer was 8-9 kg grain/kg fertilizer. The efficiency of fertilizer N is only 30-40% on rice and 50-60% on other cereals, the efficiency of fertilizer P is 15-20% for most crops, and the efficiency of K and S is 60-80% and 8-12%, respectively. For micronutrients, the efficiency of most of them is below 5%.

In India, it is estimated that about 28 Mt of NPK are removed annually by crops, while only 18 Mt or even less are applied as fertilizer, leaving a net negative balance of about 10 Mt of NPK. An analysis of the data pertaining to the rice-wheat cropping system from 24 research stations revealed that rice yields are declining more rapidly than wheat yields, and soil P and K depletion seemed to be a main cause. Similarly, other sets of data showed that the yield decline of both rice and wheat was highest when N alone was applied at 120 kg/ha. Unbalanced fertilization is therefore affecting fertilizer nutrient use efficiencies.

In Hungary, work conducted by IMPHOS on wheat and maize, to develop and promote more balanced, efficient and profitable nutrient applications, showed that previous fertilizer recommendations were not balanced, they were very often above crop requirements for the yields obtained and had low profitability (Cissé, 2006b). On wheat, total NPK applications could be reduced from 320 to 240 kg/ha without any significant yield losses. On maize, with a more appropriate NPK amount and ratio, the yield could be maintained at 11 t/ha, with the total amount of nutrient application decreasing from 560 to 350 kg/ha. These results offered, in addition to improved nutrient use efficiency and profitability, the possibility of greatly reducing the risk of nutrient losses to the environment.

Balanced fertilization for improved food quality

The application of plant nutrients has greatly increased the resistance of plants to diseases and climatic stress. Plants which have been provided with an adequate supply of K and P, for example, respond with early root growth and increased water holding capacity, thereby ensuring better survival in dry spells. The resistance of plants to frost and cold, ultra-violet radiation, pests and fungal attacks also increases when they have a sufficient supply of the major plant nutrients, micronutrients and trace elements.

The health of farm animals and human beings is directly affected by the quality of their nutrition. High quality crops are those which do not suffer from deficiencies but contain the mineral and organic nutrients that are essential and beneficial to human and animal health. Fertilizer use must therefore take into account the nutritional requirements of the animals and human beings which consume the crops.

The issue of food quality has emerged in recent years and is of increasing concern, primarily in the developed countries, but it is becoming an issue also in the developing countries. High quality is important for almost every harvested product, whether it is food, fodder or industrial raw materials.

The quality of vegetal products depends on many factors, among them the optimal supply of all substances required for growth. Minerals occupy a central position for obtaining high quality products.

Proper fertilization improves food quality through a higher quality of the vegetal products (and indirectly of animal products); so it contributes not only to the nourishment of humans and animals but also provides them with healthier living conditions.

The many important roles of P in plant metabolism is the reason why the application of fertilizer P has significant effects on food quality.

Phosphate results in the following changes (Finck, 1982):

- Increased total P contents of plants; in the case of fodder this is an important quality criterion as an insufficient P content is detrimental to the fertility of cows, milk production and quality;
- Increased content of inorganic P in green plants, and that of phytin. Phytin increases particularly in the seeds, whereas inorganic P increases mainly in the straw;
- Higher content of nucleic P;
- Higher content of essential amino acids in the seeds;
- Increased content of carbohydrates (sugar, starch);
- Increased content of some vitamins, such as B1;
- Reduced content of nicotine in tobacco;
- Reduced content of oxalic acid; in leaf vegetables this product is harmful to humans and in sugar beet leaves it is harmful to cows;
- Increased content of coumarin in grass.

Even though new crop improvement technologies, such as biotechnologies, are increasingly addressing the issue of food quality by introducing into crops genetic traits that improve their quality, fertilization remains the main tool for enhancing food quality.

Data from experiments conducted by IMPHOS in Poland provide some examples of the effects of P application, along with sufficient levels of N and K application, on the quality of wheat and sugar beet.

On wheat, increasing P applications greatly increased the total content of proteins, from 9.4% to 16.3%, that is a 70% increase. Since this is very important for wheat used for bread production, farmers will further increase their incomes thanks to better prices in response to better grain quality.

On sugar beet, the sugar content increased with increasing P applications. In particular, in Wieszczyczyn, 15 P_2O_5 kg/ha and 60 kg P_2O_5/ha, the sugar yield increased from 4.5 to 9 to 10 t/ha. This clearly shows a dramatic sugar yield limitation if there is no P application or if it is not appropriate. So, in addition to facing reduced sugar beet yields, farmers also face losses in crop product quality and finally in incomes.

A long-term programme implemented in Finland consisting of the application of selenium (Se) enriched NPK fertilizers increased both the Se concentration in food crops and improved the daily intake of Se.

In Turkey, Zn application has given very large increases in yield of wheat and maize, along with increases in the grain Zn content. This has certainly improved the Zn intake of rural populations, whose diets are mainly cereal-based.

Therefore, balanced fertilization practices not only increase crop yields and farmers' incomes but it can also greatly improve the quality of food products and, finally, benefit human health.

Conclusion

During the past few decades, the use of mineral fertilizers has been growing rapidly in developing countries starting, of course, from a low base. This has been particularly the case in the developing countries of East and South Asia, following the introduction of high yielding varieties. East Asia (mainly China) and South Asia (mainly India and Pakistan) are likely to continue to dwarf the fertilizer consumption of the other developing regions.

The demand for food will continue to increase in many regions of the world, particularly in developing countries, driven by the increasing world population. Further, the need for high value quality food will be more and more a concern, not only in developed countries but also in developing countries.

Since the agricultural land area is shrinking, due to the increase in population and land being removed from agriculture by industrial and other human activities, increasing global food production to meet the needs of the world population will more and more require an increased use of fertilizers. However, this must be accompanied by the promotion and the increased use of practices such as balanced fertilization that ensure a more efficient use of plant nutrients, of natural resources (e.g. the soils) and of financial resources, while enhancing the environment.

Balanced fertilization should ensure not only high yields per unit area but also high quality produce, either by improving the low quality of the food due to insufficient nutrient supplies, or by maintaining the high quality together with increased yields. High quality is important in almost every harvested product, whether it is food, fodder or industrial raw materials. Balanced fertilization improves food quality through a higher quality of vegetal products (and indirectly of animal products); so it contributes not only to the nourishment of humans and animals but it also provides them with healthier living conditions.

Therefore, balanced fertilization contributes greatly, or even has a pivotal role, in achieving the goals of FBMPs.

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Site-specific nutrient management

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The amounts of supplemental nutrients needed by plants to achieve high cash value of harvested product per unit of nutrient input can vary within fields as well as among fields, growing seasons and years. Site-specific nutrient management (SSNM) is an approach of supplying plants with nutrients to optimally match their inherent spatial and temporal needs for supplemental nutrients. The SSNM approach aims to enable farmers to dynamically adjust their fertilizer use to optimally fill the deficit between the nutrient needs of a high-yielding crop and the nutrient supply from naturally occurring indigenous sources such as soil, crop residues, organic inputs and irrigation water. The implementation of SSNM can involve using different management of nutrients in different areas of a field or landscape, in different cropping seasons, and in different years in the same area of a field. The SSNM approach does not specifically aim to either reduce or increase fertilizer use. Instead, it aims to apply nutrients at optimal rates and times to achieve high profit for farmers, with high efficiency of nutrient use by crops across spatial and temporal scales; thereby preventing leakage of excess nutrient to the environment. The principles and objectives of SSNM as implemented for rice in small fields with little or no mechanization in Asia are similar to the principles and objectives of SSNM in "precision agriculture" with technically sophisticated management of spatial and temporal variations in large fields.

Site-specific nutrient management as a key component of fertilizer best management practices in cereal production

The development of mechanized agriculture in Europe, North America and parts of South America led to large field sizes and the uniform application of inputs across fields. The rates of fertilizer typically matched or exceeded crop needs for nutrients in all areas of the field. Concerns about high costs of inputs relative to the value of harvested products and concerns about the environmental effects of nutrients applied in excess of crop needs, in at least portions of fields, necessitated better matching of nutrient applications with the spatial and temporal needs of the crop for nutrients. New technological tools such as yield monitoring, global positioning systems, variable rate fertilizer application, remote sensing and crop sensors made it possible to address within field variability through "precision agriculture".

In much of Asia and Africa, fields for cereal production are small. Rice fields in South and Southeast Asia for example are typically only a fraction of a hectare, and only small-scale equipment is used. Crop management, soil fertility and crop needs for nutrients can vary greatly among nearby fields and between crop-growing seasons. Existing fertilizer recommendations for rice often consist of one blanket rate of N, P and K for vast areas of rice production. The rates of fertilizer actually used by farmers often vary greatly from such recommendations and have little or no relationship with the actual amounts and ratios of nutrients required to match the needs of the crop for high profitability and protection of the environment from leakage of excess nutrients.

The SSNM approach for rice was developed across diverse irrigated rice-growing environments in Asia, where 90% of the world's rice is produced. Researchers developed the concept of SSNM in the mid 1990s. It was then evaluated and refined from 1997 to 2000 on about 200 irrigated rice farms in eight major rice-growing areas across six countries in Asia (Dobermann *et al.*, 2004). The need of a crop for fertilizer N, P or K was determined from the gap between the crop demand for sufficient nutrient to achieve a yield target and the nutrient supply from indigenous sources. A modification of the QUEFTS model (Janssen *et al.* 1990) was used to predict the amount of fertilizer N, P and K required for a specific yield target. After 2001, the initial SSNM concept was systematically transformed into a plant-based approach with simple principles, tools and guidelines for enabling rice farmers to effectively supply their crops with nutrients as and when needed (IRRI, 2007). This paper presents principles arising from the SSNM approach for rice in small fields in Asia, and it highlights how the principles and objectives of SSNM are compatible for the relatively low-tech version in small fields in Asia and the technically sophisticated version in large fields with mechanization.

Principles of site-specific nutrient management for nitrogen

Background

Nitrogen fertilizer is often split applied to cereal crops. The rate of the first N application either before or soon after crop establishment is determined from pre-existing information. Sources of information for decision-making include measured yields of previous crops in the field, estimated yield targets for the anticipated climate and crop-growing conditions, soil testing, and N omission plots for estimating the supply of native N and anticipated response to fertilizer N. For later N applications, within-season monitoring of the crop — particularly its leaf N status — can be used to adjust fertilizer N rates to match the location-specific N needs of the crop.

What does site-specific nutrient management offer?

Site-specific nutrient management provides a plant-based approach for:

- Determining the amount of fertilizer N to apply in the first N application near crop establishment;
- Estimating approximate fertilizer N rates for within-season applications;
- Dynamically varying the within-season rates of fertilizer N to match the spatial and temporal needs of the crop for N.

A pre-season estimate for total fertilizer N is used to determine the rate for the first N application at crop establishment and to set ranges for within-season fertilizer N rates that are then dynamically determined through monitoring of the crop.

In general terms, the total fertilizer N required by a crop for an entire growing season is directly related to the anticipated crop response to fertilizer N, which is the difference between a yield target and yield without fertilizer N — referred to as the N-limited yield.

Yield response to fertilizer N = Yield target – N-limited yield

The yield target is the grain yield attainable by farmers with good crop and nutrient management and average climatic conditions for a given location. It can be estimated from measured yields of previous crops in the field or through the use of crop models. The yield target can for example be set at a percentage of the climate-determined yield potential of the crop varieties. In the case of rice, the economic yield target is typically about 75-80% of the yield potential.

The N-limited yield is directly related to the supply of N from indigenous (non-fertilizer) sources, which include soil, crop residues, organic inputs, rainfall, atmospheric deposition and irrigation water. It can be estimated with soil analysis, soil sensors, and with the nutrient omission plot technique. With the nutrient omission plot technique, the N-limited yield is determined from the grain yield for a crop not fertilized with N but fertilized with other nutrients to ensure they do not limit yield.

The estimation of the N-limited yield (or indigenous N supply) is often a major uncertainty in estimating fertilizer N requirements. It is normally not cost effective to implement soil measurements or nutrient omission plots with coverage sufficient to capture spatial and temporal variation, especially in small individually managed fields. Hence, it can often be necessary to estimate N-limited yield based on appropriate available information such as existing farmer knowledge of the field, past use of organic amendments, soil texture, or previous measurements of N-limited yield on similar soils. Experiences with N omission plots across rice-growing areas in Asia fortunately enable some general approximations of N-limited yield for irrigated rice:

- Near 3 t/ha in fields with sandy and loamy soils with little or no input of manures and organic materials, and in fields with intensive cultivation of three high-yielding cereal crops per year with little or no input of manures or organic materials.
- Near 4 t/ha in field with clayey soils with two cereal crops per year and little or no input of manures and organic materials, and in fields with sandy and loamy soils with substantial input of manures or organic materials.
- Near 5 t/ha in fields with clayey soils with one or two cereal crops per year and relatively high soil organic matter or input of manures and organic materials.
- In China, N-limited rice yields of 5 and 6 t/ha are common in areas with substantial inputs of N through atmospheric deposition and rainfall.

Only a fraction of the fertilizer N applied to a crop is taken up by the crop. Hence, the total amount of fertilizer N required for each tonne of increase in grain yield depends on the efficiency of fertilizer N use by the crop. Agronomic efficiency of fertilizer N use (AE_N), which is the increase in yield per unit of fertilizer N applied, is used in the SSNM approach for rice to estimate total fertilizer N required by a crop (F_N).

$$F_N = \text{Yield response to fertilizer N} \ast AE_N$$

Based on experiences with rice, an AE_N of 25 kg grain increase/kg N applied is often achievable in the tropics with good crop management in high-yielding seasons, and an AE_N of 18 to 20 kg grain increase/kg N applied is achievable in the tropics with good management in low-yielding seasons. An AE_N of 15 kg grain increase/kg N is a realistic target for environments where existing fertilizer N management practices are very inefficient, with AE_N in farmers' fields of about 10 kg grain increase/kg N or less. Guidelines in estimating fertilizer N required by rice based on grain yield response to fertilizer N and efficiency of fertilizer N use are shown in Table 1.

Table 1. Guidelines for estimating total fertilizer N required for rice based on yield response to fertilizer N and efficiency of fertilizer N use.

Efficiency of fertilizer N use (kg grain increase/kg applied N) →	15	18	20	25
Yield response (t/ha) ↓	Fertilizer N rate (kg/ha)			
1	65	55	50	40
2	130	110	100	80
3	195	165	150	120
4		220	200	160
5			250	200

Within-season monitoring of the crop N status enables the use of corrective N applications adjusted to the spatial and temporal variations in crop need for supplemental N. Tools across a range of sophistication including high-tech measurements of spectral reflectance or biomass density of the crop canopy, intermediate-tech measurements of light reflectance or light transmission on individual plants, and low-tech manual measurements of leaf color, as well as direct determination of N concentration in plant tissue or sap are available. A crucial component of dynamic within-season fertilizer N management is appropriate calibration enabling optimal upward and downward adjustments in fertilizer N rates to achieve a yield target with high efficiency of fertilizer N use.

In the case of the plant-based approach of SSNM for rice in Asia, strategies for mid-season N applications strive to ensure the supply of N is synchronized with the crop need for N at critical growth stages of active tillering (to achieve an adequate number of panicles), panicle initiation (to increase grain number per panicle) and ripening (to enhance grain filling). A simple, inexpensive low-tech tool such as the leaf color chart (LCC) is well suited as an indicator of the leaf N status for small-scale farmers in Asia. A standardized plastic LCC with four panels ranging in color from yellowish green to dark green has been developed through the International Rice Research Institute, IRRI (Figure 1) (Witt *et al.*, 2005b) and calibrated for many rice cultivars and production systems across Asia (IRRI, 2007).

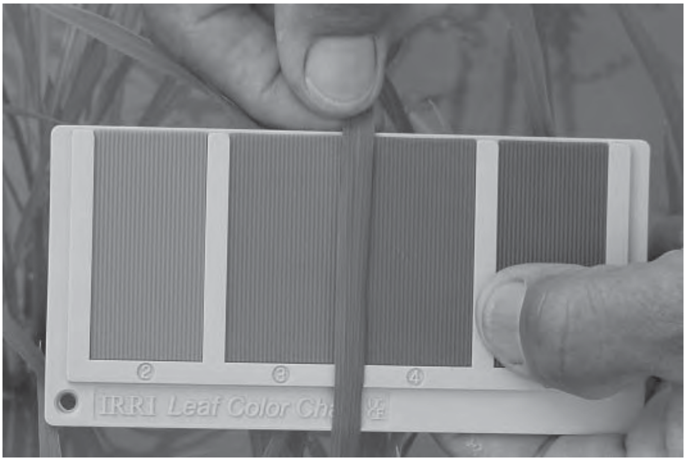

Figure 1. A standardized leaf color chart (LCC) for N management in rice (IRRI©).

Phosphorus and potassium management

The SSNM approach is based on the direct relationship between crop yield and the need of the crop for a nutrient, as determined from the total amount of the nutrient in the crop at maturity. The yield target provides an estimate of the total P and K needed by the crop. The portion of this requirement that can be obtained from non-fertilizer sources such as soil, crop residues, organic inputs and irrigation water is referred to as the indigenous nutrient supply. Site-specific nutrient management as developed for rice in Asia uses a nutrient balance approach, in which fertilizer P and K are recommended in amounts sufficient to close the gap between the needs of the crop to achieve the yield target and the indigenous supply and to ensure soil fertility is maintained by not mining the soil of the nutrient.

Because rice grain yield is directly related to the total amount of P taken up by rice, indigenous P supply can be determined from the P-limited yield, which is the grain yield for a crop not fertilized with P but fertilized with other nutrients to ensure they do not limit yield. The indigenous K supply can similarly be estimated from the K-limited yield, which is the grain yield for a crop not fertilized with K but fertilized with other nutrients to ensure they do not limit yield. Irrigation water can be an important indigenous source of K that is accounted for with K-limited yield in the SSNM approach but not with soil testing.

The attainable yield target and P-limited yield are used with a nutrient decision support system (Witt *et al.*, 2005a) to determine the amount of fertilizer P_2O_5 required to both overcome P deficiency and maintain soil P fertility. Outputs of the nutrient decision support system are summarized in Table 2 (Witt *et al.*, 2007). The guidelines in Table 2 are applicable to environments where rice is grown on submerged soils with

Table 2. Guidelines for the application of fertilizer P_2O_5 according to yield target and P-limited yield in P omission plots (Witt *et al.*, 2007).

Yield target (t/ha) →	4	5	6	7	8
P-limited yield (t/ha) ↓	Fertilizer P_2O_5 rate (kg/ha)				
3	20	40	60		
4	15	25	40	60	
5	0	20	30	40	60
6	0	0	25	35	45
7	0	0	0	30	40
8	0	0	0	0	35

negligible P fixation, which is the case for the vast majority of irrigated rice in Asia. Higher P rates could be required on P-fixing soils.

Many irrigated rice fields in Asia have historically received sufficient fertilizer P to build indigenous P supply to levels where P-limited yields match the yield target. In such cases, only maintenance applications of fertilizer P are required. A key feature of this SSNM approach is the adjustment of P rates based on yield target; P rates are increased with increasing yield targets, even for maintenance applications (i.e. when P-limited yield equals the yield target).

The attainable yield target and K-limited yield, together with an estimate of the amount of retained crop residue, are used to determine the amount of fertilizer K_2O required to both overcome K deficiency and maintain soil K fertility. Outputs of the nutrient decision support system for rice are summarized in Table 3 (Witt *et al.*, 2007). Whereas all fertilizer P is applied either before or immediately after crop establishment, fertilizer K can be split applied with up to 50% applied near panicle initiation. This within-season application of K enables corrective actions to accommodate revised yield targets for the growing season.

Implementation of site-specific nutrient management

Site-specific nutrient management involving within-season, variable rate adjustment in fertilizer N continues to be evaluated and promoted in "precision agriculture". Technology using on-the-go canopy reflectance spectra has been tested and is available in Europe for within-season variable rate fertilizer N applications to wheat, oilseed rape, maize and potato (Yara, 2007). Sensor-based, site-specific application of fertilizer N within the season has shown financial benefits as compared to a uniform per-seeding application of N to winter wheat in the United States (Biermacher *et al.*, 2006). The benefit was sensitive to the price of fertilizer N. The benefits of variable N rate management for maize in the United States have however been inconsistent and adoption is low (Doerge, 2007).

Table 3. Guidelines for the application of fertilizer K_2O according to yield target and K-limited yield in K omission plots (Witt *et al.*, 2007).

Rice straw inputs	Yield target (t/ha) →	4	5	6	7	8
	K-limited yield (t/ha) ↓	Fertilizer K_2O rate (kg/ha)				
Low	3	45	75	105		
(< 1 t/ha)	4	30	60	90	120	
	5	0	45	75	105	135
	6	0	0	60	90	120
	7	0	0	0	75	105
	8	0	0	0	0	90
Medium	3	30	60	90		
(2–3 t/ha)	4	0	35	65	95	
	5	0	20	50	80	110
	6	0	0	35	65	95
	7	0	0	0	50	80
	8	0	0	0	0	65
High	3	30	60	90		
(4–5 t/ha)	4	0	30	60	90	
	5	0	0	30	60	90
	6	0	0	10	35	70
	7	0	0	0	25	55
	8	0	0	0	0	40

Site-specific nutrient management as developed for small-scale rice production in Asia similarly uses within-season variable rate adjustments of fertilizer N but with a low-tech leaf color chart (Figure 1). This SSNM approach as compared to existing farmers' fertilizer practices has demonstrated increased yields and benefits for rice farmers across Asia. In a recent report, the increase in annual grain yield with use of SSNM in on-farm evaluation trials averaged 0.9 t/ha in the Cauvery Delta of southern India, 0.7 t/ha in Central Luzon in the Philippines, and 0.7 t/ha in the Mekong Delta of southern Vietnam (Pampolino *et al.*, 2007). Based on group discussions with farmers practicing SSNM and with other farmers not practicing SSNM, the added net annual benefit due to use of SSNM was 168 US$/ha in India, 106 US$/ha in the Philippines, and 34 US$/ha in Vietnam. In southern India, a considerable portion of the added benefit was associated with improved K management. Farmers practicing SSNM in southern India also reduced their use of pesticides. Use of on-farm data from the sites with a simulation model (DNDC; Denitrification-Decomposition) suggested lower N loss from applied fertilizers with SSNM. The model also suggested that the use of SSNM could reduce the emissions of nitrous oxide—a greenhouse gas—per unit of grain produced (Pampolino *et al.*, 2007).

Experiences with SSNM for rice in Asia indicate that farmers can achieve markedly higher financial benefits through increases in grain yield than through savings in fertilizer use with no net increase in yield. Further increases in yield can be challenging in production systems where yields are already near the climate-determined yield potential of the crop varieties. In small scale irrigated rice production in Asia with little or no mechanization, large gaps often exists between yields in farmers' fields and the yield potential. Opportunities therefore exist for further increases in yield and profit with existing varieties through integrated use of best crop management practices and balanced fertilization with variable rate N management. A promising strategy can be to tailor crop and N management toward achieving crop canopy development (i.e. tillering, panicle number and grain filling) and plant tissue N levels, which minimize the susceptibility of the crop to diseases and pests while increasing yield and achieving higher efficiency of N fertilizer use.

Acknowledgments

A. Dobermann provided the initial conceptual framework and scientific basis, including the modification of the QUEFTS model, for the SSNM approach for rice in Asia. The long-term process that systematically established the scientific basis for SSNM for rice in Asia, evaluated and refined SSNM in farmers' fields through partnerships across Asia, and is now disseminating improved nutrient management for rice across Asia, was made possible through a decade of support from the Swiss Agency for Development and Cooperation (SDC), the International Fertilizer Industry Association (IFA), the International Plant Nutrition Institute (IPNI) and the International Potash Institute (IPI).

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Integrated farming and integrated plant nutrient management

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Summary

This paper focuses on the development of integrated farming and more specifically integrated plant nutrient management across Europe. The paper also highlights some of the opportunities that integrated farming offers the European Commission and national governments through the adoption of integrated farming as a framework to support and deliver their priorities, as well as how the European Initiative for Sustainable Development in Agriculture (EISA)[1] has set about focusing the importance of a balance between the four pillars of sustainability – economic viability, environmental health, social acceptance and political infrastructure.

Introduction

With a radical reform of the Common Agricultureal Policy (CAP), farmers are embracing the environmental challenges laid down, but with the range of expectations and outcomes demanded of them, keeping ahead of new directives and legislation is not easy.

Furthermore this has to be put into context, with the globalisation of trade, rising world populations and wealth, climatic change impacts, obesity, growing urbanisation, changing consumer expectations, new communication modes, the need to deliver biodiversity, etc, all of which have an impact on farming and food production and their associated industries.

As we move towards more sustainable farming systems, how do we create a rural community that is trusted and valued in the market place, delivers society's needs and provides a fair income to farmers? This paper looks at the development of integrated farming as a realistic option for the majority of farmers and charts the development of the work of EISA and the details relating to integrated plant nutrient management.

Within EISA, the stakeholders have built their work around some key areas helping farmers and the industry manage '*the known knowns, the unknown knowns and the unknown unknowns*', trying to work out the shape of things to come, working with options such as:

- long-term global change,
- policy,
- on-farm sustainability,
- consumer choice, expectation and demand.

[1] www.sustainable-agriculture.org

Explaining integrated farming

Farmers do not operate on one aspect of their businesses at a time. Farmers are an accountant one-day, marketer another, outside in all weathers, a vet, a scientist and an environmentalist. It is that mix which makes the farming industry unique. That is why EISA's work is built on a whole farm system bringing together a mix of the best of traditional and the best of modern farming practices – integrated farming. Integrated farming (IF) is a whole farm management system which offers the farmer the chance to identify opportunities and threats and to respond to consumer demands. Traceability is such a demand from society, a challenge which IF can address. Similarly, IF offers the flexibility required to refine farming practices in accordance with government objectives.

Integrated farming is not based on a set of fixed parameters but on informed management processes. This knowledge-based flexibility and multifunctionality of IF includes attention to detail and managing all resources available. This process is capable of identifying adverse effects such as leaching, soil erosion and damage to habitats and biodiversity – and of identifying the measures to reduce them. In animal husbandry, IF is a powerful tool to maintain health and welfare of the livestock on farm, to achieve high quality and good performance and, at the same time, reduce environmental impacts.

Integrated farming is a widely accepted and practical way forward for farmers across Europe. It is a means of achieving sustainable agriculture, a core objective in the formation of EISA. Delivery includes good soil management, rotations, cultivations, crop health, animal husbandry, biodiversity, the creation of opportunities for wildlife, the maintenance and expansion of existing habitats, business planning and community issues – IF (Figure 1).

Figure 1. Integrated farming - a whole farm approach.

Integrated farming offers a whole farm policy and whole systems approach to farm management. The farmer seeks to provide efficient and profitable production which is economically viable and environmentally responsible and delivers safe, wholesome and high quality food through the efficient management of livestock, forage, fresh produce and arable crops whilst conserving and enhancing the environment.

At the core of IF is the need for profitability. To be sustainable, the system must be profitable; profits generate support for all the activities outlined in the IF framework. Financial support for environmental and biodiversity activities varies throughout the European Community but, in all cases, it requires the farmer to commit labour and planning to such activities.

Integrated farming goes beyond simple compliance with current farming regulations, reinforces the positive impact of farming practices on the environment and reduces their negative effects, without losing sight of the profitability for the farm.

Integrated farming is geared towards the optimal and sustainable use of all farm resources such as soil, water, air, farm workers, machinery, landscape and wildlife. This is achieved through the integration of natural regulatory processes, on-farm alternatives and management skills, to make the maximum replacement of off-farm inputs, maintain species and landscape diversity, minimise losses and pollution, provide a safe and wholesome food supply and sustain income.

Integrated farming methods involve the implementation of technical means in an overall approach to the farming activity. Above and beyond food safety regulations which are applicable to all systems of production, IF can facilitate the control of health risks and contribute to improving the health and safety of people at work and livestock on the farm.

Integrated farming requires considered management and a balanced approach of every farm decision. The following nine aspects are essential elements of IF as whole farm management approach:

- **Organisation, management and planning**: this sets the framework, develops a sense of understanding from staff and visitors and ensures attention to detail. Important details of farm interventions and farming practices should be recorded and records kept. Planning and evaluation of practices is essential to ensure environmentally responsible production.
- **Soil management**: soil is fundamental to agricultural systems and a rich ecosystem contributes to crop and livestock performance; "The quality of life below ground determines productivity above". Good soil husbandry will ensure the long-term fertility of soil, aid yield and profitability, and reduce risk of soil damage and associated environmental concerns.
- **Crop nutrition**: nutrient status is key to ensuring that only the recommended amount is applied. The decision making process involves crop demands, the supply that is in the soil and available nutrients from farm manure and crop residues. A balanced approach to fertilisation should be adopted, practices should be adapted to local situations, thereby reducing risks of environmental pollution by fertilisers.
- **Crop protection**: this is the basic strategy for control of pests, diseases and weeds. Any intervention must be accounted for. Crop protection practices should be ratio-

nalised by using integrated and biological methods whenever available, at the same time combining a balanced crop rotation with the selection of more tolerant cultivars to reduce risk.

- **Animal husbandry and animal health**: health and welfare are linked with performance. Integrated farming farmers employ and demonstrate techniques directed towards maintaining animals in good health, comfort and low stress. Balanced, healthy food for animals respecting their physiology is essential. Disease prevention plans and all statutory health controls should be complied with and all treatments administered be documented. National livestock identification systems have to be complied with to ensure traceability of origin, age, race and category of all livestock, animal feed and fodder, whether produced on site or purchased elsewhere.
- **Energy and water efficiency**: sustainability and the responsible management of natural resources is central to IF. More careful and selective use of inputs lowers the energy requirement. Water resource use should be balanced, and programmes which allow to determine crop needs should be used.
- **Landscape, wildlife and biodiversity**: managing wildlife and landscape is of great importance; enhancement of species as well as structural diversity of land and landscape features will benefit flora and fauna abundance and diversity.
- **Waste management, product storage and waste disposal**: wastes – including farm yard manure for example – must be seen as a valuable resource in terms of saving money and reducing pollution. Farming effluents should be managed to optimise recycling and re-use, thereby minimising effects on the environment. Also, the correct storage of hazardous substances and/or material for off-farm disposal and the subsequent proper disposal are important parts of the IF whole-farm approach. Produce on the farm is to be stored separately to avoid contamination.
- **Human and social capital**: health and safety at work and occupational training need to embrace EU standards of employment practice. Inputs can be obtained from many sources, but the use of local suppliers should be favoured where possible. Using local markets will help to maintain both local business and livelihoods and can also improve efficiency. Besides, open and active involvement of the farmer in local community live can help generate transparency and trust.

Integrated farming is a system of agriculture which is more sustainable for the environment and profitable over the long term, encourages biodiversity and which produces safe, affordable food. It provides a framework on which to build a sound future – a new way for agriculture and the countryside.

For the farmer, the approach of IF offers opportunities at all levels. Across Europe, EISA has over 1,000 demonstration farms. In the UK, Linking Environment And Farming (LEAF) has over 70 demonstration farms and innovation centres. At all these farms, other farmers can visit and discuss detailed, practical, technical developments and research about IF. These farmers are individuals who are championing the cause of IF and also acting as ambassadors for promoting industry. The farms are excellent backdrops for discussion and it is the framework of IF that acts as an excellent approach, for not only engaging individual farmers on a very personal level, but also ensuring that there is a balance of individual priorities accounted for.

It is the attention to detail of IF that also delivers farm profitability. Research in to IF throughout the 1990's was brought together within a group known as the Integrated Arable Crop Production Alliance (IACPA). IACPA studies showed maintenance of profit through the adoption of IF mainly due to lower input costs (Figure 2). A 40% reduction of crop protection volume, a 15% reduction of fertiliser volume and a 10% reduction in operating costs resulted in a 2% (-20% to +15%) increase in gross margin above conventional production techniques (Figure 3). The research also showed that the profitability improves in the IF system as grain prices fall (Figure 4).

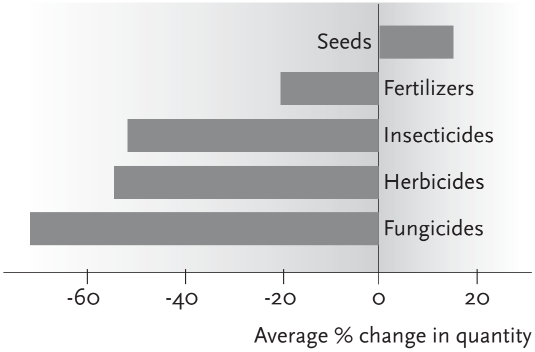

Figure 2. Integrated farming inputs as percentage of conventional systems.

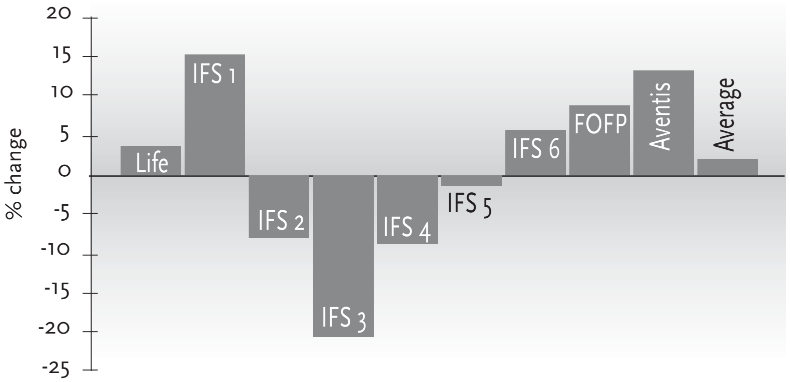

Figure 3. Integrated farming yields as percentage of conventional crop yields.

Figure 4. Profitability buffering of integrated systems in relation to grain prices (UK£/t).

Not only are there financial paybacks through the adoption of IF but there are also those demonstrating environmental responsibility:

- optimisation/minimisation of inputs,
- encouragement and increase in flora/fauna biodiversity,
- reduced potential pollution,
- adherence to waste and energy management standards,
- "goodness" returned to the land (soil management, etc.),
- reduced impact on the "countryside", meeting standards for wildlife protection (including birds).

The EISA Integrated Farming Framework explained

In November 2005, EISA presented the **Integrated Farming Framework** as a definition and characterization in detail of IF as an approach to sustainable development in European agriculture.

The Framework's principle use is as a tool on two different levels:

- For the individual farmer, the EISA Framework offers a management tool which may help to further raise awareness, to continually improve everyday practice on farm and hence equally achieve economic, environmental and social progress.
- For politics and administration, the EISA Framework presents a definition and characterization of IF, giving the basis for a common understanding, and to be applied all over Europe.

All in all, the EISA Integrated Farming Framework points out guidelines and potentials for developments in agriculture. These potentials can be taken up by farmers and – if considered useful – can also be taken up by politics to shape incentives or programs in the future.

Marketing value and opportunity

Increasingly, farmers are choosing to take market advantage by demonstrating a point of difference either through specific environmental performance as with the LEAF Marque in the UK or organics, or through promoting regional/locally sourced produce. LEAF marque farmers take forward the messages of IF, do the LEAF audit and follow specific guidelines with independent, external verification. This independent external verification determines if produce appears on the shelf in front of the consumer. The LEAF marque provides farmers with the opportunity to be proud of their farming and environmental performance. We are increasingly finding that those that are involved find this partnership extremely motivating and rewarding, and are constantly looking to develop their businesses into new outlets.

Accessing markets linkages through the food chain are likely to become of growing importance. Some markets who attach great importance to the certainty of supply make themselves become involved in the production process, sharing the costs of inputs, providing technical guidance, agreeing acceptable farming practices and the timing of production. Such linkages may range from full ownership of successive stages to relationships based on long-term contractual links. In the product areas to which they apply, agriculture may move into the sort of market where 'badge' marketing becomes possible and advertisement supports the 'teams' production.

The LEAF marque

The LEAF marque has been developed principally with four retailers (Waitrose, Sainsburys, Safeways and Marks and Spencer), who are all still involved in its ongoing development. Though to date only Waitrose and a newer retailer (Fresh and Wild) are using the LEAF marque logo in store, more and more farmers are getting accredited and are using the logo in farm shops and on their products. There are now over 60 product lines and over 100,000 hectares registered as LEAF marqued. The LEAF marque gives consumers the choice to buy affordable food produced by farmers who are committed to improving the environment for the benefit of wildlife and the countryside. In addition, the LEAF marque offers a full traceability on the food label so consumers can visit 'the farmer' virtually on the web (www.leafmarque.com), access a buyers and suppliers 'matchmaking' service and have the opportunity to visit the farms. Independent joint inspections are being carried out in partnership with other farm assurance schemes, in particular the Red Tractor – Assured Food Standards, which was set up to demonstrate food safety standards. Independent joint inspections save money and give credit to those farmers who want to go further in demonstrating best environmental practice with the LEAF marque.

Communication with consumers

The EISA members and their farmers connect all the way down the whole food chain from the demonstration farms to the retailer. A part of this is the development of the

Speak Out initiative, and a similar approach has been taken in Germany. This communication tool has been developed to enhance the energy and enthusiasm positively to take forward the skills of the industry, build bridges and gain public trust. The links with the food processors and to consumers is quite a critical part of this, building partnerships is a two-way process. Building trust is very much steering along the line of what are the interests, what are the concerns and how to effectively address them together so that the whole journey of connection is something that is very important. In particular, if we are to effectively internalise the costs of managing the environment, we must try and change the citizen who stands outside the supermarket with big virtues of environmental care and welfare, valuing the farmer to the consumer who goes into the supermarket for the cheapest food. It is about encouraging the consumers to recognise what lies behind the money that they spent. What is the depth and value behind the pound, what is the true cost of cheap food, how far has it been transported, what are the issues relating to ethics, employment, food safety, animal welfare.

In the UK, LEAF works on bridging the gap between farmers and consumers through its Speak Out initiative. This communication tool was developed to take forward the know-how of the industry and gain public trust. It is based on two main toolkits: (i) a self-help CD-Rom and audio-cassette to help farmers improve their communication skills and (ii) a range of waterproof notice boards that tell facts about nature conservation, animal welfare, crop production, etc., out in the field, the 'All on Board' project as mentioned above.

Building partnerships is a two-way process and links with the food processors and consumers are in this regard critical. It is important to get farmers to really address consumers concerns and encourage consumers to realise the practicalities and impact of their desires and wishes. LEAF endeavours to understand the concerns people have as consumers and translate this into the actions they take in supermarkets as customers.

We need to bring people out to the countryside more and get out a common message – whether it be through visits to an EISA demonstration farm or through school visits or reading notice boards when they are walking – the opportunity is great.

Sustainable consumption

We could not be more fortunate than within the food and farming industries when it comes to getting involved with consumers. We have a beautiful countryside, local food heros, and farmer profiles in magazines all conjure up images in our minds, some of them associated with holidays and special occasions, some of them an era long moved on from. However, in reality, the food and farming story is a complex one. Consumers and their buying power have changed dramatically over the past twenty years. Globalisation, the retailers, choice and availability all mean that the production of food and the story of farming lies a long way away from the food we eat.

Added to this, the way consumers receive information has also changed. We are constantly receiving 'messages' about all sorts of things, from cars to electronics, toys to holidays so there is increasing pressure for trying to get 'air time' for the farming story. As an industry we have to be clear, focused and collaborative. We need to pick our audiences well, identify our 'farmer communicators' effectively and present our message clearly – it needs to be a more united message. We need to build on the reconnection message, support the best examples in the industry and discover new means of 'connection' with the general public.

Conclusion

The development of integrated farming across Europe, is critical in delivering site specific solutions on the ground. Integrated Farming offers a realistic, achievable and logical approach for farmers as well as a framework to support and deliver the European Union's priorities, the work of EISA and its member countries have gone a long way to setting the standard for a realistic way forward for the majority of farmers.

"Teaspoon feeding": precise plant nutrition through advanced application methods

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Agricultural research is continuously seeking for ways to maximize crop yields and quality, and to minimize production costs. To maintain sustained farming systems, the environmental impact of every field operation should be considered. Optimized crop-production practices necessarily involve optimization of water supply and nutrient application, in order to maximize efficiency and minimize wastes.

Efficient fertilization schedules aim to provide plant nutrients with precise timing and composition to match plant growth needs, at a precise location to enhance uptake efficiency, and with precise dosing to avoid waste and contamination.

Advanced methods of fertilizer application permit a nutrient supply that matches very closely the requirements of the plant, in a manner sometimes described as '*teaspoon feeding*'.

It is already well established that the most advanced and efficient practice of delivering plant nutrients is fertilization via the irrigation system, known as Nutrigation™ [1] (fertigation with pure nutrients). Nutrigation combines the two major factors affecting plant performance - water and nutrients - in a controlled and balanced manner. Nutrigation features the advantages of uniform fertilizer application throughout the irrigated area, and accurate feeding based on plant needs and climatic conditions.

There are two main methods of Nutrigation: quantitative and proportional.

In the quantitative method, the fertilizer is introduced into the irrigation water using a bypass fertilizer tank. The grower determines the total quantity and the composition of the fertilizer. The concentration of nutrients in the irrigation water and in the soil decreases with time, as the fertilizer in the tank dissolves and is washed out. This method provides adequate nutrition for the crop only if the soil has some capacity to retain the nutrients. Otherwise, the plant is exposed to an excess of nutrients at the beginning of the irrigation cycle, when the concentration in the water is high, followed by a shortage later and between irrigations.

In the proportional method, the fertilizer concentration is kept steady throughout the course of irrigation, using a fertilizer pump or injector that introduces a fertilizer solution of constant composition and concentration into the irrigation line. This method permits a higher degree of control over plant nutrition, even on light soils or in inert growing media.

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[1] Trademark registered by Haifa Chemicals

Nutrigation is highly beneficial as long as irrigation and fertilizers are applied simultaneously. If the water supply depends on rainfall, the nutrient supply by Nutrigation requires technical irrigations, which involves a waste of water and extra labor. Furthermore, heavy or frequent rains may leach the applied nutrients under the root zone. For the same reason, Nutrigation is wasteful and polluting if irrigation is given in excess (e.g. to prevent salt build-up). Another limitation of Nutrigation is the dependence on relatively sophisticated irrigation and dosing equipment.

In cases where Nutrigation is not practical or inadequate, controlled-release nutrition may be employed. Here, single, pre-plant application of polymer-coated fertilizers with predetermined release longevity (e.g. Multicote®[1] products) provides the crop's nutritional requirements throughout the growth season. Following application, the granules start to absorb moisture that dissolves the nutrients inside the granules. The dissolved nutrients then diffuse, slowly and continuously, into the root zone. The rate of diffusion – the actual release rate - depends upon and is dictated solely by the soil temperature.

Efficiency is achieved by this method, due to the high correlation between the plant nutrient-demand curve, and the nutrient-release pattern from the coated fertilizer granules. This correlation occurs because both development of the plant and the rate of release of the nutrient are regulated by soil temperature. The efficiency of controlled-release fertilizers (CRFs) provides economic benefits due to reduced labor and a lower application rate, while achieving the same or even better crop performance.

To follow plant nutritional requirements as they change during the growth season, innovative products offer different NPK ratios at every stage. For both agronomic and economic reasons, controlled-release products for agricultural applications usually combine polymer-coated nutrients and non-coated-readily available nutrients.

Controlled-release nutrition is recommended on light soils, in rainy areas, where mid-season application is not feasible, or where nitrogen application is restricted (e.g. by environmental legislation).

Nutrigation and controlled-release nutrition can be combined to best suit the conditions in regions with distinct dry and rainy seasons. Nutrigation supplies nutrients in the dry season, while controlled-release fertilizers take care of the crop nutrition when irrigation is not needed and water should be saved.

Another possible combination is Nutrigation at the beginning of the growth season and CRFs with low initial release. The Nutrigation will boost initial establishment, while the CRFs provide nutrition for later stages.

Another method that offers plant nutrition with high added value is foliar feeding, whereby nutrients are applied to and absorbed by the leaves rather than by roots. Foliar feeding can provide the nutrients needed for normal development of crops in cases where absorption of nutrients from the soil is disturbed.

As the uptake of nutrients through the foliage is considerably faster than through roots, foliar sprays are also the method of choice when prompt correction of nutrient deficiencies is required.

Foliar application of nutrients during critical growth stages dramatically increase yields and improve yield quality.

Foliar nutrition may be combined with any other application method, to complete and to enhance plant nutrition.

The ideal product for foliar feeding should have a composition that meets specific crop requirements, good adhesion to the leaf surface, a reduced scorching hazard and wide-range compatibility, so it can be applied together with other agrochemicals, thus saving on field operations.

Advanced foliar formulations also feature prolonged action: the leaves absorb the nutrients over time, without being washed away.

Haifa-Bonus™[1] is an example of a fertilizer specially formulated for foliar application, fulfilling the requirements mentioned above.

Modern agriculture is required to maximize the nutrient use efficiency of all resources and inputs, while maintaining high yields and minimizing environmental impacts. This can be achieved by the "Teaspoon-Feeding" approach, taking advantage of highly efficient fertilizer application by Nutrigation, controlled-release nutrition and foliar feeding.

The ideal fertilization schedule should combine the three methods, responding to crops needs, growth conditions, technical, economical and environmental considerations. By careful planning and in-season corrective operations, if needed, it is possible to follow plant nutritional requirements very closely, thus ensuring healthy growth, optimizing nutrients use efficiency and minimizing fertilizer losses and environmental contamination.

Fertilizer best management practices in the context of product stewardship

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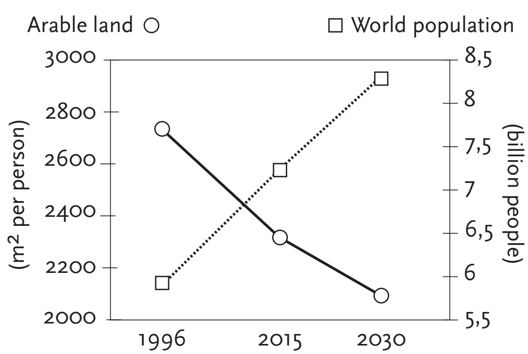
Introduction

Agriculture is facing the global challenge of increasing food production. According to the Food and Agriculture Organization of the United Nations (FAO, 2003), the increase of the world's population will require more intensive agricultural production. Since agricultural land is a scarce resource, the available land per capita (Figure 1) will decline. In addition to the increasing demand for food, the new demand for bio-energy feedstocks represents an additional market for agricultural products and requires an increasing intensity of agricultural production. Agriculture in Europe is an important contributor to world food supply because of its good natural growing conditions, its excellent logistics close to large consumer markets and the skills of the European farmers. At the same time, there is competition for land between agriculture and urban interests. It is often the best agricultural land that is used for urban expansion, with its buildings and infrastructures. All these factors contribute to the need for an increasing intensity of agricultural production.

In spite of the fact that European agriculture plays an important role in producing plentiful, affordable and healthy food, society seems to be unaware of these important benefits. There is often little recognition of the essential role of agriculture. One important reason is that, today, only a small fraction of the European population (only 5%



World population increases up to 8.27 billion people in 2030.

In the same time, the arable area can, according to FAO, only be extended by about 7%.

Thus, the arable area per person decreases rapidly, and the intensity of agricultural production has to increase.

Figure 1. Global trend: the intensiveness of agricultural production has to increase.

in the EU-15) is still engaged in agriculture. It is an urban population without direct experience of agriculture that is determining the policies. Other considerations such as the conservation of wildlife and biodiversity or the protection of water and air from emissions are being given higher priority. In consequence, agriculture has increasingly found itself in a position in which it receives only a negative portrayal in the popular press. It is seen to be the cause of environmental problems or food scandals. To explain that agricultural production has to be even more intensive in the future is not popular in such a context.

Product stewardship and fertilizer best management in Europe

The main responsibility of EU farmers is to provide wholesome and appetizing food for the European population. Society's increasing expectations regarding the environment are sometimes translated into legislation that leads to diverse objectives and legal constraints. Incidents in the transport and storage of fertilizers have shown that even where good practice is correctly implemented, it needs to be controlled and the effects need to be measured. Therefore, the European Fertilizer Manufacturers Association (EFMA) decided at the end of 2001 to engage in an ambitious and demanding program of product stewardship (Figure 2).

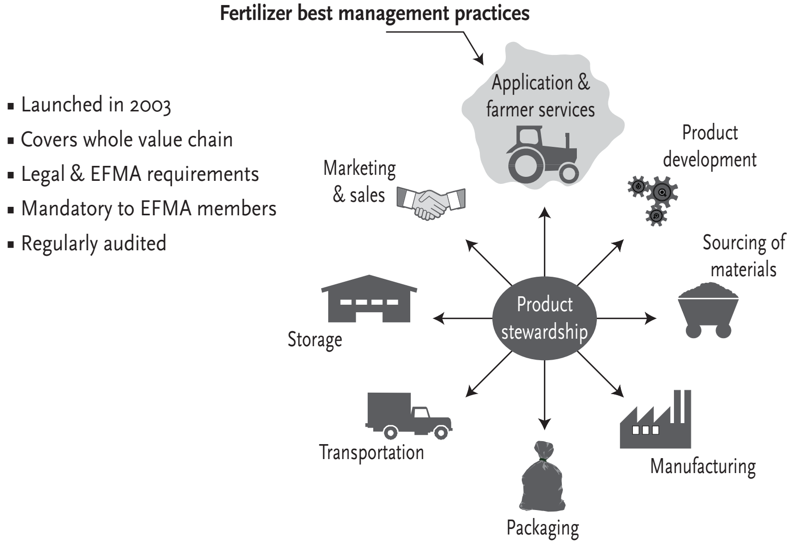


Figure 2. EFMA's product stewardship program.

The overall objective of product stewardship is to ensure that fertilizers and their raw materials and intermediate products are processed and manufactured, handled, stored, distributed and used in a safe way with regard to health, environment and safety. It is to ensure a very strict control of all safety measures at each different level of the life cycle of a fertilizer product. All EFMA companies were asked to apply an extensive set of safety rules and measures, which are controlled by external auditors on a regular basis. Adhesion to the EFMA core values and the fulfillment of EFMA safety standards is mandatory for all EFMA members. The product stewardship program was initially established to control the industrial process, from the sourcing of raw material to delivery at farm gate. It became obvious that good fertilization practices applied at farm level have to be included as an integral part of the program. The message that the industry cares for the fertilizer products even after they are sold to the customers (distributors) has become a very important element of the product stewardship program.

It must be demonstrated that the correct use of mineral fertilizer at the farmer's level reconciles optimum plant nutrition with environmental objectives. Agronomic services have therefore been developed to provide appropriate information to farmers on the best way to apply fertilizers (Figure 3). Agronomists from the fertilizer industry have developed technically advanced recommendations. Examples are computer programs to calculate the right amount of fertilizer and diagnostic systems or monitoring tools that help the farmers to assess correctly the nutrient requirements of the crops. Concerning the fertilizer management tools in Europe, these techniques and technologies already exist and are currently being applied in many EU countries, and they continue to be developed. The bottleneck is, therefore, not the development of good practices; they have already been developed over many years. Procedures and techniques are now available to address the nutrition of all crops, under all European natural and climatic conditions.

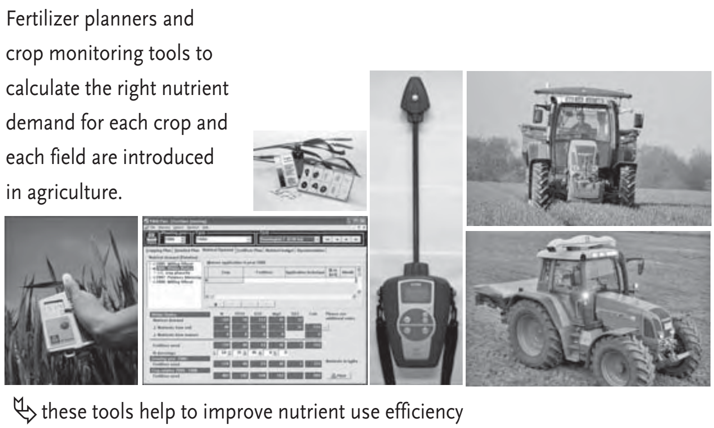


Figure 3. EFMA members have developed tools to support fertilizer best management practices.

Achievements with fertilizer best management practices

Within the product stewardship program, the main challenge at present is to communicate the recommended practices to farmers and, furthermore, to make sure they are correctly applied. In order to fulfil this objective, EFMA supports all the national and EU initiatives that develop and promote good agricultural practices (GAPs). EFMA promotes all measures aimed at the development of better recommendations for crop nutrition and soil management. In this way, the European fertilizer industry has contributed to a considerable increase in the productivity of EU agriculture. This increase in productivity can also be expressed and measured in terms of the increase in nitrogen use efficiency in Europe (Figure 4).

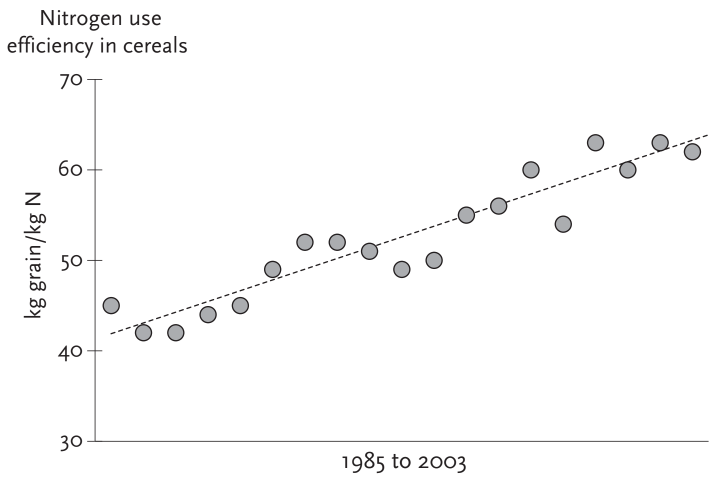


Figure 4. The efficiency of N use in Europe has increased over the last 20 years (Dobermann, 2005).

Figure 5 shows data demonstrating the achievements of European agriculture concerning mineral nitrogen fertilizer use and nitrogen removal from the field. Larger cereal yields have increased nitrogen removal from the fields by about 25 kg N/ha. At the same time, the use of mineral nitrogen fertilizer has declined by about 10 kg N/ha. These data confirm that the increased N use efficiency as shown in figure 4 is the result of both a higher crop yields and a reduction in mineral fertilizer use. This has been achieved by better recommendation tools and/or a better appreciation of nutrient supply from organic sources.

Promotion of fertilizer best management practices

For the fertilizer industry, it is much easier to control what is "in house", in factories, than what is outside the factory. Therefore, in the product stewardship program, par-

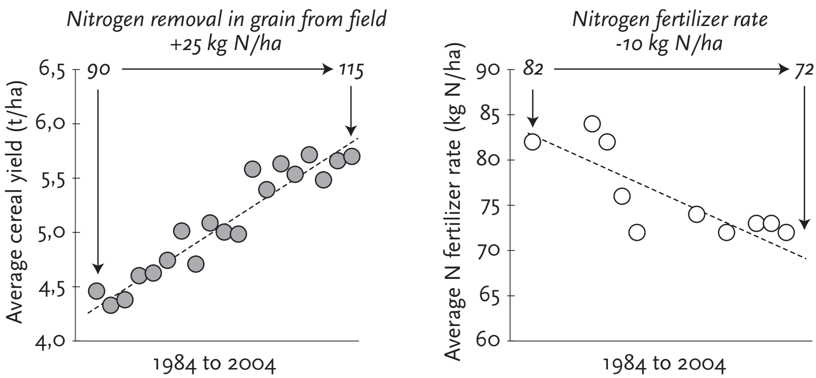


Figure 5. An increase in N use efficiency means higher crop yields with either less or the same amount of fertilizers (Example: cereal production in Western Europe, EU-15).

ticular attention has been given to the communication of the principles to customers, external partners and to the general public, in order to make known the efforts of the fertilizer industry to implement FBMPs. The European fertilizer industry cannot reach all EU farmers individually and the progress shown in figure 5 is therefore not just a result of EFMA's own initiatives on FBMPs. EFMA has also developed collaboration with the main farmers associations, on a national and EU level. The product stewardship program actively supports all initiatives, national and European, which aim at developing and promoting FBMPs. The objective is to help these organizations to develop and promote their tools at EU level. The main aim is to contribute to the development of a European framework for sustainable farming, which will help agriculture to meet society's environmental expectations.

As can be seen from Figure 6, fertilizer consumption in Europe has decreased significantly during the last 25 years (minus 25% for nitrogen), although EU agricultural production has increased dramatically during the same period. This is a logical consequence of adopting FBMPs in European agriculture. The fertilizer industry has understood and accepted that the promotion of FBMPs at farm level is the best approach. The consequences have been positive, as can be seen in Figure 6.

The adoption of FBMPs could lead to a decline in the growth rate of fertilizer consumption in some markets. In other markets, as has been the case in Europe, it may even lead to a decline in fertilizer consumption. However, agriculture has to increase the intensiveness of crop production and this is not possible without the correct application of plant nutrients. The development and dissemination of FBMPs is necessary in order to combine intensive crop production with a low impact of agriculture on the environment. In this respect the former director general of EFMA, H. Aldinger (2006), stated that ".... the mission of EFMA is to steer the industry through outside challenges in order (negatively speaking) to preserve the industry's license to operate or (positively speaking) to safeguard the industry's well-being in the long-term".

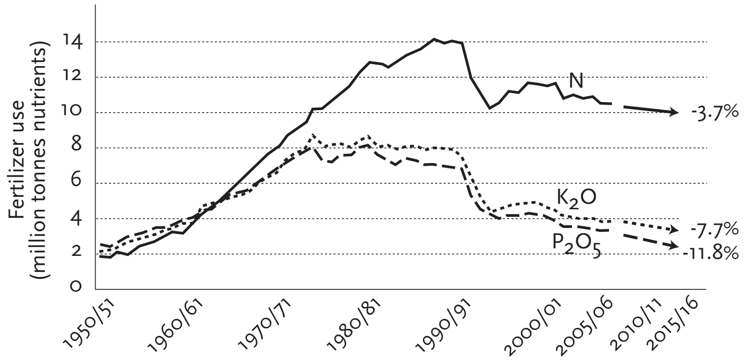


Figure 6. Development and forecast of fertilizer use in the European Union (EU-25). Data are from EFMA.

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Can we define a global framework within which fertilizer best management practices can be adapted to local conditions?

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The title of this paper is not a statement, but rather a question, and it does not ask "Can I define a global framework …" but rather can we define a global framework. As such, no attempt to answer the question will be made in this paper. It is assumed that "we" refers to the global fertilizer industry and that, if a meaningful global framework can be defined and should be defined, the discussions of this meeting should offer an opportunity to do so or at least to start the process. "We", as a global industry, will need to determine whether a global framework within which fertilizer best management practices (FBMPs) can be adapted to local conditions can be defined.

So if this paper will not answer the question of its title, what will it attempt to accomplish? The following issues related to definition of a global framework will be discussed with the hope of facilitating later deliberations at this meeting:

- challenges in defining a global framework,
- potential foundation for a global framework,
- potential benefits to the industry of a global framework.

Challenges in defining a global framework

Definition

The first challenge to address is perhaps the definition of best management practices (BMPs). Many definitions over the last two decades have been offered for BMPs, with emphasis varying depending on the primary interest of the definer. Examples across a range of interests follow:

1. USDA-ARS (Sharpley *et al.*, 2006) – Best management practices include soil and water conservation practices, other management techniques, and social actions that are developed for a particular region as effective and practical tools for environmental protection.
2. FDCO and FAO (Tandon and Roy, 2004) – A set of agronomic and other soil-crop management practices, which lead to the best possible use of applied inputs for crop production, resulting in minimal adverse effect on the environment. A pre-requisite for efficient and environment-friendly fertilizer use. Important for all soils, crops and fertilizers.
3. BMP Challenge (Anonymous, 2006) – BMPs are designed to save you money by using your field history and soil test results to cut fertilizer costs and maintain yield.

4. North Carolina State University (Lilly, 1991) – Farming methods that assure optimum plant growth and minimize adverse environmental effects.
5. PPI (Griffith and Murphy, 1991) – Practices which have been proven in research and tested through farmer implementation to give optimum production potential, input efficiency and environmental protection.

The first definition clearly emphasizes environmental protection without mentioning production or profitability. The second is more inclusive, referring to "best possible use of inputs" but the specific meaning of such an expression is unclear. The third definition is part of an incentive program designed to reduce fertilizer use and this definition certainly reflects that focus, while admitting that the best you could hope for by following these practices is yield maintenance, an objective likely falling far short of future demands agriculture must meet. The fourth explicitly mentions the need for the practice to provide optimum nutrition to the crop along with environmental protection. The last definition was offered by fertilizer industry representatives and has a stronger emphasis on practicality and productivity while including efficiency and environmental protection. I admit a bias towards the latter two definitions because they incorporate a primary objective of fertilizer use … economically optimum crop production built on well-researched principles.

Limiting technical breadth without limiting usefulness

Another challenge involved in defining a global framework for fertilizer BMPs is defining the technical breadth of that framework. Darst and Murphy (1994) wrote about the lessons of the U.S. Dust Bowl coupled with thousands of research studies showing the merits of proper fertilization and other new production technology, catalyzing the fusing of conservation and agronomic BMPs. The challenge is to address the specific BMPs dealing directly with fertilizers while recognizing the myriad agronomic and conservation practices with which the fertilizer practices interact.

Science and experience clearly show that the impact of a fertilizer BMP on crop yield, crop quality, profitability and nutrient loss to water or air is greatly influenced by other agronomic (plant population, cultivar, tillage, pest management, etc.) and conservation practices (terracing, strip cropping, residue management, riparian buffers, shelter belts, etc.). Practices defined with sufficient specificity to be useful in making on-farm fertilizer use decisions, often are "best" practices only when in the appropriate context of other agronomic and conservation BMPs. A best fertilizer practice can be totally ineffective if the cropping system in which it is employed has other serious inadequacies.

The title of this paper limits the breadth of its discussion to fertilizer BMPs in contrast to nutrient BMPs, which is a broader topic. Nutrient management BMPs include livestock manure management and practices designed to capture nutrients before they are lost from the agro-ecosystem, such as cover crops, crop residue management, contour planting, field buffer strips and controlled drainage. These practices, that extend beyond fertilizer management, are often essential for farmers to accomplish many of the objectives of nutrient management, especially those related to the environment. Focus on fertilizer BMPs should not be taken as diminishing the importance of these other nutrient management practices. As mentioned earlier, failure to follow BMPs in these other areas can cause failure of fertilizer BMPs as well.

An important aspect of creating a global framework is knowing how "deep" or detailed the global version should be. On the one hand, too much detail could overly constrain the appropriate site specificity of BMPs and involve technology implications that cannot be generalized across a global scale. On the other hand, an overly general framework would give insufficient uniformity to the resulting fertilizer BMPs. This would prevent full realization of the benefits of showing the global support of the fertilizer industry for a meaningful BMP concept. Another consideration is the need for companies to show unique value in the market place. If the "sameness" from a framework goes too far, some might argue that a company's ability to deliver unique value becomes compromised.

Targeting a specific audience

Descriptions referred to as BMPs occur at all levels of scale and specificity. At one end of the spectrum you have "Apply fertilizer according to annual soil test recommendations. Do not apply more fertilizer than is recommended. Apply fertilizer to actively growing crops only (NCSU, 2007)." This is the only reference to fertilizer management in a university publication on BMPs. However, the same institution has another publication on BMPs that includes four pages of fine print, with numerous references to additional publications covering the details of specific nutrient BMPs (Lilly, 1991). Clearly the audience for the first publication was not the same as the latter. Both have utility, with the first intended for communication of the general aspects of BMPs to a non-technical, non-practicing audience, while the latter would be meaningful to farmers or their advisers.

To be most effective, the presentation of a global framework for fertilizer BMPs would need to be directed to a specific audience. A single complete framework could be developed with sufficient detail to serve as the skeleton for site-specific, detailed local practices where the target audience is the farmer and the farmer's advisers. However, a much more compressed but visual presentation of the same framework might be in order for non-technical communication with policy influencers and the general public.

Potential foundation for a global framework

Science-based principles

A global framework would likely be built with the science-based principles that lead to the best practices. The principles would serve as a guide to practices with the highest probability of accomplishing the objectives of fertilizer management. Those objectives were described by Roberts (2007) earlier in this workshop, as application of the right product, at the right rate, at the right time and in the right place. It is essential that these practices be presented as offering the **highest probability** of accomplishing the objectives rather than **guaranteeing** that the objectives will be accomplished. Figure 1 illustrates the complexity of the cropping systems in which fertilizers are managed. Many of the factors markedly influencing plant growth, metabolism and nutrient needs are uncontrollable, resulting in considerable uncertainty as to what the right form, rate, placement or timing will be at a specific site in a specific growing season. The best the manager can do is to adopt those available practices that have the highest probability of leading to the right fertilizer management decisions. Science allows us to define those practices.

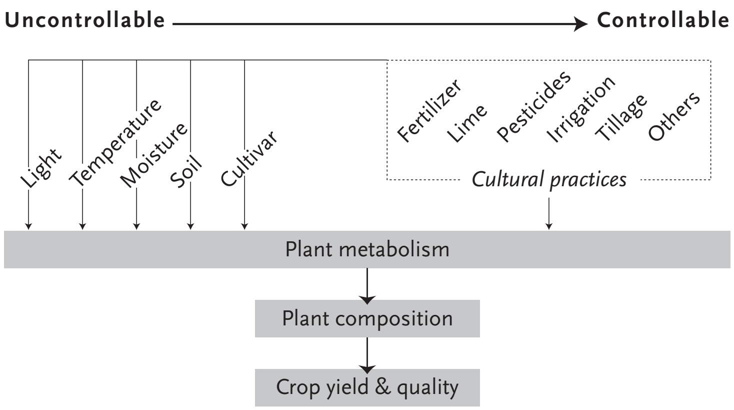

Figure 1. A complex system involving uncertainty (After Beaufils, 1973).

Tested through farmer implementation

However, science-based knowledge offers only part of the foundation for the fertilizer BMP framework. The other part is referred to in BMP definition 5 above - «tested through farmer implementation». Science can lead at times to practices which simply are not workable on real farms. For example, the time or labor requirement may be too high, or one apparent BMP may be in conflict with another BMP. Therefore, an element of practicability must be part of the foundation; the most assured evaluation of practicability is testing on real farms.

Flexibility in the framework

Scientific truths are seldom permanent but change as scientific knowledge grows. Likewise, BMPs are dynamic and evolve as science and technology expands our understanding and opportunities and practical experience teaches the astute observer what does or does not work under specific local conditions.

Figure 2 illustrates schematically how science-based decision support tools can facilitate the integration of multiple site-specific factors into a prediction of the right product, rate, time and placement. That prediction leads to a management decision and associated action. With time, the economic, agronomic, environmental and resource impacts of the action are known, and that experience is fed back into the decision making process, allowing for better future predictions of right product, rate, time and placement.

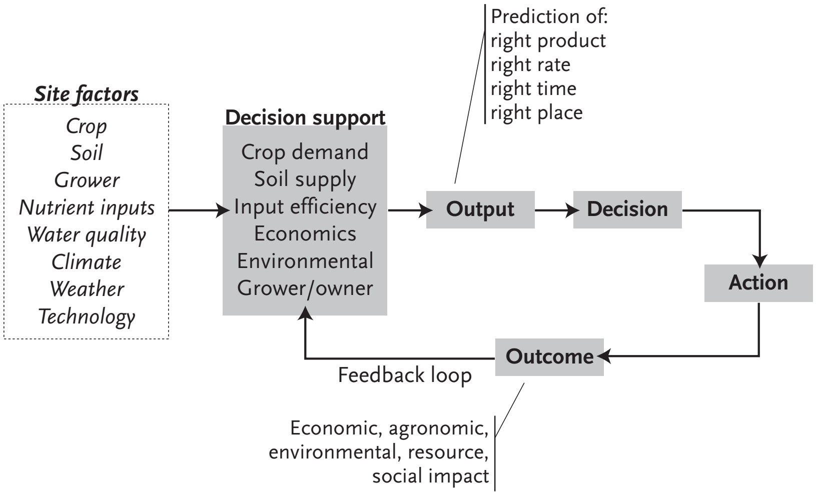

Figure 2. Decision support leading to fertilizer BMPs as a dynamic process requiring local refinement (After Fixen, 2005).

Consideration of the many possible site factors that can influence the exact nature of fertilizer BMPs reveals why local flexibility is essential. For example:

- **Crop factors** usually include yield potential and crop value and in some cases tissue nutrient concentrations or leaf color, as well as several crop cultural practices that can influence nutrient management;
- **Soil factors** often involve soil nutrient supplying indices or other physical, chemical or biological properties that influence nutrient cycling and crop growth;
- **Grower factors** might include land tenure, availability of capital, opportunity costs, the experience/education of the farmer and local advisers, or philosophical nutrient management objectives;
- **Nutrient input factors** incorporate information on sources available such as commercial forms or nutrient-containing wastes, fertilizer costs and application costs;
- **Water quality factors** might include restrictions on nutrient application in riparian zones or near other water bodies or considerations due to ground water quality;
- **Climate factors** drive some types of model-based support systems while others respond to near real-time weather information for a specific growing season and short term weather forecasts;
- **What relevant technologies** are available at the site in question may certainly influence definition of best practices. For example, in-season refinement of N application rate and timing may be best accomplished with electronic sensor technology in some cases, and leaf color charts in others.

The dynamic nature of site-specific fertilizer BMPs and the importance of local flexibility present a significant challenge to mandated fertilizer BMP adoption. Mandates may speed adoption, but may also result in loss of beneficial fine-tuning based on local expertise.

An example of a partial global framework

So, what might a global framework actually look like, considering the challenges and essential characteristics previously discussed? Several approaches could be taken. One possibility is outlined in Figure 3. This framework has five parts – goals, objectives, principles, practices and assessment. The first three parts are considered global while the fourth and fifth are considered local.

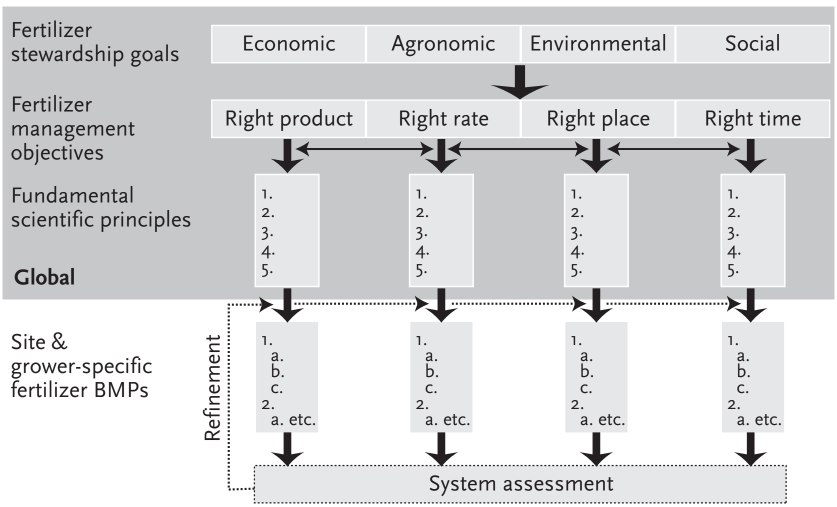

Figure 3. One potential global framework from which fertilizer BMPs can be adopted.

- **Fertilizer stewardship goals**. It is important that the industry should clearly articulate these goals to the public and that we have them in front of us as we go about our daily business. Most organizations already have developed their own stewardship goals and the task here is to connect the goals the industry shares with the other components of the framework … show that we do practice what we preach. Often only three categories of goals are shown but in this case "agronomic" has been included to allow emphasis on the interaction of fertilizers with other factors of crop production.
- **Fertilizer management objectives**. The "rights" have been discussed elsewhere. The horizontal arrows connecting the fertilizer management objectives illustrate that considerable interaction exists among the four objectives. For example, the right timing and placement is often influenced by the product being used. And the rate is likely to be right only if the product, placement and timing are appropriate. All four objectives are met or not met as a set since a system is what exists in the field.
- **Fundamental scientific principles**. These were also discussed earlier and, in this framework, they serve as the conduit between the global segment of the framework and site and grower-specific fertilizer BMPs. For the most part, current BMP litera-

ture does not link recommended practices to the scientific principles behind them as shown here. This is a critical void since these principles are the foundation local advisers use to refine generalized BMPs for local conditions. They are essential for maintaining the flexibility to truly create site and grower specific BMPs. The intention of the framework is that the principles should be stated in such a way that their application is universally essential to define fertilizer BMPs, regardless of local conditions.

- **Site and grower-specific fertilizer BMPs**. These are actions that can be practiced by farmers and their service providers or advisers. They are therefore very specific. A couple of examples of fertilizer BMPs related to the "right rate" objective are shown in Figure 4. Five principles are listed under "right rate" with the first being to assess soil nutrient supply. A universal need for determination of "right rate" is some assessment of the soil's ability to supply the nutrient in question. If sufficient research supports the tests and laboratory access exists, appropriately conducted soil testing is a BMP based on that principle. In other cases, omission plots may be more appropriate. The appropriate target level for the soil test is influenced by several soil and farmer-specific factors, and may also be influenced by water quality considerations.
- A**ssessment**. As in the process model outlined in Figure 4, local feedback is important for the refinement of site- and grower-specific BMPs. Since the objectives of fertilizer management are met or not met as a set, the system is assessed rather than the practices associated with individual management objectives. In many regions a need exists for clear guidance on appropriate system assessment methodology to evaluate progress in attaining fertilizer stewardship goals.

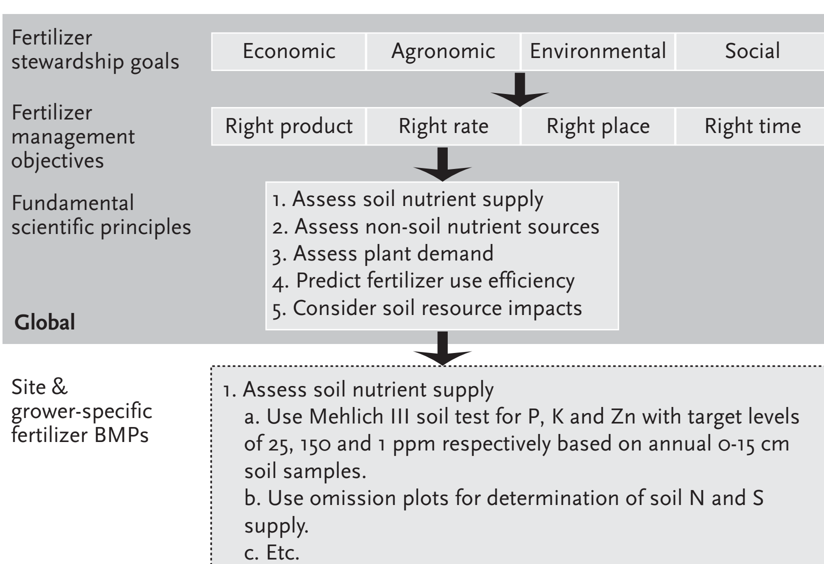

Figure 4. One potential global framework with fertilizer BMP example.

Potential benefits to the industry of a global framework

What incentives might exist for the industry to develop a global framework for fertilizer BMPs? If no such framework is adopted, those individual companies, countries or regions that perceive value in defining, promoting and evaluating fertilizer BMPs will continue do so with or without such a framework. So, why bother?

Several potential benefits of a global framework come to mind:

- **A better framework**. If one believes in the collective intelligence of multiple technical experts from diverse backgrounds working on a common problem, all should benefit from the high quality product resulting from such an effort. We start the process of establishing site-specific fertilizer BMPs at a better place.
- **The power of a unified voice**. An entire industry speaking the same language concerning fertilizer BMPs and its support of them should be more effective at clearly communicating, internally and externally, sustainability issues related to economic, agronomic, environmental and social performance.
- **More effective use of science and technology**. The science-based principles of nutrient cycles, soil fertility and plant nutrition are universal. How they manifest themselves in specific management practices varies with climate, soils, access to technology, local economic conditions and culture. However, the global soil map (Figure 5) reminds us that there is predictable order in soils that can be invaluable in helping to define the global inference space associated with specific research findings. This permits the adaptation and refinement of BMPs according to local conditions. In the "flat world" described by Friedman (2005), the global plant nutrient industry could be connected to the global plant nutrition science … in real time. A common framework should facilitate that connectivity.

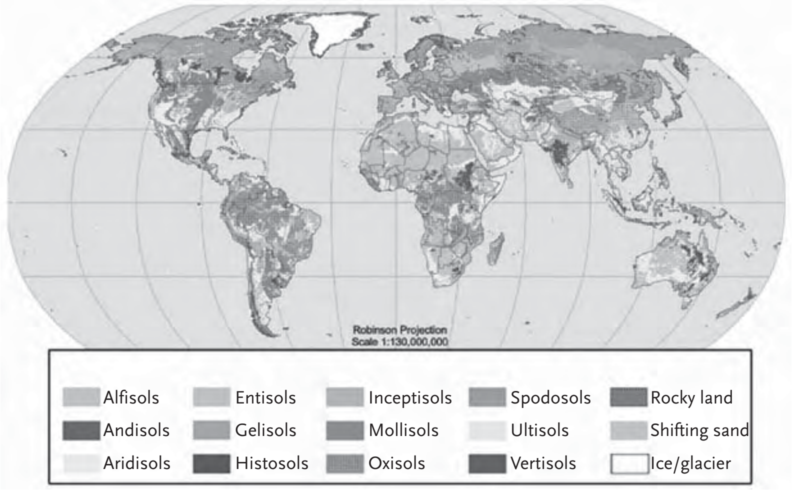

Figure 5. Global soil regions.

- **A universal educational (and marketing) tool**. A framework accepted around the world would justify significant investment in state-of-the-art and state-of-the-science educational tools based on that framework and a mechanism for maintaining them. An educational focus on the fundamental principles involved in defining site- and grower-specific BMPs would be akin to teaching a hungry person to fish rather than simply offering a fish. Improving the expertise required to adapt BMPs to local circumstances rather than attempting to teach generalized BMPs may have a more positive impact on nutrient management. The recent extension of electronic technologies such as cell phones to nearly every corner of the globe has opened the door for sweeping impacts of such educational tools. This same framework should be useful in the marketing efforts for specific products or services, by showing how the specific item fits into the generally accepted principles leading to BMPs.

The fertilizer industry's success at promoting greater implementation of fertilizer BMPs may greatly influence how rapidly and to what extent the newly redefined potential of agriculture is realized. Impacting that success will be whether sufficient value is recognized in localized intensive management to generate profit margins sufficient to cover its true costs.

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Fertilizer best management practices: what level of adaptation to local conditions is realistic in a developing country context?

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Abstract

World food production is largely dependent on the use of chemical fertilizers, mainly nitrogen (N), phosphorus (P) and potassium (K). With an increasing world population, especially in developing countries, future yield increases will even be more dependent on fertilizer nutrients since the increased production has to come from land currently in cultivation, given the limited potential for any significant expansion in cultivable land. Reflecting changing demographics, fertilizer use has levelled out in developing countries, but has generally increased in developing countries.

Intensification of fertilizer use has given rise to concerns about efficiency of nutrient use, primarily driven by environmental considerations in developed countries and more by economic considerations in developing countries. The distinction between the two categories of countries, often referred to as the West and the South, the "have" and the "have-nots", is invariably related to climatic and associated bio-physical factors, as well as a suite of socio-economic conditions. Such unfavorable conditions characterize developing countries in general.

As one of the 15 international agricultural research centers of the Consultative Group for International Agricultural Research (CGIAR), the International Center for Agricultural Research in the Dry Areas (ICARDA) deals with agricultural development in the countries of West Asia and North Africa, and recently Central Asia. Despite the antiquity of civilization and settled agriculture in that region of the world, due to the low rainfall in such a Mediterranean-type climate, merging to a continental one, drought is invariably a crop production constraint, exacerbated by a range of common socio-economic factors. While crop production has increased in several countries of the region, largely due to expanded irrigation, improved varieties, and particularly increased use of N and P in the past few decades, per capita food production has actually declined due to rapid population growth. The increased use of fertilizers has been accompanied by research that has identified individual nutrient constraints, and subsequently quantified nutrient use efficiencies in individual crops and within cropping systems.

Implementation of improved nutrient use efficiency at farm level has been hampered by weak-to-nominally existing extension systems, limited use of combine-drilling of fertilizer, small holdings with variable nutrient levels, imbalanced use of fertilizers in

the absence of a rational basis for application using soil and/or plant analyses, although such guidelines are available. As many of these problems are intractable institutional ones, compromise approaches can be adopted to achieve some gains in terms of fertilizer best management practices (FBMPs).

Introduction

Despite the advances that have been made in agricultural production through research and technology transfer in the past half century, many areas of the world still fail to meet the nutritional needs of their people; in some countries the spectre of hunger and malnutrition looms large. The food supply-demand equation is unbalanced by excessive population growth. Many of the world's poorest countries reside in the low rainfall, arid to semi-arid regions. As we ponder the question of how mankind can adequately feed and clothe today's world population of over 6 billion people, with the likelihood that this figure will increase further to 10 billion given burgeoning populations in several developing countries, it is heartening to reflect on the optimism expressed by Norman Borlaug, the father of the Green Revolution "*The world has the technology to feed 10 billion people. Improvements in crop production can be made in tillage, water use, fertilization, weed and pest control and harvesting. Both conventional breeding and biotechnology will be needed"* (Borlaug, 2003). If low-income, food-deficit nations are to be able to feed themselves, Borlaug estimated that chemical fertilizer would have to increase several-fold in the coming decades.

Given these sobering facts, it was hardly any surprise that a recent analysis of fertilizer use concluded that *at least 50% of crop yields are attributable to commercial fertilizer nutrient* use. The remaining crop nutrients come from organic sources, native soil reserves and biological nitrogen fixation (Stewart *et al.*, 2005). As future increases in crop production will have to come from higher yields from land already in production, *the contribution of added fertilizer nutrients is going to be proportionally greater in the future.* This scenario underlines the need for emphasizing efficient fertilizer use in order to produce an adequate and quality food supply based on increasing input and energy costs, bearing in mind environmental implications of excessive or inappropriate fertilizer use, especially N and P, the two main fertilizer nutrients required by crops.

Despite the global resources available to produce food and fibre, great geographical disparities exist in terms of societal wealth, access to food and medicine, and general wellbeing and living standards. In many ways, *the disparities between rich and poor were never greater*. Notwithstanding the considerable strides that have been made in Asia in bringing living standards up to those in the developed countries of the West, some areas of the world, notably Africa, lag far behind. Indeed, in some African countries, per capita food production is less than it was decades ago. While there are many historical, cultural and economic factors associated with such poverty, climatic and associated biophysical factors are invariably major constraints in Africa, as they are in other developing regions of the world. One such region is West Asia and North Africa (WANA), which is generally a food-deficit one. Adverse climatic conditions and a host of other socio-economic, political and biophysical factors plague agriculture in the region (Kassam, 1981). Today's conditions are ironic in view of the fact that the region is the centre-of-origin of many of the world's crops (e.g. cereals, pulses, nuts) and where settled agriculture and civilization as we know it began.

Despite the advances that have taken place in the region's agriculture, population growth in most WANA countries has outpaced its capacity to produce food. Recognition of the urgent needs of the region to accommodate demographic changes has underpinned efforts by the various national governments to give impetus to the region's agricultural development through applied research (Rao and Ryan, 2004). The establishment of ICARDA in Aleppo, Syria, in 1977 was a milestone in this endeavour.

The subject of this paper is *fertilizer best management practices*, a concept broadly similar to "fertilizer use efficiency", "efficient plant nutrition management", "optimized plant nutrition", "integrated nutrient management", "site-specific nutrient management" and even "precision agriculture". As the context of the present paper is related to developing countries, it is pertinent to briefly allude to the broad climatic and socio-economic conditions that define developing countries as well as typical farming conditions in such countries. As fertilizer use has increased globally, especially in developing or Third World countries, both economic and environmental conditions underpin the need for fertilizer use efficiency. The extent to which FBMPs can be realized at farm level is limited by specific local factors impinging on developing-country agriculture. While the focus is on the countries south and west of the Mediterranea, many generalizations are applicable to other areas of the world.

West Asia-North Africa

Of particular relevance to fertilizer practices in the WANA region is the climate and soil resources that dictate its agricultural sector and specific farming systems. This vast region of the world exhibits great diversity in its landscapes, climate, natural resources and its people (Ryan *et al.*, 2006), but it has many common features, notably low rainfall and a dry climate, in addition to high population growth rates and poorly developed agriculture and rural infrastructures.

Climate

The WANA region is mainly characterized by a Mediterranean climate, with cool to cold, wet winters and warm to hot, arid summers (Kassam, 1981). However, local conditions are modified by topography and nearness to the sea. Thus, the countries of North Africa are milder due to maritime influences and low elevation, and are typically Mediterranean, while those of West Asia and higher elevations, and in larger land masses, are characterized by a Mediterranean-type climate merging to a continental climate.

Rainfall, though generally low, is highly variable in space and time, generally from October to May (Harris, 1995). The range of rainfall in most countries is about 100-600 mm, the extremes being in desert areas and high mountains. Snow is common in high plateaus and mountainous areas, often lasting for several months of winter and early spring. Severe droughts which result in partial or complete crop failure are common.

Topography and maritime conditions similarly influence temperatures, especially in winter. Thus, winters are milder in the lowland areas of West Asia and in North Africa and severe in highlands areas of West Asia (Harris, 1995). There, the inverse pattern between rainfall and maximum and minimum temperatures and the relationship with evapo-transpiration influence crop water use. Both climatic variables dictate the extent to which rainfed cropping is possible for the region.

Soils

While the agriculture of the Middle East region is dominated by climate, specifically limited rainfall, the quality of the region's soils is also of vital concern. Historically, civilizations have flourished in areas of the Mediterranean basin where both soil conditions were favourable and where water was adequate. The soil resources of the region are as variable as in other parts of the world, reflecting variation in climate and topography (Ryan *et al.*, 2006). Although soils of arid regions have unique features, about half of the world's soil orders are found in such areas.

While broad soil variation can be expected as a result of wide climatic variation in Syria (Ryan *et al.*, 1997), a diversity of soils can occur over a small range. Such soils range in texture from sands to clays; most are shallow and have serious inherent or external drawbacks (Matar *et al.*, 1992). Limitation on depth, in turn, limits the water-holding capacity of the soil–a major factor, since with infrequent rains most rainfed crops survive on residual soil moisture; shallow soils are also particularly vulnerable to soil erosion. While clay soils are deep and inherently productive, with good water-holding capacity, the range at which they can be tilled is limited. Frequently, they are either too wet or too dry to cultivate. Crop yields from these soils are usually more than double those of shallower soils in the same rainfall zone.

Dryland soils are usually low in organic matter, which, in turn, limits soil structure and chemical fertility. Thus, inherent soil properties dictate nutrient behaviour and fertilizer use. As a consequence, N is invariably deficient (Ryan and Matar, 1992). Prior to the advent of commercial fertilization, P deficiency was also widespread (Matar *et al.*, 1992). These deficiencies reflected many centuries of exhaustive cropping, with little or no return of nutrients, since crop residues were usually grazed to the ground. While K is rarely deficient in Mediterranean–region soils, increasingly there is evidence of other nutrient stresses being locally important.

The agricultural sector

Agriculture in the WANA region is largely subsistence farming, and rainfed production is low; it is labour-intensive with relative low inputs to new technology (Gibbon, 1981); however, there has been a rapid increase in fertilizer use in the past 3 decades, albeit from a very low base. The farm holdings are small-often only a few hectares, and frequently in fragmented parcels. Effective change in land management is hindered by traditional inheritance laws, tribal and common lands and nomadism. Most farmers have little formal education. Support services are less than satisfactory for most rural communities, i.e. limited credit, poor roads and distribution systems, weak marketing and research structures and, in most cases, ineffective extension services. The private commercial sector is poorly developed in most countries. Such socio-economic constraints are often as insurmountable as the biophysical ones, but an understanding of the social context in which farmers operate is essential to developing the region's natural resources and improving people's lives.

Farming systems

Agriculture as we know it evolved in the Middle East; the soil of the "cradle of civilization" has been tilled for millennia, and its landscape and vegetation have been degraded in the process. Since detailed accounts of rainfed farming in the Middle East (Gibbon, 1981; Cooper *et al.*, 1987), many changes have occurred in the last two decades, but much of the traditional character remains, e.g. from animal traction to mechanical cultivation and from hand broadcasting of seed to drilling. Similarly, hand-harvesting to combine-harvesting is nearly complete in some countries--the harvesting of lentils is still the exception. The last few decades have witnessed increased use of chemical inputs, i.e. fertilizers and, to a lesser extent, pesticides (Ryan, 2002). Although dryland farming dominates the region, and will continue to do so, supplementary irrigation is being increasingly introduced in order to stabilize rainfed yields in areas where groundwater or surface water sources can be tapped (Oweis *et al.*, 1998). In the arid zones of the region cropping is totally dependent on irrigation.

Dryland cropping in most cultivated areas with winter rainfall is dominated by cereals (i.e. wheat and barley) and livestock and combined enterprises. A close relationship exists between crop yields in general and rainfall, the effectiveness of which is modified by the soil's water storage capacity and the evapo-transpiration rate. Associated with cereal production are food legumes, i.e. chickpea, lentil, faba bean and peas. Forage legumes are also common, i.e. vetch for hay and *Medicago* for grazing. As all rainfed crops in the WANA region are invariably limited by drought to some degree in most years (Pala *et al.*, 2004), the cropping "strategy" that has evolved to mitigate this constraint is the use of rotations, i.e. growing of crops in a particular sequence.

ICARDA's applied agricultural research

As one of the international agricultural research centers under the auspices of the CGIAR, ICARDA was established to primarily address dryland agriculture in the WANA region; it later embraced the newly independent countries in Central Asia. *Its mission is to improve the livelihood of the region's poor though agricultural research, while preserving biodiversity and protecting the environment*. The Center's research evolved with changes in its mandate, with a gradual shift towards irrigated agriculture and biotechnology. Most of the Center's research and development hinge around three main areas: *natural resource management, crop genetic improvement, and institutions and policy*.

Soils and soil fertility have played a major role in ICARDA's research (Ryan, 2004). Initial efforts focused on identification of nutrient constraints in the field, mainly N and P, as well as assessing crop growth responses in a range of rainfall and soil environments (Harmsen, 1984). Research quantified the quantities of N fixed by crops, N uptake and use efficiency, and long-term fertilizer P recovery by crops. This effort was supported by laboratory and greenhouse studies of nutrient interactions with soils and water. Later, the emphasis shifted to micronutrients (Materon and Ryan 1995) and organic matter (Ryan, 1998) as an index of soil quality, with implications for cropping systems on carbon sequestration in relation to greenhouse gasses and climate change.

Individual field-response of trials gradually gave way to a series of long-term rotation trials that evaluated fertilization and nutrient dynamics within a cropping system. A major effort involved a region-wide program designed to provide a rational basis for fertilizer use in the field, i.e. soil test correlation and calibration (Ryan and Matar, 1992; Ryan, 1997). Related studies sought to improve quality analytical control and laboratory efficiency (Ryan and Garabet, 1994; Ryan *et al.*, 1999). ICARDA's soil fertility work (Ryan, 2004) demonstrated the broad range of factors that impinge upon crop nutrition and fertilizer response patterns in the field, as well as the economics of fertilizer use. From such work the concept of fertilization efficiency emerged.

Strategies for fertilizer best management practices

Both the soil itself and the growing crop can provide the basis for balanced fertilization and consequently balanced nutrition. The main approach is through soil analysis. In essence, this involves the development and selection of appropriate tests (extractants and associated procedures) that established a relationship between the soil test value and plant uptake of the nutrient in question, i.e. *correlation*. The second phase of testing involves *calibration* or developing guidelines for fertilizer recommendations in the field; in this way, "*critical*" levels can be established below which a nutrient level is deficient, *with the probability of a response to fertilizer*, and a point *beyond which there is no need to apply fertilizer*. Other factors such as soil type, soil moisture or rainfall, and nutrient spatial variability have to be considered in practical field situations. Though excellent guidelines are available for sampling, handling and analyzing the tissues, along with criteria for deficiency to adequacy (Ryan, 2004), in addition to quick tests designed to give results in the field without delay, based on qualitative nutrient determination in the expressed fresh plant sap, in contrast to soil analysis, there is little application of such tests as a guide to efficient fertilization.

While these approaches to assessing soil fertility are commonplace in developed countries, they are less frequently used in developing countries - and in some countries not at all. The major obstacles to such approaches include a weak extension sector, the absence of laboratory facilities for such analysis, and limited applied on-farm research related to soil fertility and fertilizer use. Nevertheless, much has been done through the regional soil Test Calibration Program to promote the awareness of fertilizer nutrients in the agriculture of WANA, particularly with soil analysis (Ryan and Matar, 1992; Ryan, 1997). Soil analysis will be more adopted as a tool in fertility-crop nutrient management than at present in view of increasing crop intensification, especially with irrigation, and the increasing use of farm chemicals, but constraints in terms of analytical facilities are major obstacles. However, Middle Eastern farming is–and will remain–a long way from a situation where nutrient application is tailored to each crop and farm holding. At the outset, the nutrient use data raise the issue of balanced fertilization.

Balanced fertilization

Despite the fact that balanced fertilization has gained considerable currency in the literature, the concept is an old one that dates back to the 1840's and Liebig, who expanded on "limiting nutrients" in his famous "Law of Minimum". In a recent overview of optimizing plant nutrition for food security, Roy *et al.*, (2006) expanded on *balanced fertilization* which, in turn, creates *balanced plant nutrition*. Some of the points made are worthy of listing.

1. *Balanced fertilization* is the deliberate application of all nutrients that the soil cannot supply in adequate amounts for optimum crop yields.
2. There is no fixed recipe for balanced fertilization; it is soil and crop-specific.
3. Any deficiency of one nutrient will severely limit the efficiency of others.
4. Imbalanced nutrition results in "mining" of soil nutrient reserves.
5. Luxury consumption is often a consequence of nutrients supplied in excess.
6. Imbalanced fertilization is *inefficient, uneconomic and wasteful.*
7. Balanced fertilization depends on soil test values and crop removal.
8. Crop nutrient requirements are related to yield level.
9. Fertilization with time can cause a buildup of P and K, thus reducing their fertilizer requirements.
10. The concept of balanced fertilization has expanded to integrated plant nutrition, embracing *all* sources of nutrients.
11. Integrated plant nutrition seeks to improve nutrient-use efficiency, build up nutrient stocks in the soil, and to limit losses to the environment.

While much of the fertility research in the WANA region was at the level of individual nutrient deficiencies–and using fertilizer to overcome them–the concept of "balanced nutrition" was also in evidence, reflecting the need to ensure *environmentally benign integrated plant nutrient management*.

Issues for fertilizer use efficiency

Concepts related to best management practices in terms of nutrients supplied by fertilizers are used extensively on farms regardless of whether in developed or developing countries. In that context, it is pertinent to comment on fertilizer use trends. Globally, levels of total fertilizer consumption have remained static in the last two decades or so and, in fact, have declined in "developed" and "transition" economies; the only increase have been in developing countries (IFA, 2006). Similarly, only N use increased in this period, with actual declines in P and K consumption. In the longer term, growth in total consumption is estimated to be 2.2% per annum in developing countries, but only 0.2% in developed countries.

Data from Middle East countries reveal broad similarities. Prior to 1970, little fertilizer was used in these countries. This was followed by a rapid increase in use of N and P, with limited amounts of K. Except in the case of Egypt, N use doubled that of P. While N and P use seems to be stable in the last decade for Syria, Turkey and Morocco, as examples, the increase was continuous for Egypt. While various circumstances such as internal production, importation and marketing can influence the amount of fertilizer nutrient used in any one year, the variability in N and P use, and the minimal amounts of K use inevitably raise the issue of how appropriate are the ratios of nutrients applied to satisfy the specific crop's needs.

Theoretically, the nutrient needs of any crop are dependent on the crop species and the actual yields. The nutrients that do not come from the soil have to be supplied in fertilizer form, allowing for losses that inevitably occur. These discrepancies are reflected in the wide variation in the amount of fertilizer nutrients used as well as fertilizer nutrient ratios for many countries in the region.

Obstacles to efficient fertilizer use

Prior to considering overall strategies for improving the efficiency of nutrient use, one has to examine obstacles that lie in the way of achieving optimum nutrient use efficiency. Some of the factors are briefly mentioned, some being more intractable than others.

1. **The means of purchasing fertilizer**
   Given the small size of most holdings in the WANA region–similar to many arid/semi-arid areas of Africa and other parts of the world–having the necessary cash, after paying for essentials, to invest in fertilizer is difficult for most small holders. Yet despite the uncertainty of getting an economic response from the harvested crop due to varying degrees of drought, most farmers now use fertilizers for some extent. While the availability of credit to buy fertilizer varies greatly in countries of the region, and within countries, some countries such as Syria have institutions such as the Agricultural Bank that provides credit for purchase of fertilizers.
2. **Methods of applying fertilizer**
   Efficiency of fertilizer use is greatly influenced by how it is applied. In the WANA region, application methods run the gamut of traditional to modern. The former category involves hand broadcasting of the fertilizer; this involves a rough estimation of the application rates and uneven application with consequent variable yields. With more mechanization, fertilizer is either broadcasted by a tractor-powered disc spreader to more precision in application of fertilizer with the seed. Combine drills that apply the grain and fertilizer from separate hoppers in bands in the soil are rare except on larger farms. Regardless of the method used, the common practice is to apply some fertilizer, usually N and P sources at sowing time, and the remaining half of N broadcasted by hand or machine as topdressing in early spring depending on seasonal rains. Split applications are usually more efficient, but there could be loss of N as ammonia gas following broadcasting of urea, the most common N source.
3. **Spatial variability and implications for nutrient efficiency**
   Crop growth is the outcome of soil physical and chemical properties, especially nutrients. Growth is maximized and optimum nutrient efficiency achieved, with a uniform crop stand where no part of the field has growth-limiting conditions. In reality, land areas of most small holdings are extremely variable. While little can be done about the natural variability in soil properties, i.e. texture and depth–the latter is particularly important in dryland cropping as it dictates the soil's moisture-holding capacity–variability imposed by uneven nutrient application, selective grazing and

manure and residue deposition can be overcome by uniform nutrient application. In developed countries, uniformity is achieved by precision farming using variable fertilizer rates based on soil test values. However, such approaches have little relevance to farming conditions in developing countries.

4. **Rational basis for fertilizer application rates**
Despite the fact that the regional soil test calibration program established a scientific basis for defining appropriate application rates for N and P through the use of field-validated nutrient availability tests, and that criteria for critical levels of soil test values for various crops have been identified, this approach has little or no impact at farm level. The main obstacle to implementation of such fertilizer application guidelines is the absence of any effective system of widespread farm-service analysis system; even where laboratories do exist, they often are suspect in terms of analytical quality and reliability. Private laboratories are rare, if non-existent in the region, as in most developing countries, in contrast to developed countries. Even where government soil testing services do exist, as in countries of the former Soviet Union, there is often little effective communication between soil people, who take the samples, analyse and interpret the results, and agronomists or field people who implement fertilizer use recommendations.

Conclusion: possible solutions

In theory, efficient fertilization or fertilizer best management practices, leading to better crop nutrition cannot be argued with. However, many of the necessary conditions to respond much to such concerns do not exist in developing countries. The WANA region is one such area of the world, and indeed is representative of many arid and semi-arid areas of the developing world. Nevertheless, science has inexorably moved agriculture forward in the past few decades, especially with the widespread adoption of chemical fertilizers in both irrigated and rainfed cropping conditions.

The research that has taken place clearly shows the value of chemical fertilizer application in terms of crop quality, economics and environment. What is needed at government level is adoption of policies that guarantee the timely and economic availability of fertilizers, and the necessary support services that backstop modern agriculture; this includes increasing technical education for farmers and the rural community, including personnel from the fertilizer industry. A key prerequisite is the provision of laboratories to perform soil, plant fertilizer and water analysis; efforts should be made to involve the private sector in such ventures. In order to provide an economic outlet for food supplies generated by increased fertilizer use and irrigation, markets, transportation facilities and the overall rural infrastructure need to be developed.

With the inevitable increase in fertilizer use intensification, there is a quest to achieve greater use efficiency of the nutrients applied, in terms of crop yields, crop quality and production economics. While environmental concerns will increase in developing countries, it is unlikely to achieve the level of concern attained in developed countries. Although there are many intractable obstacles to improving nutrient use efficiency in developing countries, there are possibilities such a simple improvements in fertilizer application equipment, e.g. better calibrated spinners and seed drills with dual-hoppers that allow for application of seed and fertilizer in separate bands. These developments are already occurring in a much-changing agriculture. As many of the technologies for improving farm practices that lead to more efficient nutrient use are already known and applied in developing countries–and indeed validated by applied research in the region–the focus should be on technology transfer, and exploiting whatever resources are available to get the message to developing country farmers.

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Adoption of fertilizer best management practices: the need for a sociological approach

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Abstract

Ensuring technology adoption should not only consider the profitability of the technology but the social and cultural dimensions as well. This is because the act of adoption by farmers is a deliberate decision made after considering a wide range of issues, and done within a social context where different individuals may interact and influence the decision. The goal of this paper is to present a sociological understanding of the process of adoption of fertilizer best management practices (FBMPs) such as the site-specific nutrient management (SSNM), within the context of rice research at the International Rice Research Institute (IRRI). The paper highlights the importance of building on farmer knowledge, experiential learning, and social capital for ensuring adoption of FBMPs and accelerating its spread for small scale farmers in Asia.

Introduction

The impacts of agricultural research are only realized when technologies or research results are practiced by the end users – the farmers. Thus, there have been many studies examining the efficiency of transfer of new technologies to farmers. However, there is no single recipe for disseminating technology to ensure farmer adoption. Adoption is defined as the decision to continue full use of an innovation (Rogers 1995). Adoption in agriculture is problematic especially in developing countries. Research has shown that, in many cases, there have been poor rates of adoption or poor sustainability (Wearing 1988; Roling, 1990; Bonifacio 1994; Stür *et al.* 1999; Utama, 2002). Many agricultural technologies developed are published in journals but not practiced by the end users, especially by the many resource poor farmers of Asia.

The issue of the adoption of knowledge intensive technologies, where most of the natural resource technologies (NRM) fall, is even more complicated since these are in the form of knowledge and information, which are made accessible to the end user in a less tangible form than physical products such as seed or machinery (Price and Balasubramanian, 1998). Like integrated pest management (IPM), FBMPs are considered as knowledge intensive technology because, in essence, they are techniques to fine-tune farmer nutrient management, enabling farmers to make decisions that translate into sound agronomic practices. Adoption of FBMPs by farmers, especially those with limited holdings as in the case of most Asian farmers, is a great challenge in order to realize the goal of sustainability, increasing profitability and environmental integrity.

Adoption is usually conceptualized with economics as its key driver. However, while the profitability of an innovation is a very important attribute, it is not the only aspect that matters in adoption. This is because technology adoption is both a social and cultural process (Vanclay 2004). The act of adoption by farmers is a deliberate decision made after considering a wide range of issues. This is done within a social context where different individuals may interact and influence the decision. For this, a need for a sociological approach in looking at adoption is highly necessary. In the case of knowledge intensive technologies like IPM and FBMPs, social complexities need to be factored into the adoption process.

The goal of this paper is to present a sociological understanding of the process of adoption of FBMPs. The concepts that can be used to facilitate adoption will be presented. We will highlight the process through drawing on case studies of technologies extended to farmers within rice-based systems. The challenges to operationalize ways to facilitate adoption and possible ways to address them will also be explored. The paper is written within the context of rice research at IRRI. Hence, the FBMPs cited will focus on SSNM, which is a plant-based approach for optimally supplying rice with essential nutrients (Dobermann and Witt, 2004; Buresh, 2007; IRRI, 2007).

Key sociological concepts for facilitating adoption of fertilizer best management practices

This section discusses three key concepts in facilitating the adoption of FBMPs namely (i) farmer knowledge, (ii) experiential learning and (iii) social capital.

Building on farmer knowledge

Farmers, as end users of nutrient management technologies, have a deep and complex understanding of the natural environment on their farms. They are not passive consumers, but active problem solvers addressing the needs of the moment using varying strategies developed through experience and farmer-to-farmer communication (Rajasekaran 1993). Their local ecological knowledge reflects the history and experience of their farming communities, and the social relations rooted in the process of accumulating and using that knowledge in the management of agricultural production systems. This knowledge system makes farmers well informed about their own situations, their resources, what works and does not work, and how one change can have an impact on other parts of the system (Butler and Waud 1990). The knowledge that they have embodied has much to contribute to how a new technology will be useful for them.

Farmer knowledge on nutrient management is stored in their minds and memories but this also is reflected in their perceptions about fertilizers and is embedded in their nutrient management practices in the whole rice production process. The way that farmers in the Philippines deal with rice farming, for example, may be a useful avenue to consider in the development and extension of FBMPs. The parallels of plant and human health are clear in the metaphors or linguistic terminologies employed by farmers (Palis *et al.*, 2006). In the specific case of Filipino farmers, this worldview on plant and human care affects their fertilizer practices.

Filipino farmers normally apply fertilizer in a scheduled manner two to three times in one season in accordance to the growth stage of the rice crop (Table 1). Farmers recognize that the plants require different amounts of nutrients at different growth stages. The first application happens at the early stage of the plant, within 15 days after transplanting (DAT). The plant is described as a baby or child emphasizing the vulnerability of both the plant and human growth to illnesses. Thus, at this stage, farmers apply more fertilizer (Table 1), particularly nitrogen to improve crop growth and enhance vigor of the plant. In the same way that a baby is given vitamins, making sure that the child is well fed and great care is given for good growth and good health, the bulk of the nutrients are applied to the young rice crop. Farmers often commented that "if the plants are still young, they have to be taken care of", to ensure good health, good growth, and eventually good yield.

Table 1. Fertilizer application at different stages of the rice plant, by 146 farmers in 2004, Central Luzon, Philippines.

Fertilizer application		Farmers applying at a given time		Human-plant analogy	Fertilizer rate (kg/ha)		
Number	Timing (mean DAT)	Number	%		N	P	K
1	14	146	100	Baby	53.09	5.63	7.73
2	38	109	75	Adolescent - pregnancy	35.86	2.11	3.25
3	53	19	13	Adult	11.65	0.12	0.74

DAT: days after transplanting

The second application is on average at about 38 DAT, which is near panicle initiation, and then the third application is at about 55 DAT when the plant is at the reproductive stage. Farmers normally considered their second and third applications as top dressing. On their 2nd and 3rd applications, the amount of fertilizer is reduced because they view that the plant is going towards adulthood implying that the nutritional requirements of the plant would be lesser as an adult person requires less care.

Implications and challenge

The logic of science as compiled into the SSNM approach is very in line with the farmers' logic that considers nutrient management in the context of growth stages. However, in terms of the amount of nutrients needed at growth stages, SSNM differs with farmers' logic. Site-specific nutrient management espouses that farmers need to often apply less nitrogen (N) early, more N at critical stages of active tillering and panicle initiation (PI), and less or no N at latter reproductive stages. In the context of human growth, a baby actually needs very little food because it is growing slowly, a teenager needs the most food — such as at active tillering and especially panicle initiation — which is somewhat like adolescence towards pregnancy.

So, the challenge here is on how to operationalize on changing farmers' mindset with regards to the amount of fertilizer applied at specific stages of crop growth. One effective way is through the process of engaging farmers both in research and extension projects called Participative Research and Extension (Percy, 2005). This way, the farmers are engaged in the technology development and validation process that may lead to local modifications of the technology (Peng *et al.*, 2006). Sustainability of new practices is more likely if farmers are directly involved in research and development activities such as in participatory experiments for technology validation, demonstration farms, and in farmer-to-farmer training.

Another example, farmer knowledge on soil classification and its associated fertility can also be used for predicting the nutrient indigenous supply of corresponding farmers' fields. Because of the vast experience of farmers acquired through a lifetime of work and witnessing how their crop responds to fertilizer use and climatic conditions among other risk factors, there is merit to include farmers' perspectives in developing field-specific fertilizer practices based on SSNM principles.

Realizing that a fusion or integration of farmer local knowledge and scientific knowledge is necessary to modify any technology and to make it more appropriate for end users, it becomes evident that farmers' knowledge, experience and experimental capacity should be utilized in the design and validation of the technology. The challenge is how to operationalize this building on farmer knowledge in technology development.

Understanding farmers' perceptions, knowledge and beliefs of fertilizer and fertilizer management practices such as what type of fertilizer to use, when to apply it, and why etc., would help scientists and extension specialists to interpret how they manage their plant nutrient problems. Such an understanding would enable those in research and extension to fit scientific recommendations within the context of the existing practices of farmers, thereby increasing the relevancy of the adaptation and adoption. In anthropology, this is referred to as the 'emic' or the insider's point of view in contrast to the 'etic' or the outsider's point of view, which can be redefined in this context as our scientific knowledge. Hence, sustained understanding of evolving ecological practices and accumulated knowledge by farmers ensures that farmer-scientist-extension collaboration in research continues to be responsive and complementary. One important result is a better understanding by scientists of farmer knowledge and their appreciation of scientific agricultural knowledge, which in turn can enhance research design, technology adaptation, and technology adoption and diffusion.

Experiential learning

The issue of adoption of an innovation is intricately intertwined with the way that farmers accumulate or gain knowledge. It is essential that the research, development and extension of technologies, especially knowledge intensive technologies, take into consideration how knowledge is most efficiently passed through different people and how it can be effectively learned by end users, so that the likelihood of success of extending such technologies will be greater. The challenge is to promote the innovation in a way that takes into account its social and cultural suitability, as well as the avenues that culture provides for efficient delivery of the innovation to end users. Culture is an important component in farmer learning and adoption of a technology, because it can enable (or impede) cooperative behavior and experiential and collective learning (Palis 2006).

According to Kolb (1984), learning is the process whereby knowledge is created through the transformation of experience. Effective learning entails the possession of four elements, which represent the experiential learning cycle: (1) concrete experience,

(2) observation and reflection, (3) the formation of abstract concepts and (4) testing in new situations (Kolb and Fry, 1975). Experiential learning is effective in adult education and technology adoption (Palis, 2006).

Learning is a socially active process whereby an individual within the context of the interaction constructs meaning for themselves and integrates it into their own cognition. As McDermott (1993) puts it, learning is in the conditions that bring people together. It organizes a point of contact that allows for particular pieces of information to take on relevance; without the points of contact, without the system of relevancies, there is ineffective learning and there is little memory.

An important example of effective transfer of knowledge intensive technologies in agriculture is the experiential learning that occurs in farmer field schools (FFS) that has resulted in the adoption of IPM. Farmer participants used their concrete experiences to test ideas and consequently change their pest management practices through group experimentation. In this context, farmers interpret observations, facts and experiences both individually and as a group, and generate a consensus that is culturally enforced. The experiential learning in the FFS context enables the participants to overcome various fears both individually and collectively. Farmers were able to generate courage when confronted with different kinds of fears – physical, technical, economic and social - and their decisions went beyond risk utility analysis (i.e. weighing the economic benefits and costs) because risk and technology adoption are social processes rather than physical entities that exist independently of the humans who assess and experience them (Douglas and Widavsky, 1982; Bradbury, 1989). An example is in the case of IPM in the Philippines where the perceptions of Filipino rice farmers that all insects are harmful changed through experiential learning in the FFS (Palis, 1998; Palis, 2006). The FFS participants learned that not all insects harm rice plants through group insect-zoo experimentation where spiders and brown planthoppers were placed in a cage with a rice plant in it. They were able to see how the spiders ate (actually entrapped with the spider's web) the pests after some time. The knowledge they gained from that experiment gave them the courage to ignore insects when they saw them on their respective farms, as long as there were sufficient spiders around.

Aspects of culture such as social relations, for example, became a driving force for change, allowing individual farmers to become more confident in challenging normative ideas and practices (Palis, 2006). In the Philippines, for example, *pakikisama* (the commonly-shared expectation of getting along with others for the good of the group) and *hiya* (variously defined as shame, embarrassment, timidity and shyness) are two strong group-oriented norms or aspects of Filipino culture that regulate social relationships (Jocano, 1997). At the core of interpersonal relations are the concepts of *kapwa* (a sense of fellowship, reciprocally shared identities) and *pakikiramdam* (a feeling for another). These norms influence how a farmer relates to other farmers, how they act together, and how they follow principles introduced in an innovation.

Fear of risk, coupled with the confidence to face it, is directly related to the knowledge, culture and social relations that exist among the members of a society or social group. In the FFS experience, the practice of continuous use of insecticides is based on the fear or risk of crop loss due to insects that are harmful to the plants. However, with the FFS approach of collective and experiential learning, farmer knowledge regarding non-harmful insects was validated through the experiences of farm neighbors. Overcoming fears collectively led to the adoption of IPM.

The experiential learning process, however, is not easy or straightforward. A lot of individual negotiations and group negotiations have to take place. Social pressures – such as those associated with public failure – and the social bonds that existed among the farmers, help to generate the collective courage to overcome the commonly shared fear of crop failure. Filipino culture, particularly as expressed through group oriented norms such as *pakikisama* and *hiya*, regulate social relations among farmers. This includes providing social pressure to encourage cooperation and participation in learning activities and enabling experiential and collective learning. The knowledge gained through experience is essential in forming new practices geared towards adopting new methods and technology like the FBMPs.

Implications and challenge

Farmers' decision making in nutrient management practices is predicated on the integration of knowledge on several factors. Among them are: climate, variety, plant color, price of fertilizer and price of crop. So, with farmers actively participating in FBMPs both individually and collectively, farmer feedback and farmer adaptation of the technology would be generated, resulting to refinements in FBMPs and, at the same time, ensuring farmer adoption.

The challenge is how to operationalize farmer learning. The question of whether it should be through FFS arises. An important constraint of FFSs is the high investment cost in the development and implementation of effective training. When FFS programs already exist in a country, FBMPs like SSNM can be incorporated into them. When FFS programs do not exist, an alternative approach would be to disseminate FBMPs through simple messages where extension cost is lower. The critical question, however, is whether simple messages would generate farmer learning. Perhaps, a modified FFS can be considered where a nucleus of farmers is recruited strategically.

Capitalizing on social capital

Most studies conducted on adoption and diffusion focus on individual attributes as factors contributing to the successful adoption and diffusion of agricultural technologies. Human behavior, however, is the result of interactions and interrelations among people. Social capital is therefore another necessary concept to consider in understanding the mechanisms of the adoption and diffusion processes of agricultural technologies.

Social capital comprises the resources derived from social relations such as networks, norms and trust that facilitate collective action. These resources are actually the products of the process of social relations. Social relations, in turn, are the products of enculturation. Hence, the sources of social capital and the type of social capital formed are largely determined by culture. Since culture among societies varies, the sources of social capital likewise differ. Although there may be some commonalities in some societies, most sources of social capital are distinctly associated in each society.

Social capital as an analytical concept shifts the focus of analysis from the behavior of individual agents to the pattern of relations among agents, social units and institutions; it reinserts issues of value into the heart of social scientific discourse such as terms of trust, sharing and community that are central to it; and it directly generates questions about the assumptions on human behavior on which analysis and policy are based (Schuller *et al.*, 2000). And the efficient use of existing social capital among farmers in a village can generate social learning, which can lead to fast, sustained and widespread adoption of an agricultural innovation like IPM (Palis, 2005). Social learning is about people learning from other people through observations (Bandura, 1977).

How does social capital facilitate adoption?

In the process of the building-up of social capital, the process also is working towards the facilitation of the adoption of technologies through sharing and learning of both knowledge and skills within the networks of farmers, and eventually it will spontaneously go outside the networks resulting in social learning. This is because most human behavior is learned observationally through modeling: from observing others one forms an idea of how new behaviors are performed, and on later occasions this coded information serves as a guide for action (Bandura, 1977). And central to social learning is meaningful interaction between and among individuals (Roling,1990). Thus, farmers are more likely to adopt a technology if they see the outcomes they value. In the Philippines, *huntahan* or plain conversation is the avenue of the farmers' building-up of social capital. This commonly happens in the house neighborhood and farm neighborhood. Conversation in the house neighborhood is generally wide in scope; however at the farm neighborhood level discussion is often on farming practices.

In the Philippine case, the major sources of social capital identified are kinship, house neighborhood, farm neighborhood and membership in farmer's association (Palis, 2005). Kinship holds primacy among social relations of Filipino farmers. Characterized by strong ties, mutual trust and norms, it is a closed network that promotes coordination and cooperation for mutual benefit. Secondary to kinship is farm neighbor relationship. More often, farmers' interactions are more with farm neighbors because they spend most of their time on the farm. So, sharing of information and knowledge about new intervention is directed first towards kin members, but sharing and learning is more with farm neighbors (Palis, 2005). This is because farmers normally talk about their concerns, observations and problems with respect to their crop in the farm. Hence, a farmer with a farm neighbor who practices FBMPs does not need to be convinced further because he or she can validate new information through on-site observations as well as meaningful discussions with the FBMP farmer practitioner in the field. The resulting spontaneous discussion and observation among FBMP and non-FBMP farmer would facilitate social learning and accelerate the spread of farmers practicing FBMP. In effect, social capital reduces the transaction costs that enhance the efficiency of farmer-to-farmer extension as shown in the fast diffusion of IPM in central Luzon, Philippines (Palis, 2005).

In Vietnam, farmers' cooperatives is a key social capital for farmer learning and rapid adoption of natural resource management technologies as evidenced in the adoption of ecologically based rodent pest management (Palis *et al.*, 2004; Brown *et al.,* 2006). The organized community participation for rodent control in the villages in northern Vietnam is attributed to the presence of strong cooperatives, which are born of the traditional commune system in the country. Likewise, the Chinese influence of Confucianism, which is viewed as both a philosophy of life and as a religion, emphasizes the importance of loyalty, respect for authority, and peacefulness (Quang 2003). Respect for social hierarchies is basic to Vietnamese families and society. By far the most important of these values are those associated with family and community, where individual interest is subordinate, if not irrelevant, to the welfare of the whole group (Muoi 2002). Thus, a technology disseminated through this cooperative system would have an efficient uptake.

Implications and challenge

The promotion of FBMPs like SSNM should consider the existing social capital in place in each country for incorporation in strategies for farmer participation, and institutional partnerships. The challenge is to identify key social capital that could facilitate the spread of FBMPs through social learning. Capitalizing on social capital does not only ensure adoption but also serves as an engine in the fast natural spread of the FBMPs.

The International Rice Research Consortium, an avenue for participatory research and extension

Given these lessons and principles learned regarding the adoption of technologies, IRRI through the Irrigated Rice Research Consortium (IRRC) came up with partnerships and farmer participatory approaches, instigating a research and extension interface for diffusion of technologies including SSNM. IRRC and its national agricultural research and extension system (NARES) partners collaborate through validation, integration and scaling out of principles, approaches and technologies allowing for multi-stakeholder processes and social learning thereby diffusing the technologies within irrigated rice-based systems. IRRI scientists in the IRRC and partners in national programs serve as facilitators for multi-stakeholder processes and social learning including the public and private sectors and farmer groups.

IRRC, through the Coordination Unit and Productivity Workgroup, is facilitating the dissemination of SSNM across multiple scales. Below are two cases where we work with different partners, from both the public and private sectors, for the dissemination of SSNM in the Philippines.

Case 1. Working with the public sector – state universities and local extension, Iloilo, Philippines

Background

In the Philippines, agricultural extension in the public sector is decentralized; it is the responsibility of local government. IRRI has been collaborating with public institutions in developing a locally adapted SSNM practice. IRRI, the Western Visayas State University and the University of the Philippines at Los Baños (UPLB) are involved in working with farmers in SSNM trials, and then with municipal agricultural officers from the local government for the dissemination of the developed recommendations. This is implemented in Iloilo, the rice bowl of central Philippines, and usually considered as second or third in the country's rice production.

It all started with a thesis proposal to IRRI by Greta Gabinete, a then PhD student majoring in soil science at UPLB and a professor at Western Visayas State University in Iloilo. "I saw great potential for improving the productivity of rice in the province," says

Dr. Gabinete. She found out that the farmers were not practicing right nutrient management, and their timing in applying fertilizer was off. Iloilo farmers were applying either too much or too little fertilizer.

Preliminary results

1. An SSNM recommendation for Iloilo was developed using farmers unit of reference (bags/ha instead of kg/ha);
2. Initial results show that farmers involved in the participatory experiment had changed their timing of application;
3. In January 2007, results were presented to the Department of Agriculture at a regional meeting. As a result, a follow-up meeting with SSNM proponents (the scientists) has been requested and will be attended by all municipal agricultural officers in the province for incorporation in their recommendations to farmers. Other stakeholders will include representatives of fertilizer companies and farmer groups.

Case 2. Adoption of SSNM recommendations by the private sector in the Philippines

Background

With the decentralization of national agricultural extension systems in the Philippines, the private sector is playing an increasing role as a provider of technical information (Pluske, 2005). In the Philippines, fertilizer manufacturers recognize the need of coming up with more efficient use of fertilizers for the benefit of Filipino rice farmers whose sources of information regarding fertilizer use is widely varied and unreliable. Sectors of the fertilizer industry visited IRRI in 2004 to gain familiarly with SSNM for rice and examine how the principles in the SSNM approach could be incorporated into their recommendation for rice to farmers. The technical information generated from IRRI's research was fitted into their research and marketing to form an improved fertilizer recommendation for farmers, which was in turn evaluated with farmers through their network of field staff. Fixed time N management was validated through the industry conducting participatory on-farm experiments with farmers. The partnership continues with updates on SSNM provided through the IRRC for refinements of recommendations that farmers can readily understand and adopt.

Preliminary results

1. Modification of recommendation on the timing for fertilizer application such as: (a) increasing the standard number of N applications from two to three; (b) providing a 'window' of about two weeks for the 'basal' fertilizer application; (c) better matching N application with critical growth stages and (d) better matching K fertilization with critical growth stages.
2. A switch from a soil test approach to making fertilizer recommendations through an omission plot based approach. The general recommendation for wet and dry seasons now provides the optimal rates of N, P and K for rice based on SSNM principles.
3. Clear recognition by important players in the private sector that yield targets, as provided with SSNM principles, are valuable in helping farmers adjust nutrient management to match their financial capacity.

The adoption of SSNM by both the public and private sectors provides strong evidence of the relevance of IRRC outputs to end users, and that SSNM recommendations will be both sustainable in the long term and likely to diffuse rapidly through the rural sector.

Concluding remarks

Farming is not only an economic activity, but it is also a social and cultural activity. Thus, ensuring technology adoption should not only consider the profitability of the technology but the social and cultural dimensions as well. The importance of farmer knowledge, farmer experiential learning and the existing social capital are therefore deemed necessary for ensuring adoption of FBMPs and accelerating their spread for small scale farmers in Asia.

Acknowledgments

Research on SSNM in Asia has been supported by the Swiss Agency for Development and Cooperation (SDC), the International Fertilizer Industry Association (IFA), the International Plant Nutrition Institute (IPNI) and the International Potash Institute (IPI).

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Changing farmers' behavior in developing countries for a wider adoption of fertilizer best management practices – experience in Thailand

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Abstract

Increasing the use of fertilizer best management practices (FBMPs) by farmers in Thailand, as an integral part of their farming system, is one of the agricultural development strategies. A number of research projects aim at introducing and transferring this technology to the stakeholders. Although many farmers are interested in the technology, the problems encountered in communicating the FBMPs still need to be resolved. It was found that there are problems in transferring research results to the stakeholders. To overcome this, several programs have been established, including the promotion of collaborative research and related activities concerning FBMPs, in partnership with national research and extension systems. The establishment of these links, by strengthening capacities, proved to be the solution.

We have learned that, in order to change farmers' attitudes towards adopting FBMPs, they should be involved in the extension program. The participatory extension approach (PEA) to transfer the FBMPs to the target farmers over wide areas is important in this respect. We have also learned that the activities of the PEA are made more effective by the *establishment of a networking system* for both donors and receivers. The *farmer to farmer extension approach by training Lead Farmers* is quite effective at achieving widespread empowerment. The *research, extension and fertilizer traders' linkage* is very important and needs to be improved. The activities aimed at facilitating the adoption process include regular meetings, training and monitoring programs. To change farmers' behavior, the extension programs have to be designed to change farmers' attitudes, increase the receptivity of communities and modify traditional practices.

Introduction

The objective of this paper is to review experience in changing the behavior of farmers for the wider adoption of FBMPs in Thailand.

In most developing countries, agriculture is the foundation of the national economy. The main policies are designed to increase crop production and farm income and to sustain productivity. To achieve this, several supporting factors are needed. One of these factors is the sustainable and improved fertility of soils. Consequently, soil and fertilizer extension services need to put increasing emphasis on the various methods of improving soil fertility in the packages of recommendations given to farmers, such as the integrated use of organic fertilizer and mineral fertilizer. The improvement of soil fertility is a challenging task. The FBMPs have to be modified in order to be adapted to the traditional agricultural practices presently used by farmers. The development of the technology depends also on the capability of the agricultural extension service and the farmers. The present challenge for agricultural extension is to promote appropriate fertilizer recommendations for sustainable agriculture. By improving farmers' cultivation practices, the utilization of farm inputs should become more efficient. The communication of information and technology will play a major role in the rapid and wider adoption of FBMPs by small scale farmers. To achieve this, the PEA should be used. Linkages must be strengthened, in partnership, between research, extension and the fertilizer trader sector.

Principles

Factors affecting farmers' behavior

Farmers' behavior is the set of activities performed by the farmer and influenced by cultures, attitudes, emotions, values, ethics, authority, relationships, persuasion and coercion. The factors affecting farmers' behavior are attitude, social norms and perceived behavioral control.

Attitude is the degree to which a person has a favorable or unfavorable evaluation of the behavior in question.

Social norms are the influence of social pressures that are perceived by the individual, to perform or not to perform a certain behavior.

Perceived behavior control is the individual's belief concerning how easy or difficult it will be to adopt the behavior.

The FBMPs extension program has to take into consideration and be established in relation to these key factors.

Steps towards the adoption of fertilizer best management practices

The **adoption process** is an individual mental process through which an individual passes from first hearing about an innovation to its final adoption. The five stages of adoption are (1) awareness, (2) interest, (3) evaluation, (4) trial and (5) adoption.

Elements for a wider adoption

The **diffusion of an innovation process** consists of four main elements: **innovation**, **communication** through appropriate channels, **over time**, and among the members of a **social system**. The diffusion of innovation processes can be traced on a micro level, as in the case of an individual who is a targeted member of an audience, or traced at the macro level in the context of economic development or technological advances.

Role of extension

Farmers in the developing countries have been left behind by the rapid changes in agricultural technology and information. For the farmers to keep track of these rapid changes, agricultural extension plays an important role in terms of the development of **knowledge, attitude and practice (KAP)**. To strengthen the **capacity** of small scale farmers, it is necessary to integrate the important factors such as agricultural credit, production inputs and marketing strategies, and to overcome bottlenecks through a comprehensive agricultural extension program.

Methodologies

The participatory extension approach

To facilitate adoption by the farmers, the participatory approach is used and the farmers become the center of the extension process. The PEA is a way of improving the effectiveness of extension efforts. The PEA can help to improve organizational performance at the interface between the service providers (extension) and the clients (the farmers).

The technology that is promoted must meet the needs of the farmers and has to be modified and adapted to their conditions in each locality, so as to make it more appropriate and relevant. The development of **KAP** must rely upon **farmers as the learning base** for enhanced capacity building. Farmers need to participate in the development of strategies for the adoption of a new innovation.

Characteristics of the participatory extension approach

- Integration of the community in the planning and realization of rural development projects, in collaboration with agricultural extension, research and other stakeholders.
- Based on equal partnerships between farmers, researchers and extension agents, who can thus learn from each other and contribute their combined knowledge and skills.
- Strengthening the problem-solving, planning and management abilities of the rural population.
- Promotion of farmers' capacity to adapt and develop new and appropriate technologies/innovations.
- Encourage farmers to learn through experimentation, building on their own knowledge and practices (implicit knowledge) and blending them with new ideas (explicit knowledge). This takes place in a cycle of action and reflection which is called 'action learning'.
- Communities of farmers are not homogenous but consist of various social groups with conflicts and differences of interest, power and capabilities. The goal of the promotion of FBMPs is to achieve equitable and sustainable development through the reconciliation of the different interests and by including the poor and marginalized farmers in the collective decision-making. The role of the extension agent is to facilitate this process.

The community technology transfer center

Training is a major strategy for the extension of FBMPs. A training curriculum has been developed, focusing on soil and fertilizer management technologies, including the proper use of soil diagnostic tools.

One of the key elements of extension technologies for targeting farmers is to set up a representative body of the villagers.

In the target areas, the knowledge and experience gained from the training will be transferred to the **Tambol** (Village) via the **technology transfer and service center**

(TTC) (Figure 1). One to five well trained volunteer farmers in the village will be "village farmer trainers" and will constitute the TTC of each village.

Figure 1. Agricultural technology transfer center.

Development of fertilizer best management practices

The strategies used to prioritize and select the FBMPs that are to be promoted have to be adapted to the situation of the farmers. The FBMPs generated through research must be modified to match the existing conditions as regards the farmer's resources and his farm. Information about the FBMPs and an effective service for diagnosing nutrient deficiency problems are lacking.

The development of a field (Figure 2) *soil test kit with a simplified soil series diagnosis, a fertilizer recommendations hand book* and a *decision support system* are aimed at facilitating the adoption of FBMPs by the farmers. The concept of using a *decision support system* and a simple test kit is an attractive approach for disseminating FBMP technology and creating a positive change in the attitude of farmers.

Figure 2. Soil test kits.

The soil test kits coupled with a decision support system (Figure 3) are innovations that are assisting farmers to solve their nutrient management problems. This extension approach for the technology involves the active participation of farmers and enables them to decide which FBMP best fits their farming needs.

Figure 3. Decision support system.

The extension of the FBMP process can be traced on a site-specific micro level in the targeted area (the nucleus site). The channel used for the transfer or communication of information with the objective of the wider spread of FBMPs, is social systematic diffusion.

Selection of sites and target farmers

The first step in the extension project is the selection of the site. The major objective of the program is to achieve widespread adoption of the technology under conditions of limited resources. The selection of the best possible sites and clients for the target group selection is the key to success of the pilot FBMP villages. The participatory rural appraisal (PRA) and rapid rural appraisal (RRA) tools are used for site selection.

Participatory rural appraisal and RRA were used to assess the household circumstances. Farmers acted as partners in the site selection process. The criteria for site selection were location in an area with physical problems, villagers' awareness of the problems, and the willingness of local extension officers to cooperate. The extension workers acted as facilitators to aid farmers in identifying the problems of the village and farmers' needs and preferences, including finding potential solutions. Reports and proposals were prepared and presented by the farmer representatives at provincial meetings, which were attended by the relevant stakeholders, that is extension workers, farmer representatives from each village in the target areas, specialists, researchers and provincial project coordinators. After presentation and discussion, field visits were carried out. Pilot villages were then selected as the nucleus sites for the FBMPs extension program.

Participatory selection of volunteers

Farmer groups in the target villages were formed according to their interest, readiness and willingness to volunteer. The volunteer farmers themselves select those among them who would join the project's activities and would be called, for example, a "lead farmer" or a "farmer trainer".

The pilot or nucleus village activities

Selected villages in the target areas are chosen to be pilot FBMP villages. The farmers in these villages are encouraged to test whether the recommendations are suitable for adoption or need adaptation. The on-farm testing and verification are managed by the farmers themselves, involving a group of trained farmers and volunteer farmers, with technical advice and support from extension agents and collaborating agencies. The progression is as follows:

- **First year**: the combination of traditional knowledge and new ideas and practices is discussed with the farmers to identify alternative solutions to the problems they encounter. The activities are based on the participatory approach and an equal partnership.
- **Second year**: the FBMP villages are a core, or nucleus, for learning and for the dissemination of FBMPs to neighboring or surrounding villages. The volunteer lead farmers are trained and then, with a farmer-to-farmer extension approach, a number of farmers in the core villages are trained in turn and carry out FBMPs on their individual farms.
- **Third year**: neighboring villages are persuaded by lead farmers in the core villages to join in the activities, as satellite villages (Figure 4), for the application of FBMPs.

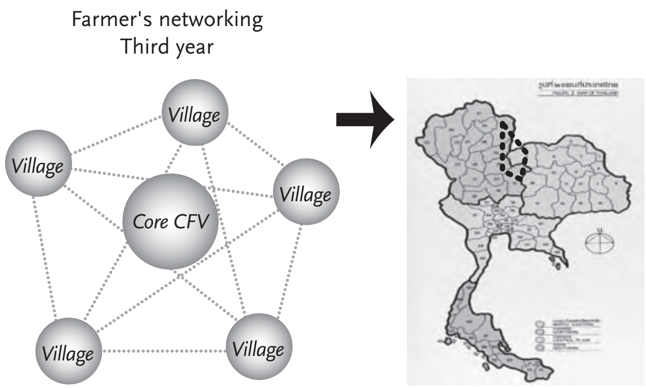

Figure 4. Establishing a network of satellite villages.

Using the farmer-to-farmer extension approach

Emphasis has been put on the farmer-to-farmer extension approach in order to encourage the involvement of farmers in conducting their own field studies, sharing knowledge and experience, learning from each other and using the field as the primary learning base. The farmers "learn by doing" by comparing different soil fertility management systems. Consequently, they become experts on the particular practices they are investigating. Such farmers can therefore serve as "farmer promoters" or "farmer scientists". The extension workers act as facilitators for the learning process and provide assistance and support.

The volunteer farmers who attended the training program jointly conducted on-farm farmer-managed trials in their villages when they returned home. The farmers independently selected different FBMP recommendations for their investigations. In addition to a joint on-farm farmer-managed trial, each farmer also tests FBMPs of personal interest for his own farm. The soil tests, crop growth observations and yield comparisons showed the effectiveness of the different practices. The farmers also observed and learned about changes in their own fields. However, this is not the end. The farmers and extension workers then initiate discussions on how to improve soil fertility for improved agricultural production.

On-farm trials/demonstrations

One of the major aims is to find out how to transfer the FBMPs to the target farmers. Core villages and satellite villages are the target sites for this purpose. On farm trials/demonstrations are established. These on-farm trials/demonstrations were conducted using the participatory approach. Lead farmers from the core villages representative of each target area, identified their problems and solutions. They decided on the design and implementation of the farm trials, under the supervision of research and extension agents. The members of the village discussed how their on-farm trials/demonstrations should be managed.

Farmers' training program by lead farmers

The farmer-to-farmer training program was then established. The lead farmers underwent the intensive trainers program, which included the use of the extension material for technology transfer, how to be good trainer and effective practices. The farmers themselves planned the one-day training program in consultation with the extension agents. This training program involved an analysis of the village's problems on crop production, an overview of the solutions, possible recommendations and visiting farm trial/demonstration sites (Table 1).

Table 1. Lead farmers monitor of competence.

Level 1	Level 2	Level 3	Level 4	Level 5
Less than average	Average or slightly less	Slightly higher	Higher	Much higher
1.00 -1.80	1.81-2.60	2.61-3.40	3.41-4.20	4.21-5.00
		Inadequate rice cultivation skills	Average competence. Ambition to be a technology transfer agent. Good rice cultivation skills	Ambition to be a lead farmer

Farmer networking

Apart from mutual learning in the village, farmers also benefited from cross-site visits to other villages. Farmer networks or linkages have been initiated and the farmers have exchanged knowledge and experience, including the sharing of planting materials on a non-profit basis. By caring and sharing, individual farmers and groups have been empowered and can further improve their agricultural production through self-help and mutual aid.

The main objectives of a farmers' network are to encourage close cooperation between and among farmers, within their village and with other villages. Farmers share their experience and their local resources through this networking. Lead farmers were selected by vote to comprise the farmer's networking committee, to act as a steering committee.

Establishing the stakeholders network

A research, extension, fertilizer trader and retailer network, at local and national levels, has been developed to strengthen collaboration between partner agencies. The collaborative activities are effected through meetings, training, sharing resources and information and field visits. This networking is established both at local and at the national level.

For the capacity building of the stakeholders, several activities with integrated activities, such as training workshops, meetings and discussions and cross-site visits were established.

Farmer networking

The farmer network was established for sharing experience and resources, and also for co-operation with mutual benefit. The committee is composed of lead farmers from villages participating in the project. There are a number of activities for farmer networking, such as committee meetings and cross site visits. The main objectives of the meetings are to review and plan the activities and those of the cross site visits.

Farmer training

Three to five volunteer farmers from each village were nominated to attend a five-day training workshop. This enabled a core group of farmers to jointly conduct on-farm farmer-managed trials in their villages. The extension workers in charge of the five target villages also joined in this training workshop, in order to learn and share knowledge and experience with the farmers. Teaching and learning activities included lectures (as necessary), discussions, class exercises, field exercises, study trips and workshops.

Fertilizer retailers' training program

There are more than 4500 fertilizer retailers in the country. The fertilizer retailer is a key person who supplies not only fertilizer and other inputs to farmers (their customers) but also recommendations on which and how much fertilizer should be used. The retailers are at the end of the line for contacts with farmers for fertilizer use. A fertilizer retailers training program was established, aiming to increase the retailers' knowledge and improve their business oriented approach. Under the Fertilizer Act, fertilizer retailers have to apply for a license to sell fertilizers and the training certificate has to be attached.

Lessons learned

- It was learned that, in order to encourage widespread adoption of FBMPs and their implementation by farmers, an **interdisciplinary approach** is needed and it should be conducted in a **participatory manner**. Team members from various disciplines should work together to identify the problems, needs and interests of the farmers, then plan, execute, monitor and evaluate the program.
- The development and transfer of the technology have to be **integrated with human resource development** to ensure that the FBMPs that are introduced are able to solve the productivity problem and be socially and economically acceptable.

- Various strategies and activities have been implemented in a participative manner. For example, establishing pilot villages as nucleus/core villages for testing and disseminating FBMPs to satellite villages, using the farmer-to-farmer extension approach, has proved to be crucial. Also simple field soil test kits and decision supporting documentation for FBMPs provide useful and practical information to field extension workers, helping in their discussions with farmers and to reach sound decisions. They also build up the technical capacity of field extension workers and farmers. **Monitoring and evaluation** also are very important. All these activities are like the pieces of a jigsaw, coming together to produce a full picture of the goal.
- We have learned that a participatory approach in transferring FBMPs to target farmers is productive and efficient. Activities as regular meetings, cross-site visits, and the training of lead farmers are effective for **empowering them**.
- **Human resources development** is a key to success for widespread adoption of the technology.
- The **farmer networking** proved to be quite effective in stimulating farmer participation, as they shared experience and resources and co-operated between themselves. This lead to growth and development based on self-help principles. There are no strict rules and regulations but only active participation with an equal partnership for all.
- The farmer-to-farmer extension program is a lesson learned from the PEA that makes technology transfer more efficient.

Summary and conclusion

Despite the promising FBMP techniques that are available, the number of farmers adopting them is low. It is therefore necessary to find the best methods of promoting the improved technologies to farmers in the problem areas, by strengthening existing research/extension partnerships, including the NGOs.

The goal of the FBMP extension program is to increase the efficiency and improve the productivity and income of farmers through their widespread adoption of FBMPs, with sustainability of their production.

The important bottlenecks to their adoption are not only the target farmers but also the research and extension personnel, fertilizer traders and policy makers.

Several activities have been implemented using the participatory extension approach. A weakness is the preparation of extension workers for collaboration in the FBMP program, that is improvement of agricultural production through a combination of traditional knowledge and new management technologies. As facilitators, using the farmer-to-farmer extension approach, their methods of interaction and provision of expert and concise feedback need to be reviewed. Advice and support need to be provided at the *national policy level.*

The further development of the program should put more emphasis on improving the competence of all concerned by capacity building, strengthened research-extension linkages, making institutional collaboration operational and empowering national teams by providing them with a more active role.

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Farmers' behavior and codes of fertiliser best management practices in India – viewpoint of Tata Chemicals Ltd

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Introduction

Agriculture in India is not only an enterprise, but also a livelihood for 60% to 70% of its population. It contributes more than a fifth of the country's Gross Domestic Product (GDP) and generates 60% of the employment. The country has nearly 170 million hectares of arable land, with a wide range of agro-climatic conditions and producing a large array of food crops, dairy products and fish. However, crop production dominates the sector, representing 70% of the total value of agricultural output. The country has changed from having a begging-bowl image to a situation of self-sufficiency, mainly due to advent of the Green Revolution during late sixties, involving the adoption of high yielding cultivars of food grain crops supported by an improved irrigation infrastructure and enhanced use of fertilisers. However, an ever-increasing population along with a shrinking land mass is creating increasing pressure on the sector. Major issues of concern are related to the slow rate of growth of the agricultural sector, which has been widely attributed to (a) an inadequate infrastructure, (b) erratic monsoons, (c) fragmented land holdings, (d) low and imbalanced use of inputs and (e) lack of awareness among farmers regarding improved technologies. Current productivity is low, compared to the world average, and there is a stagnation in yields of most field crops. Central and State bodies as well as corporate sectors, with their business interests, are engaged in combating these constraints in order to usher in a second Green revolution.

Farmers' behavior in today's India

The majorities of Indian farmers are poorly organized and have a very low level of literacy. In addition, the average size of their land holdings is very small. They are caught in the vicious circle of a low input – low output system, preventing them from escaping from the poverty trap. In consequence, both awareness and skill levels are in a low to medium range, and their level of motivation is very low. Evidently, persuading them to adopt new technologies and practices is a great challenge. Fertiliser being one of the most important inputs, corporate sectors engaged in this business cannot avoid their social responsibilities in this respect. They must make judicious use of various tools such as awareness campaigns, training and demonstration programmes, opening of farmers' schools, understanding of Government regulations, analyzing the resource pools, customizing products/services, etc. The objective is to bring the awareness, skill and motivation levels of Indian farmers to a very high level. In order to preserve environmental sustainability and ensure a high yield and profitability of the crops, there is an urgent need for a paradigm shift in Indian agriculture from conventional farming practices to fertiliser best management practices (FBMPs). These practices include: adoption of proper methods of fertiliser application, use of soil and crop specific fertiliser application, integrated pest and nutrient management, irrigation practices and cropping patterns suited to the agro-climatic conditions. Thus, FBMPs represent holistic management practices with different inputs such as fertilisers, other sources of plant nutrients, water, seed, plant protection products and cropping patterns that ensure sustainable agricultural growth.

Agribusiness model of Tata Chemicals Ltd

Tata Chemicals Ltd (TCL) is a flagship company in the well known Tata Group of Companies, engaged in industrial chemicals, fertilisers, food additives, agribusiness and fruits and vegetables. The fertiliser business of TCL aims at providing a total crop nutrition solution to its clients (i.e. the farmers) in the five states of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal, located on the Indo-Gangetic Plain of India (Figure 1).

Figure 1. Operating geography of TCL.

The operational area is located around the fertiliser factories of TCL situated at Babrala in Uttar Pradesh and Haldia at West Bengal, producing urea and diammonium phosphate (DAP) respectively. In addition to the regular sales channel through wholesale dealers, distributors and retailers in the states where it is operating (Figure 2), the fertiliser and other agro-inputs business of TCL operates through its farmers' interface, 'Tata Kisan Sansar' (TKS) meaning 'Tata Farmers' Family'.

Figure 2. Branded retail outlet for TCL.

The TKSs are operated through franchises selected by TCL, with agreements to maintain the standards and guidelines of TCL. The TKS has an extensive network of exclusive retail outlets in the rural areas where it is operating. The TKS operating model is based on the hub and spike model, whereby each of the 20-25 TKSs is connected to one 'Tata Kisan Vikas Kendra' (i.e. Tata Centre for Farmers' Development). The TKVKs act as hub resource centres for the TKS operations in their areas and usually include a farmers' training centre, soil testing laboratory, farmers' library, warehouse and demonstration farm (Figure 3).

Figure 3. Infrastructure-resource centre (TKVK).

Each TKS provides its clients with various *products*, such as fertilisers, manures, seeds, plant protection chemicals (Figure 4) and equipment and *services* related to both relationship building (crop seminars, small farmer meetings, TKS membership, soil/water testing) and revenue generation (contract farming, crop loan and application services). The average area of operation of each TKS amounts to 21,000 acres within a 5 to 8 km radius with the TKS at the centre, covering around 4,800 farmers in 40 villages. The TKS agronomist plays a crucial role in the customer interface and acts as a two-way

Figure 4. Product range of agri-inputs.

channel to make the farmers aware of the latest technologies as well as arranging solutions to farmers' problems through the crop specialists.

The total numbers of TKSs currently operating under TCL is around 550, reaching about 2.8 million farmers cultivating 4 million hectares. The entire network is managed by 550 field staff, 80 crop specialists and 60 agronomists. TCL has a business turnover of around $83 million through the TKS network. Forty thousand farmers are linked with TKS as members, while around 30,000 farmers are engaged in contract farming with TCL. About 50,000 farmers have participated in the soil testing services, while 440,000 farmers have had some kind of involvement with TKS. Around 170,000 farmers have received training on various key technologies.

Customized fertiliser – a step towards customization of products and services

In the context of the paradigm shift in the TCL business approach, from selling fertilizer to offering a total crop nutrition solution, TCL has taken a further important step by developing customized fertilizers i.e. steam granulated compound fertilizers, which are tailor-made for the crop specific as well as the crop/area specific application of nutrients. TCL believes that this value-added input will not only reduce the trouble that farmers need to go to in order to procure and apply various fertilisers, but also ensure the balanced and uniform application of the fertiliser. This should lead to improvements in both the quality and the quantity of the produce, which ultimately should fetch a better market price. In order to achieve this goal, it is important to decide which grades of the various fertilizers should be produced, based on sound scientific principles. As a first step, TCL has inaugurated a large soil, plant and water sampling programme, based on pre-determined and geo-referenced grid points (0.05' x 0.05') uniformly distributed throughout the study area. This will provide a reliable database regarding soil fertility, ground water quality and plant requirements for the target crops such as rice, wheat, potato, sugarcane, maize and mustard. The data will be processed in a GIS framework in order to derive a multilayered information database, in the form of the mapping of zones according to the pre-defined parameters. The crop demand for a particular nutrient, based on the target yield levels of a crop, has to be met through both the natural (soil) and the external (fertiliser) sources of nutrients. The fertility level of the natural soil being known, the need for external inputs, taking account of the expected level of efficiency of fertiliser use, will provide the required fertilizer nutrient application rates. Multilayered calculations for all the nutrients in question (N, P, K, S, B, Zn, Mn, Fe, etc.) in the GIS (gegraphic information system) environment and the extent of the needs in the operating area will help in deciding on the ratios of the various nutrients for crop/area specific grades of the customized fertilizers.

In a second step, TCL aims to use a crop modelling approach to take account of the nutrient interactions, in order to further refine the choice of grades of fertilizers. The modelling approach will also help in the near future in the monitoring of crop growth and the provision of agro-advisory services for the farmers. Moreover, the soil and ground water database generated through the sampling exercise will permit the detection and monitoring of both temporal and spatial variations in the studied parameters.

This will help us to identify changes resulting from the use of this newly developed input.

Conclusion

We at TCL are determined to take the leadership in a "total crop nutrient solution", through the introduction of many improved products and services, our mission being ultimately to improve the quality of life of our customers – the poor farmers of this country.

Preliminary synthesis of farmers' attitudes and preferences towards nutrient application in China and India

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Abstract

The International Potash Institute (IPI) has initiated the distribution of a questionnaire to several hundred farmers in villages and locations across India and in two locations in East China, and to approximately a hundred fertilizer dealers in India. The results were compiled and compared between the two countries and, in some cases, between villages of the same country.

The results show that Chinese farmers rarely avoid the annual application of nitrogen (N), phosphate (P), potash (K) and organic matter (OM), when compared with farmers in India. About 40% of farmers asked in India add K 'sometimes' or 'never', while 10% only apply 'sometimes' in China. The use of a soil test was highly varied between the various locations in India, but was very low in the two locations surveyed in China. Dependence on precipitation and the socio-economic level of farmers strongly affects the use of nutrients and consumption of services such as soil testing.

Regular contacts with extension services also varied greatly between locations in India and were quite high in China. Indian farmers appear to appreciate less the knowledge of the fertilizer dealers, mostly ranking their knowledge as poor to medium, but Chinese farmers tend to rank the dealers' knowledge as "good" and "very good".

Most farmers in the survey appreciate workshops and meetings as the best channels for receiving agronomic information, followed by TV and information sheets.

It is concluded that, in order to make the most efficient dissemination of agricultural knowledge, a site-specific knowledge transfer policy has to be tailored according to the local agronomic, social, economic and societal parameters and the needs of the region.

Introduction

Agriculture and information knowledge systems today position the farmer at the centre with research, education and advisory services surrounding him and maintaining direct links to the farmer and between themselves (Birner *et al.*, 2006). Yet, public extension and research systems compete for budget, and often research institutions have an advantage due to their higher status, better management quality and links with the global science community. This creates tension and militates against an effective two-way communication (Mureithi and Anderson, 2004). Nevertheless, Anderson *et al.* (2006) strongly advocate that the dependence of extension programs on science and technology and vice versa is very strong, i.e. the linkage effect is more important than it is among other sub-sectors. Even though in many countries, in particular in developing countries, research scientists often do not have strong incentives to interact with extension.

The economic benefit from extension work was highlighted in 1995 by the International Food Policy Research Institute, IFPRI (Rosegrant and Evenson, 1995). The authors show that public research, extension expenditures, irrigation and foreign private research each had a statistically significant, positive impact on the total factor productivity (TFP) in India from 1956 until 1987. Public sector agricultural research and extension contributed nearly 60% of TFP growth. The authors also encourage investment in these segments and indicate that, as a result of the greater complexity of post-green revolution technologies, increased investment in education and human capital is likely to have high returns.

The private sector plays an important role in extension work in developed countries. In recent years, the private sector in India (e.g. fertilizer companies; see Gahlaut, 2006) has developed sustainable activities, promotion centres and dissemination projects. Indeed, private sector and extension often have different objectives and priorities. For example, the main extension projects designed in 2001 and 2003 in the Wuhe County, Anhui Province (China) were organic farming, breeding programs, various cultivation and machinery practices, introduction of varieties, control of pest and disease and so on. Among the 20 main extension projects listed, only one was related directly to fertilization and nutrient management, entitled "testing soil nutrition and formulated fertilizer applying technology" (Mei, 2005). In this respect, there is a great challenge to create incentives and agreed programs between the private sector and extension services.

Often, a small pilot or a small component within another project, with close supervision or other additional circumstances (e.g. irrigation development, delivery of abundant subsidized inputs, or simply the small and easily-managed scale of the project) will create a perception (often justified) of success. The extension model of the small-scale pilot will then be promoted to both the donor agency management and to developing-country policymakers as worthy of scaling up to the national level. The traditional reluctance of national policymakers is temporarily overcome by the availability of abundant external funds that are provided outside of the normal budget framework (Anderson *et al.*, 2006). This principle nicely demonstrates the success of the site-specific nutrient management (SSNM) project with the private sector from the fertilizer industry (IFA, IPI and IPNI) together with the International Rice Research Institute (IRRI) and generous donor money from the Swiss Agency for Development and Cooperation (SDC), all working together for the last seven years in a project that greatly improves nutrient management of irrigated rice in Asia. The project is now at its transfer and dissemination stage in which the scientific knowledge is transferred to the extension systems and farmers in East Asian countries.

Scientific success is not a guarantee for adoption of a new technology. In Indonesia, where SSNM technology was introduced, half of the farmers in Garut village in Bali (n=25) did not know the benefit of 'balanced fertilization', and in other villages, a large number of farmers was not familiar with the relationship between balanced fertilization and pest-disease occurrence (Djatiharti *et al.*, 2006). The use of the 'leaf color chart' (LCC) is another example of the SSNM technology that requires further concerted effort to achieve adoption: only 24, 4 and 8% of the farmers adopted the use of LCC, even though it was an integral part of integrated crop management (ICM) and has an acknowledged record of success (Djatiharti *et al.*, 2006).

In order to create and maintain an efficient dissemination strategy for transferring the knowledge of 'balanced fertilization', IPI has created a questionnaire for farmers and dealers. IPI conducted this survey among hundreds of farmers and dealers in China and India during the period 2004 – 2007. The results of this survey may assist in adopting specific strategies for dissemination to farmers.

The survey

Locations of the survey

The survey covered 10 locations in India (Table 1) and two locations in China. It included 350 farmers and 105 dealers in India, and 125 farmers in China. Locations were in North, West and South India, and in East China. In China, the survey was conducted on farms around the city of Changsha (Province of Hunan) and the city of Yuyao (Zhejiang Province).

Table 1. Locations where the survey was conducted in India.

State	Locations of survey
Haryana	Gurgaon, Rewari
Uttar Pradesh	Meerut, Sahajahanpur
Uttrakhand	Pantnagar
Madhya Pradesh	Indore
Punjab	Gurdaspur
Jammu & Kashmir	Jammu[1]
Kerala	Kottayam[1]
Maharashtra	Kolhapur[1]

[1] In these locations, dealers were responding to a similar set of questions, with additional queries targeted to dealers only

Farm size

Half of the farmers in India had 1-2 ha of cultivated land, 27% had 0.1-1 ha and 22% had less than 0.1 ha. Most of the Chinese farmers (81%) had 0.1-1 ha.

Main crops

The major crops grown in the survey plots are shown in Table 2.

Results from the survey and discussion

In order to learn more and receive first-hand information on the farmers' practices and preferences, we asked them a series of questions in a written form. This took place during or following meetings with large groups over discussion or a visit to various demonstration plots. To ease the replies and its analysis, no free text questions were asked.

Table 2. Main crops (>70% of land) grown in the survey plots in India and China.

Crops grown (rate)	India								China	
	Pantnagar	Sahajahanpur-1	Sahajahanpur-2	Indore	Gurdaspur	Gurgaon	Meerut	Rewari	Changsha	Yuyao[1]
	N=30	N=23	N=22	N=94	N=40	N=41	N=52	N=72	N=95	N=30
1	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat	Rice	Peanut
2	Rice	Rice	Rice	Soybean	Rice	Pearl millet	Rice	Pearl millet	Soybean	Tea
3		Vegetables	Vegetables	Maize					Vegetables	Vegetables

[1] The crops grown in Yuyao are very different from the other locations, with farmers in the survey putting 30% of their land to peanuts

Table 3 describes farmers' attitude toward the frequency of application of N, P and K fertilizers and OM.

Nitrogen

The vast majority of farmers in India (53.6-96.0%) and many more in China (98.3-100%) use N every year (Table 3). Nitrogen application is relatively low in three regions in India: only 53.6% of the farmers asked in Indore apply N every year, and about 10.0% do not apply N at all. A possible reason for this is that the main crop in this region is soybean. The relatively low level of N application in Rewari (73.3%) is explained by the fact that Rewari is highly dependant on rainfed agriculture, and thus fertilizer application varies according to actual rainfall. Meerut (63% answered 'every year') is another example of low application of N, but we have no observations to explain this phenomenon.

The difference between the Indian and the Chinese farmers is very clear and shows that the latter are applying N, P, K and OM in a more frequent manner (Table 3, Figure 1). A possible reason for this is the higher crop index in Changsha, better returns for the product, less dependence on rainfall and higher level of agricultural knowledge.

Phosphorous

The application of P in India is less frequent compared to N, and the percentage of farmers replying 'never' to P application is 0-22.1%, the highest being in Meerut district, India. In the two locations from China (Changsha and Yuyao), no farmer answered that they "never" applied P.

Potash

The frequency of K application in India is lower than that of N and P, and the percentage of farmers replying 'never' to the question 'I apply potash' varies between 7.4 to as high as 64.9% (Table 3). In three regions in India (Pantnagar, Sahajahanpur-1 and 2) and in both locations in China, farmers always apply K, either every year or less frequently. Farmers in Gurgaon district displayed the lowest rate of K application: only 18.9% apply

Table 3. Farmers' practice concerning regular application of N, P, K and OM (% of farmers).

Farmers' practice	India								China	
	Pantnagar	Sahajahanpur-1	Sahajahanpur-2	Indore	Gurdaspur	Gurgaon	Meerut	Rewari	Changsha	Yuyao
	N=30	N=23	N=22	N=94	N=40	N=41	N=52	N=72	N=95	N=30
'I apply nitrogen' (%)										
Every year	96.0	91.0	77.3	53.6	75.9	81.1	63.0	73.3	100.0	98.3
Every 2 years	4.0	4.5	4.5	9.5	10.3	10.8	15.2	14.7	0	0
Sometimes	0	4.5	18.2	27.4	13.8	5.4	15.2	9.3	0	1.7
Never	0	0	0	9.5	0	2.7	6.6	2.7	0	0
'I apply phosphorus' (%)										
Every year	84.0	87.0	65.2	50.0	37.9	80.6	59.7	68.2	100.0	98.3
Every 2 years	4.0	13.0	4.3	15.2	10.3	8.3	6.6	10.6	0	0
Sometimes	8.0	0	26.1	30.4	41.4	5.6	11.6	13.6	0	1.7
Never	4.0	0	4.4	4.4	10.4	5.5	22.1	7.6	0	0
'I apply potash' (%)										
Every year	84.6	79.2	81.8	39.3	40.7	18.9	63.5	32.6	100.0	94.0
Every 2 years	0	8.3	4.6	15.7	11.1	5.4	5.8	13.9	0	0
Sometimes	15.4	12.5	13.6	29.3	40.7	10.8	15.4	16.3	0	6.0
Never	0	0	0	15.7	7.4	64.9	15.3	37.2	0	0
'I apply organic manure' (%)										
Every year	76.9	45.8	40.9	64.4	23.5	37.5	54.2	72.1	86.3	18.7
Every 2 years	0	45.9	40.9	18.4	35.3	2.5	37.5	22.9	0	15.6
Sometimes	23.1	8.3	18.2	12.6	35.3	20.0	6.2	3.3	13.7	65.6
Never	0	0	0	4.6	5.9	40.0	2.1	1.6	0	0

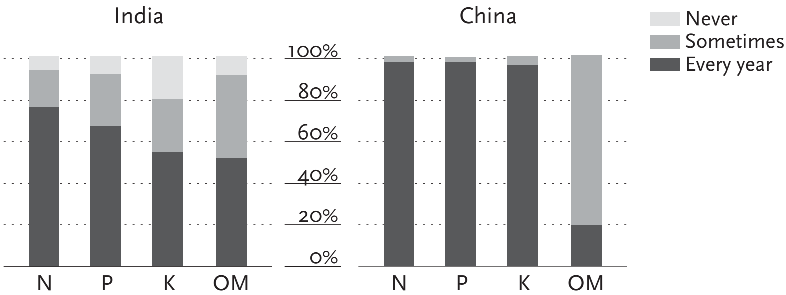

Figure 1. Farmers' practice for application of N, P, K and OM in India and China (average of 374 and 125 farmers in India and China, respectively).

K every year, 16.2% apply sometimes and every second year, but 64.9% answered 'never' to the question 'I apply K every…'. This is the highest rank for 'never' application we received in this survey.

Another contrasting figure is the low use of soil test services reported by the farmers in Gurgaon (Table 4): only 27%, the lowest rank in all the sites across India, use laboratory soil testing facilities. Since Gurgaon is close to Delhi, with a good logistic infrastructure, the reason for this is obviously not related to a reliable supply of K. Gurgaon region has light textured soils, the soils are poor in fertility and rainfall is quite low. Farming is mostly rainfed, and the predominant crops in the Kharif season are pearl millet and cluster bean, followed by wheat and mustard in the Rabi season. Yields are generally not high and if rains are not adequate, farmers tend to apply low levels of fertilizers. The area in Gurgaon where our survey was conducted is characterized as a low socio-economic level area, which reflects the low education level, the large number of children per family, a high level of drop-out from school and the large extent of disease born by unhygienic conditions. With such a social structure and conditions, the agricultural performance is also poor. We thus assume that this low socio-economical level is the main reason for the low level of farmers' knowledge as well as the low level of technical support from extension and others, as reflected by the low level of soil test laboratory use. Interestingly, Shen *et al.* (2005) showed that there is a good correlation between per capita net income of rural households and N surplus and K deficit in soils of China. The authors conclude that the level of economic development plays an important role in nutrient balances of various agro-ecosystems.

To overcome the low level of K application in Haryana, near the Gurgaon area, IPI initiated a demonstration program in 2001, where numerous field trials with excellent agronomic results for K application in pearl-millet, wheat and mustard were demonstrated to farmers (Yadav *et al.*, 2005). The impact of this activity can be observed in some locations with a relatively higher demand for K.

Table 4. Percent of farmers using soil test laboratories and farmers maintaining contact with extension and private sector in India and China.

Location	I use soil test laboratory		I have regular contacts with extension and private sector	
	Yes	No	Yes	No
India (%)				
Pantnagar	36.4	63.6	90.9	9.1
Sahajahanpur-1	95.4	4.6	100.0	0.0
Sahajahanpur-2	54.5	45.5	85.0	15.0
Indore	53.7	46.3	60.9	39.1
Gurdaspur	62.5	37.5	74.3	25.7
Gurgaon	27.3	72.7	35.3	64.7
Meerut	40.0	60.0	58.7	41.3
Rewari	52.4	47.6	71.2	28.8
China (%)				
Changsha	11.5	88.5	69.5	30.5
Yuyao	17.0	83.0	58.0	42.0

Organic manure

The application of organic manure appears to be well accepted by the Indian farmers. Unlike very similar results for N, P and K application in China obtained in the two locations surveyed, the farmers of Yuyao apply organic manure at a relatively low frequency (Table 3). Most of the farmers in Yuyao (65.6%) apply organic manure 'sometimes', the highest rank among all locations in India and China. A possible reason for this is the quite different crops and crop rotations in Yuyao (peanut, tea and vegetables; Table 2).

In conclusion, farmers are much more 'dedicated' to precise, frequent N application than to P and K application. Crops and irrigation facilities or, alternatively, dependence on rainfall also largely affect the practice of nutrient application. We also assume that agricultural knowledge gaps, sometimes induced by poor socio-economic levels, affect the application of K more than that of N and P.

Soil testing in the laboratory and contacts with extension and the private sector

In order to assess the farmers' attitude towards the use of soil tests, and to learn of their links with extension and advisors from the private sector, we asked the questions listed in Table 4.

Approximately 50% of the Indian farmers that participated in the survey use soil test laboratories (Table 4). The low level of soil test usage in Gurgaon (27.3%) is again explained by the high dependence on rainfall and the poor socio-economic structure. In contrast, the very high level of soil tests in Sahajahanpur-1 could be due to the fact that the farmers in the survey area are in the vicinity of Shriram's sugar-mill Haryali Bazar (a shopping mall for farmers' needs run by Shriram fertilizers) that has been very active and instrumental in promoting the orderly, systematic use of soil tests.

In China, the high fertilizer application rates do not rely on soil tests: only 11-17% of the farmers in the survey reported the use of this service.

Most of the farmers in both India and China did have regular contacts with extension and private sector (Table 4). It is again the Gurgaon region that has relatively low levels of contact (only 35.3% said 'yes' to maintaining regular contact with extension and private sector).

Ranking the knowledge of the fertilizer dealers

In order to learn more of the interface between farmers and their dealers, we asked the farmers to rank the knowledge of the dealers they work with (Table 5). The reply to this question may also relate to the status of the dealers in the eyes of the farmers.

Table 5. Ranking the knowledge of the fertilizer dealer by farmers in India and China.

Location	Ranking the knowledge of the fertilizer dealer				
	Poor	Low	Medium	Good	Very good
India (%)					
Pantnagar	0	0	21	10	69
Sahajahanpur-1	0	5	37	10	48
Sahajahanpur-2	42	33	17	0	8
Indore	35	29	14	13	9
Gurdaspur	50	0	34	8	8
Gurgaon	60	0	40	0	0
Meerut	40	7	27	3	23
Rewari	18	40	24	0	18
China (%)					
Changsha	0	6	7	75	12
Yuyao	0	0	30	44	26

In general, the farmers participating in this survey in India showed considerable less appreciation of the knowledge of their fertilizer dealers, whilst in the two locations monitored in China, it appears that the general ranking is between 'medium' to 'good'. Only farmers in Pantnagar and Sahajahanpur-1 (India) ranked their dealers positively. In all other locations of the survey in India, more than 50% of the farmers ranked the knowledge of their dealers as 'poor' or 'low'. As in other questions of this survey, farmers in Gurgaon have the highest negative rank towards the knowledge of their dealers, and 60% of the farmers answered that the knowledge level of their dealers is 'poor'.

These results pose a question over the role fertilizer dealers may play in promoting the use of 'balanced fertilization' practices. In addition, the status of the Indian dealers in most of the regions where the survey was carried out needs to be addressed.

Ranking farmers' preference for receiving agricultural information

In order to better evaluate the means IPI needs to use for the dissemination of 'balanced fertilization', farmers in the survey group were asked their opinion of the effectiveness of various agricultural information delivery channels. Their replies were graded into 4 categories: low, medium, high and very high (Table 6).

Table 6. Preferred communication channel for farmers in India and China for receiving agricultural information.

Location	Preference for receiving agricultural information						
	Information sheet	Workshops & meetings	TV	Radio	Experimental demo plots	Dealers	Successful neighbour
India (%)							
Pantnagar	High	High	Low	Low	Medium	High	Low
Sahajahanpur-1	Low	Very high	Medium	Medium	Medium	Medium	Medium
Sahajahanpur-2	Medium	High	Low	Medium	Low	Low	High
Indore	Medium	Medium	High	Low	Medium	Low	High
Gurdaspur	Medium	Medium	High	Medium	Low	Low	Medium
Gurgaon	Medium	Medium	High	High	Medium	Low	Medium
Meerut	Medium	High	Medium	Medium	Medium	Medium	Low
Rewari	Medium	High	High	High	Medium	Low	Medium
China (%)							
Changsha	Low	Very high	High	Low	Very high	Medium	Low
Yuyao	High	Medium	High	Low	Medium	High	Medium

In general, the ranking varies greatly from location to location. For example, TV was ranked 'low' in Pantnagar but 'high' in many other locations (Table 6). Attending workshops and meetings appears to be the most preferred channel for agricultural dissemination, as it scored 'very high' and 'high' in six locations, and not even a single 'low' rank. TV was also highly preferred as a channel of acquiring agricultural knowledge and scored 'high' in six of the ten locations. Dealers were the least preferred channel for this purpose, and scored 'low' in five locations. The use of information sheets is received by farmers in a very moderate way, and it appears that they prefer face to face means such as workshops and meetings. Between the two media channels, TV is much preferred over radio.

No significant differences were found between the India and the Chinese farmers in this survey.

Dealers' response

Fertilizer dealers are probably the closest circle around farmers as they often meet, trade, discuss and share information with the farmers. In order to better understand the dealers' opinions regarding their business environment and the interface with the farmers and extension workers, we launched a similar survey in 2007 with similar and different questions. Dealers from Jammu (Jammu and Kashmir; n=33), Kolhapur (Maharashtra; n=43) and Kottayam (Kerala; n=29) were selected for this purpose.

Asked "what is the dealer's most urgent problem", dealers from North (Jammu), Central (Kolhapur) and South India (Kottayam) replied similarly, and indicated that the reliable supply of fertilizers is the most pressing problem they face (Table 7). Reliable supply is highly relevant to dissemination of knowledge: we face many situations where, following the completion of a field experiment or demonstration plots, farmers are convinced of the value of potash and willing to purchase it. A year of no potash availability at the market damages the results and simply impairs the willingness of the farmer to adopt the experiment's different nutrient management techniques.

Storage capacities and the number of clients do not appear to be a serious limitation, but cash flow and the financial arrangements with the suppliers seem to be another constraint.

Asked "what is your attitude towards extension workers", the dealers across the three locations were very clear, and the vast majority (80%) had a positive approach, seeing the extension worker as a "friend/advisor" rather than "controller/invader" (Table 7). This finding shows that the interface between dealers and extension workers may be of positive value.

Table 7. Dealers approach to management and financial issues and attitude towards extension workers (total 105 dealers).

Location / issue	Jammu	Kolhapur	Kottayam
	N=33	N=43	N=29
Dealer's most urgent problem is: (%)			
Reliable supply	42	34	38
Own storage capacity	6	16	0
Cash flow / financial arrangements with suppliers	21	32	31
Not enough customers	6	5	16
Too limited variety of products	25	13	15
What is your attitude towards extension workers? (%)			
Friend / advisor	79	81	89
Controller / invader	7	5	4
Neutral	14	14	7

Conclusion

This survey clearly demonstrates that farmers surveyed in China were applying N, P and K much more frequently than those surveyed in India, and this is especially true for K. The reason for this is not better soil testing procedures in China, but probably the differences in cropping systems, location of the villages and, thus, the income that can be generated by the farmers. In India, it was demonstrated that the lack of irrigation facilities and the total dependence on erratic precipitation leads presumably to a lower socio-economic status, with less income generated and, thus, lower frequency of fertilizer application.

The two groups surveyed, farmers and dealers, felt positive towards extension workers. This provides an opportunity for empowering extension workers so that they can assist farmers' decisions: we also found that dealers, especially according to the survey in India, did not enjoy the appreciation of farmers as a source of agricultural information and, thus, cannot replace the role of extension workers.

There is a large variety of channels for disseminating agricultural information, and its ranking by farmers varies from location to location. However, we assume that attending workshops and meetings (with resourceful extension and/or private sector workers) is more appreciated by the farmers, in addition to mass media such as TV and radio.

In general, we found a large variation in the opinions of the farmers towards the questions we asked, both in India and China. We conclude that establishing a process in which the physical and societal conditions are assessed is vital for conducting a successful dissemination process of agricultural information.

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Stewardship of crop protection products: maximising benefits and minimising risks

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Introduction

The plant science industry, represented by CropLife International, actively promotes the responsible management of crop protection products, more commonly called pesticides, throughout their lifecycle. Lifecycle management, or stewardship, of crop protection products starts with research and development, and includes manufacture, transport and storage, through use and eventual disposal of wastes, including empty product containers and management of obsolete pesticide stocks. The overall aim of the stewardship approach is to maximise the benefits and minimise any risk from using crop protection products.

For ease of presentation, stewardship of crop protection products can be broken down into seven interrelated elements as illustrated in Figure 1.

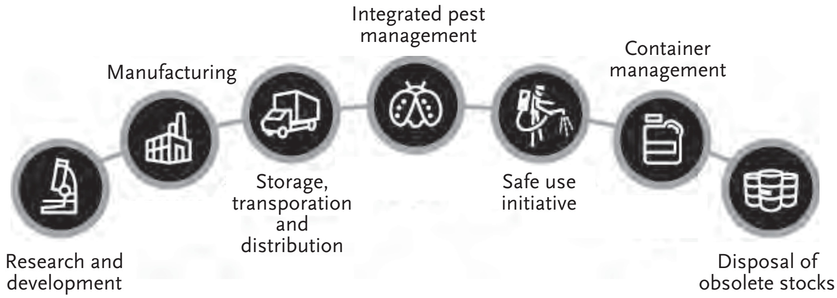

Figure 1. Elements of crop protection product stewardship.

Research and development

Discovering and developing new active ingredients that are biologically efficient, environmentally sound, user friendly and economically viable as well as improving the activity and safety of older products through improved formulation, packaging and delivery.

CropLife International's member companies[1] invest an average of 7.5% of annual sales in research into developing new crop protection products, or improving the activity or safety of existing products. Bringing a new product to the market costs some US$200 million and takes eight to nine years. The overall aim is to develop products that are biologically efficient, environmentally sound, user friendly and economically viable.

Advances in technology are therefore not only focusing on improved crop yields, but also on meeting the sustainable development objectives of the industry.

Manufacturing

Manufacturing products with due respect for people and the environment, through designing and operating processes sustainably and applying best available industry standards globally.

CropLife International's leading companies make significant investments to:

- improve energy efficiency,
- improve water efficiency,
- reduce waste,
- improve worker health and safety.

Companies report on these activities through various publicly available reports (e.g. CSR and environmental reports). Progress includes improvements in energy efficiency of between 11 and 37% and water efficiency of up to 40% since 1990.

As well as strictly adhering to international, national and local laws and regulations regarding manufacture, companies are also part of voluntary schemes, such as Responsible Care®, which sets guidelines for environmental, health and safety performance. Additionally, CropLife International's member companies set guidelines and requirements for manufacture of products that are outsourced to other companies.

Storage, transportation and distribution

Ensuring that products are stored, transported and distributed safely and appropriately through proper design of facilities, adherence to appropriate regulation and through training. This also includes marketing and sales, ensuring that products are promoted and sold responsibly through training and/or certification of retailers and facilities.

CropLife International's leading companies have supported the development of, and complied with regulatory regimes and standards established by international and national laws. Additionally, voluntary schemes are in place that promote proper and safe storage transport and distribution. For example, companies have introduced strict standards and training for planning and monitoring the transport of goods. The associations have also been involved in developing guidelines on warehousing and transport[2], especially directed at developing countries, which lay down effective and practical standards. Associations have also been involved in setting up schemes that regulate some of these activities, including registration of pesticide retailers in Egypt and certification of

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[1] CropLife International's member companies are BASF, Bayer CropScience, Dow AgroSciences, Dupont, FMC, Monsanto, Sumitomo and Syngenta. Additionally, CropLife International has regional member associations: CropLife America, CropLife Africa Middle East, CropLife Asia, European Crop protection Association, Japan Crop Protection Association, CropLife Latin America and CropLife Canada. Through these regional associations, CropLife is represented by national associations in 91 countries worldwide.

[2] These and other guidelines can be ordered or downloaded from the CropLife International website, www.croplife.org

warehouses in Canada. Finally, as part of the associations' 'safe use' training, globally, some 5,000 pesticide retailers are trained each year.

Integrated pest management

Development and promotion of integrated pest management (IPM)[3] strategies that incorporate a range of pest prevention and control strategies, including the responsible use of crop protection products. The plant science industry promotes IPM strategies as the optimal approach to pest control. All CropLife associations and companies provide training in IPM. All companies and selected associations are involved in developing IPM strategies, often in partnership with other groups. Research by companies aims to develop new products and tools that can be used within IPM strategies.

Associations are mainly involved in training in IPM principles. Thus, 99% of the more than 92,000 individuals trained by CropLife associations in 2003, received information on IPM principles. Surveys show that this training results in a significant increase in understanding of IPM. Additionally, training resources in IPM have been developed, including an on-line facility that is freely accessible (www.aglearn.net). Companies and associations report case studies showing the positive impact that IPM has on optimising pest management, improving yields and farmer incomes, or eliminating unnecessary use of crop protection products (Figure 2).

Figure 2. Guatemala: percentage of field technicians that knew of different pest control techniques used within IPM strategies.

Safe use initiative

The responsible and effective use of crop protection products, implemented through appropriate advice and training to all users. The plant science industry promotes the responsible and effective use of crop protection products within the context of IPM – if a product must be used it should be used properly and safely. Safe use training has been provided by companies and associations for many years, with the latter starting a coordinated initiative ('the Safe Use Initiative') in developing countries in 1991. Training is

[3] IPM, as defined in the FAO International Code of Conduct on the Distribution and Use of Pesticides is 'the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimise risks to human health and the environment. IPM emphasises the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms.'

provided to a range of stakeholders, including government officials, farmers and their families, pesticide retailers, school children and medical practitioners (Figure 3).

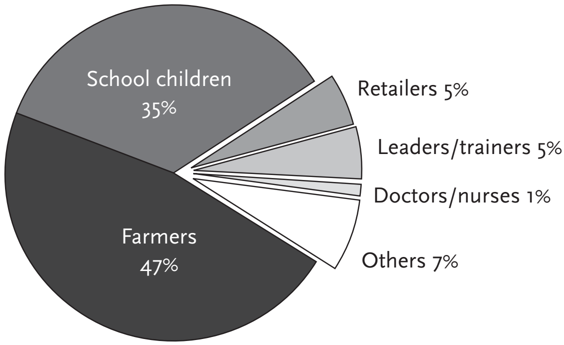

Figure 3. Global safe use training percentages - 2003.

Between 100,000 and 300,000 individuals are being trained each year through programmes supported by CropLife International. Since 1991, more than 3 million have been trained. Significantly, around 10% of those trained are retailers, extension agents or others that will train or advise further individuals, raising the total number of people reached each year to more than a million. Company training programmes also include hundreds of thousands of individuals each year. Training programmes are complemented by key safety messages broadcasts in various media; depending on the country, this may include television, radio, newspapers, magazines and wall posters.

Monitoring of these programmes has mainly relied on numbers of people trained, with a lesser emphasis on measuring an increase in knowledge. It is recognised that there needs to be an increased emphasis on measuring real changes in behaviour/impact; this has been done – and behavioural change showed – in some cases, for example reduced pesticide exposure by farmers demonstrated in Indonesia following training on responsible use of crop protection products. However, it is recognised that more needs to be done to improve impact and outreach.

Impact and outreach are also improved through appropriate partnerships, and a number of successful programmes have been developed between individual companies or associations with international and national organisations, NGOs and other stakeholders; these include the International Fund for Agricultural Development (IFAD) in Latin America, US EPA in Mexico, IFDC in West Africa, Agricultural Extension Service in Cambodia and the Vietnamese Ministry of Health.

CropLife International and its member associations and companies have produced a number of guidelines on the responsible handling and safe use of crop protection products that are freely available to all stakeholders (see CropLife International's website, www.croplife.org, or individual company or association websites).

Container management

The safe and sustainable management of used containers and packaging, including support of recycling/energy recovery and refillable programmes.

The plant science industry supports container management through research and design of containers and support of recycling programmes. Research has included the development of water-soluble bags, multi-trip, returnable containers and one-way single trip containers made of recyclable materials. Recycling programmes have been established with industry support in many regions, most notably Europe, Australia, North America and South America. These programmes promote proper rinsing of containers, their collection and recycling. Recycling includes re-use, but normally involves use of recyclate for other products, such as plastic fence posts, or energy recovery through incineration.

Recycling rates vary in different countries; in France, for example, it is currently 42.7% (equivalent to 3,200 tonnes of plastic per year), whilst in Brazil it is almost 87% (equivalent to over 13,000 tonnes of plastic per year); Costa Rica, 30.8%; USA, 19.8%; Belgium, 92% and Canada, 67%. The average rate of return for all 29 countries where there are established recycling programmes is 39.1%.

Where recycling programmes are not established, associations and companies promote proper rinsing, plus destruction of the container to make it unusable. Pilot recycling programmes are being developed in some countries. Approximately 50% of CropLife national associations reported (88% of the 56 that have responded) that they have a container management scheme in place, or that they are being developed or discussed.

Obsolete stocks

The safe removal and disposal of obsolete pesticide stocks as well as, through effective training and stock management, the prevention of build-up of new obsolete stocks.

CropLife International's leading companies are committed to working with other stakeholders to manage obsolete pesticide stocks – that is those products that are unfit for further use or reconditioning. It achieves this by providing expertise, and support to remove current obsolete stocks – this includes the possibility of paying for the destruction of stocks originally manufactured by the leading companies (most stocks originate from local companies that are not part of CropLife International). Additionally, through appropriate training to a range of stakeholders and good business practices (including stock management), the industry is helping to prevent future build-up of stocks.

In the last ten years, the industry has assisted in more than 25 disposal projects that have removed over 5,000 tonnes of, mainly government owned, obsolete products from developing countries, and has promoted initiatives that have resulted in the collection of over 5,000 tonnes of obsolete products from farmers in developed countries. Industry's continued commitment is demonstrated by its support for the Africa Stockpiles Programme (ASP), which will remove all obsolete stocks from the continent of Africa (www.africastockpiles.org).

FAO International Code of Conduct for the Distribution and Use of Pesticide

Stewardship underlies the FAO Code of Conduct for the Distribution and Use of Pesticides (www.fao.org/ag/AGP/AGPP/Pesticid/Default.htm). CropLife International and its member companies and associations fully support the Code, adherence to which is a condition of membership of the federation. The Code recognises, and is mainly aimed at, those countries where good regulation or enforcement regulations are not fully developed or in place. It is recognised that it is in these areas where the challenges of stewardship, and measuring true impact (i.e. changes in behaviour and practices) is greatest. The industry's stewardship programmes also recognise this challenge.

Improving impact and outreach of stewardship programmes

As part of its commitment to increase impact and outreach of its stewardship activities, the plant science industry has embarked on a process to improve measurement of the effectiveness of these programmes. The first step is to put in place appropriate performance indicators that will provide a baseline measurement of impact. This is currently being done, following consultation with a range of stakeholders. Once in place, the industry's programmes will be assessed and adjusted, as appropriate, so that they are better targeted and more effective. A consultation paper, a well as more details on CropLife's stewardship programmes, is available on the CropLife International website (www.croplife.org).

An economic evaluation of best management practices for crop nutrients in Canadian agriculture

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Producers realize there is usually some cost involved in adopting best management practices (BMPs), whether the BMPs take up valuable time or cost money for services such as soil testing. In many cases, however, there are offsetting economic benefits. An evaluation of the costs and benefits of BMPs should start with the premise that producers are making decisions they expect will maximize their profits. The federal government has recognized that there are net costs to producers by continuing to review the need for incentives to adopt and/or maintain certain BMPs. Producers need to have a good understanding of the costs and benefits of BMPs when deciding to adopt or continue using them. The purpose of this project was to determine what the economic benefit would need to be to encourage agricultural producers to participate in BMPs, specifically those related to crop nutrients.

Phase I: literature review

The purpose of the literature review was to develop a solid understanding of existing research regarding the economics and adoption of crop nutrient BMPs. The literature review focused largely on research from Canada and the United States. In the literature, a number of factors were analyzed that could influence a producer's decision to adopt BMPs. Characteristics of farms and farm operators that appeared to influence adoption were education level, farm size, level of gross sales and whether or not the producer earned off-farm income. Higher levels of education, larger farms, farms with higher levels of gross sales, and producers who earned off-farm income were generally more likely to adopt BMPs. However, these findings were not necessarily consistent across all literature reviewed as some studies did not find significant relationships among these variables.

In assessing why some of these factors were found to influence BMP adoption, Fulgie (1999) suggested that education increased a producer's ability to learn and adapt new technologies to farm operations. Fulgie (1999) and Deloitte and Touche (1992) also suggested that producers with off-farm income were more likely to use reduced tillage systems because of a higher opportunity cost of labour. Larger farms and farms with higher gross sales were more likely to use BMPs because they generally had more financial resources.

With regards to programs in place that encourage the use of BMPs, producer participants in focus groups conducted by Agnew and Filson (2004) mentioned that participation could be improved if there was greater involvement of farm organizations and producers in the design of BMP programs, programs were clear and straightforward, and there was sufficient financial compensation offered. Producers also stated that, in the absence of financial incentives, they would use BMPs if they were cost effective for their farming operation.

In addition, the literature review presented information on adoption levels of BMPs for Canada, and data suggested that familiarity with BMPs was lacking in certain provinces. This finding suggests that simply increasing awareness of BMPs may improve adoption levels in these provinces. In other provinces addressing the lack of research conducted pertaining to the economics of BMPs may help increase adoption. Canadian data sources suggested that certain BMPs are more commonly used in the different agricultural regions of Canada. Environmentally sustainable fertilizer application methods such as banding and injecting appear more common in the Prairie provinces. Reduced tillage practices, especially no-till are gaining widespread acceptance not only in the Prairie provinces, but also in Ontario and Newfoundland. Quebec and Ontario were the provinces most likely to adjust fertilizer applications to account for nitrogen from previous crops and the nitrogen content of manure. These two provinces also had the highest percentages of farms that indicated they had formal nutrient management plans and environmental farm plans.

Also reviewed in the literature were Canadian incentive programs available for the adoption of BMPs. The specific programs included the National Farm Stewardship Program, the Federal-Provincial Environmental Farm Plan Program, the National Water Supply Expansion Program, the Greencover Canada program and assistance programs available for the adoption of manure application BMPs. Payments varied across provinces and programs, but most incentives for BMPs are offered on a cost-share basis with funding caps. The most expensive program offering funding for BMPs was the National Farm Stewardship Program.

Phase 2: economic modelling

The purpose of this phase of the work was to estimate farm profitability before and after participation in crop nutrient BMPs using representative farm models for Alberta, Saskatchewan, Manitoba, Ontario, Quebec and Prince Edward Island. The models were developed to represent typical crop rotations in each of the provinces, in order to evaluate BMPs by crop rotation, by province.

A national survey of producers was used to obtain the data required to estimate the economic costs and benefits of participation in BMPs. The George Morris Centre worked closely with Ipsos Reid, a market research company, to identify statistically representative sample sizes and to design questions that would provide the necessary data for this component of the research. The BMPs selected for evaluation in the survey were based on the findings in the literature review and included: soil testing, variable rate fertilization, manure management planning, buffer strips, no-till, minimum till and nutrient management planning.

Insufficient survey data was collected for manure management planning to conduct a complete economic analysis; however, the results obtained from the survey were included as a qualitative assessment for western and central Canada, with specific reference to provinces where appropriate. According to the survey results, the percentage of farmers applying manure is lower in western Canada than in eastern Canada.

Western Canadian producers have been using manure on their farms since the land was first settled. Of the western farmers surveyed by Ipsos Reid, 53% apply manure on their farms (Alberta 64%; Saskatchewan 43%; Manitoba 65%). For producers who use manure (from the survey), approximately 18% of their acres were treated with manure (Alberta 22%; Saskatchewan 15%; Manitoba 22%). Surprisingly, however, only 27% of the producers who apply manure use a formal manure management plan (Alberta 34%; Saskatchewan 22%; Manitoba 30%). Approximately half of the producers who use manure in the Prairies use a custom operator to apply manure on their behalf (Alberta 55%; Saskatchewan 42%; Manitoba 41%).

Of the farmers in central Canada surveyed by Ipsos Reid, 76% apply manure on their farms (Ontario 75%; Quebec 78%). For producers who use manure (from the survey), approximately 45% of their acres were treated with manure (Ontario 42%, Quebec 49%), more than double that in western Canada. In Quebec, 90% of producers who used manure followed a formal manure management plan. In Ontario, only 35% of the respondents who used manure indicated that they used a formal manure management plan. Of those who apply manure, 83% self apply (Ontario 92%; Quebec 65%) rather than hire a custom operator.

A total of 39 models were developed (eight base models of representative farms prior to the implementation of BMPs and 31 iterations of the models after the implementation of BMPs). The farm models were developed using 2006 crop enterprise budgets obtained from the respective provincial governments[1]. The enterprise budgets provided an estimate for revenue, variable costs, fixed costs[2] and expected net revenue for individual crops on a per acre basis. The enterprise budgets were based on average cost and return estimates (e.g. average provincial crop yields, and average farm prices for a specific crop).

The models were also run with the estimated financial assistance available from federal and provincial programs in Canada. Financial assistance was determined to be available for all of the BMPs evaluated, with the exception of soil testing. Note that financial assistance for the development of a nutrient management plan does include

[1] Provinces where enterprise data was unavailable or outdated were left out of the analysis (enterprise data is a serious research gap in the Atlantic provinces and British Columbia). Crop enterprise budgets for Ontario were obtained from the Ontario Ministry of Agriculture, Food and Rural Affairs. Crop enterprise budgets for Quebec were obtained from the Ministère de l'Agriculture, des Pêcheries et de l'Alimentation (MAPAQ). Crop enterprise budgets for the Prairie provinces were obtained from Alberta Agriculture, Food and Rural Development, Saskatchewan Agriculture and Food, and Manitoba Agriculture, Food and Rural Initiatives. Crop enterprise budgets for PEI were obtained from Prince Edward Island Agriculture, Fisheries and Aquaculture and updated by Meyers Norris Penny.

[2] Although fixed costs do not change with changes in acreage, overall fixed costs, including depreciation, must be covered to maintain long-term profitability.

the cost of soil testing. However, for the purpose of this analysis, no financial assistance was incorporated in the soil testing BMP models.

Representative farm models were developed based on specific crop rotations and by using the per acre profitability estimates for the individual crops. The models for central Canada assumed an even distribution of crops across the farm while the models for western Canada were based on typical crop rotations. Because the crop enterprise budgets were based on per acre data, the representative farms were given an assumed size. The size of each representative farm was based on the mean farm size from the survey for each of the provinces.

The results of the model analysis suggested that soil testing, nutrient management planning, minimum tillage and no tillage were the top-performing BMPs. These practices generally produced increased yields that offset any increases in operating costs. Producers using minimum tillage and no tillage identified fewer increases in yields, although these BMPs typically showed improvements in expected net revenue (ENR) due to reductions in operating costs despite equipment costs (annualized over a 10 year period).

In general, variable rate fertilization and buffer strips were not as profitable. Typically, these practices reduced profitability because of increased costs. In all cases, buffer strips reduced ENR due to the higher costs for the establishment of the buffers and the lost crop production in the area of the buffer.

The following tables present the whole farm results for all provinces evaluated. What is shown in the tables is the percent change of ENR over the base model when the various BMPs are implemented. Table 1 illustrates the results without financial assistance.

Table 1. Provincial whole farm results: change in ENR from base model with BMPs, without financial assistance.

	Soil testing	VRF	Min-till	No-till	NMP	Buffers
Alberta - black		53%			78%	-10%
Alberta - brown	19%		34%		33%	
Sask - black	24%	25%			38%	
Sask - brown	15%		17%		30%	
Manitoba	12%	-7%	12%	12%	20%	-1%
Ontario	59%	-9%	23%	23%	42%	-3%
Quebec	1%	-6%	12%	8%	13%	-2%
PEI						-0.6%

ENR – expected net revenue
VRF – variable rate fertilization
Min-till – minimum tillage
No-till – no tillage
NMP – nutrient management planning
Sask – Saskatchewan
PEI – Prince Edwards Island
NB: The crop rotations are different accross the provinces

In all cases, the inclusion of financial assistance resulted in greater ENR than the models without financial assistance. However, the magnitude of improvement depended highly on the cost share percentages of available funding and the number of years over which the funding was amortized. In the case of buffer strips, with an assumed life of 10 years, the funding in all provinces evaluated was not sufficient to generate a positive change in ENR over the base model when financial assistance was included. This may suggest that funding for buffer strips under Canadian programs is not sufficient, given the assumptions in the representative models.

Variable rate fertilization was another BMP that demonstrated negative changes in ENR when compared to the base model for many of the provinces. However, producers in Ontario and Quebec indicated that they used custom application services which are ineligible for financial assistance. For the Saskatchewan and Alberta black soil models, the change in ENR for variable rate fertilization improved, although it was positive to begin with. Finally, in Manitoba, the financial assistance for variable rate fertilization was not sufficient enough to improve the change in ENR to the point where it was no longer negative. In Manitoba, variable rate fertilization was also the only BMP in which the program payment reached the maximum funding limit based on the estimated costs from the producer survey. Table 2 illustrates the results with financial assistance.

Table 2. Provincial whole farm results: change in ENR from base model with BMPs, with financial assistance.

	Soil testing	VRF	Min-till	No-till	NMP	Buffers
Alberta - black		57%			79%	-8%
Alberta - brown	19%		35%		33%	
Sask - black	24%	28%			39%	
Sask - brown	15%		20%		31%	
Manitoba	12%	-3%	12%	13%	20%	-1%
Ontario	59%	-9%	26%	27%	44%	-2%
Quebec	1%	-6%	13%	9%	14%	-1%
PEI						-0.5%

At the individual crop level, spring wheat in western Canada and Quebec and winter wheat in Ontario were the crops that were most responsive to the introduction of crop nutrient BMPs, showing an increase in ENR for all BMPs analyzed (with the exception of buffers in all provinces and variable rate fertilization in Manitoba) regardless of the province. The results at the individual crop level were the same with the inclusion of financial assistance.

Assessment of incentives for best management practices

Although the producers in the survey did not generally access financial assistance (1-7% of the respondents received financial incentives depending on the BMPs adopted), this study determined that funding was available for all BMPs (with the exception of soil testing[3]). The following list from the National Farm Stewardship program and Greencover program recaps the relevant categories of funding, the cost share amount and maximum available for the BMP. Individual provinces may provide 'top-ups' in addition to the national funding, as detailed below (AAFC 2005 and AAFC 2006).

- Manure land application - Includes 30% cost share to a maximum of $10,000.
- Product and waste management - Includes 30% cost share for product and waste management to a maximum of $15,000.
- Riparian area management - Includes 50% cost share for establishing buffer strips to a maximum of $20,000.
- Land management for soils at risk - Includes 50% cost share for establishing forage or annual barrier to a maximum of $5,000. Top-ups are available in BC (funding provided by Ducks Unlimited Canada). Provincial top-ups are also available in PEI.
- Improved cropping systems - Includes 30% cost share for improved cropping systems (including equipment modifications and variable rate fertilization) to a maximum of $15,000. [4]
- Shelterbelt establishment - Includes 50% cost share for shelter belt establishment (similar to buffer strips) to a maximum of $10,000. Provincial top-ups are available in Quebec and PEI.
- Enhancing wildlife habitat and biodiversity - Includes 50% cost share for buffer strip establishment to a maximum of $10,000. Top-ups are available in BC (funding provided by Ducks Unlimited Canada).
- Species at risk - Includes 50% cost share for plant species establishment to a maximum of $10,000. Top-ups are available in BC (funding provided by Ducks Unlimited Canada).
- Preventing wildlife damage - Includes 30% cost share for forage buffer strips to a maximum of $10,000. Top-ups are available in BC (funding provided by Ducks Unlimited Canada).
- Nutrient management planning - Includes 50% cost share for consultant fees to establish a nutrient management plan and for planning and decision tools to a maximum of $4,000 (including costs for soil sampling and analysis). Provincial top-ups are available in Manitoba.

It is worth noting that funding for certain BMPs (e.g. buffer strips) is available through several categories of the National Farm Stewardship Program and Greencover program. Therefore, program administrators and producers can select various categories from which funding can be accessed.

[3] Financial assistance can be obtained for soil testing with the development of a nutrient management plan.

[4] Category 14 provides cost share on the specialized components of conservation equipment. Therefore, in some cases, the cost share may not apply to the entire implement, but only to the specialized components. However, for GPS, the 30% cost share can be applied on the entire unit, up to the category cap of $15,000.

Conclusion

Producers have lacked information on the economic viability of BMPs. The goal of this study was to provide a framework for producers to assess the benefits and costs of BMPs for their farm operations. It is important to note that changes in farm profitability due to the adoption of BMPs for individuals farms may vary from the results of this study. This is because the research is based on producer perceptions, representative farm models that are based on industry averages, and additional assumptions for modelling purposes. Therefore, individual producers may experience different effects on farm profitability from the adoption of BMPs due to factors such as the site-specific nature of their property (resulting in varying yield changes from BMPs), as well as revenues and expenses which are different from those used in provincial enterprise budgets (due to different management styles).

Based on producer perceptions and the assumptions used in this analysis, the results of this study indicated that the majority of the selected BMPs, including soil testing, minimum tillage, no tillage and nutrient management planning, improved profitability for the representative farms. The profitability of farms using variable rate fertilization depended on the crop grown and the province in which the BMP was practiced. In all cases, the models suggested that buffer strips reduced ENR. Although many of the BMPs evaluated in this study were found to be profitable, these results are not meant to suggest that financial assistance programs are not required. As stated above, results will vary, thereby impacting profitability and the need for financial assistance.

Another goal of this research was to assess the incentives currently available for producers to adopt BMPs. The study found that funding was available for all the BMPs evaluated except soil testing (unless obtained through the development of a nutrient management planning). Despite this, respondents in the Ipsos Reid survey indicated that they were not taking advantage of the funding programs. Only 1-7% of the respondents received financial incentives depending on the BMPs adopted on their farms. The National Farm Stewardship Program administrators were contacted to understand current uptake levels in the national program. As of September 30, 2006, approximately 6,000 producers had applied and received funding for 9,623 BMPs (Snell, 2006). This represents 3% of all Canadian producers (6,000 of approximately 200,000 producers). For this reason, it would seem that there are additional barriers to adoption that need to be addressed.

The results of the survey suggested that the greatest barriers to adoption were cost and not understanding the need for the BMP. One observation made while doing this analysis was that many producers did not recognize that the BMP could have an economic net gain for their farm. While financial assistance deals with the cost barrier, not understanding the need for the BMP or recognizing the economic viability of the practice implies that future work needs to include communication and education regarding the environmental and economic benefits of the BMPs.

Transition costs, real or perceived, may also be barriers preventing further adoption by producers. The capital costs (e.g. equipment) required for no-tillage and variable rate fertilization may prevent producers from establishing these practices. Transition costs may also include costs dedicated to learning about BMPs (e.g. time, education) and perceived risks of adopting new practices versus continuing reliable methods. There may also be transition costs involved in accessing financial assistance for BMPs such as costs of paperwork and meeting program requirements (e.g. completion of Environmental Farm Plan). Overall, transition costs may hinder producers from adopting BMPs despite the economics of the practices after adoption is established.

According to the survey, the following types of resources would assist producers in adopting and using best management practices:

- written material on how to adopt/implement the practice,
- workshops or seminars,
- more financial assistance,
- agricultural extension assistance,
- more information.

One final conclusion that can be drawn from this research is that at least some types of BMPs (e.g. variable rate fertilization and buffer strips) were not affordable to many farms without incentives, regardless of the environmental benefits gained from the practice. Even though some incentive programs already exist to address these low profit BMPs, it is key that governments ensure that:

- producers are aware of the programs;
- there is sufficient compensation from the programs; and
- the application processes are simple (as found in the literature review).

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Fertilizer best management practices in South America's agricultural systems

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Introduction

South America has a great diversity of agricultural systems. To date no government of any country has endorsed or forced on the farming sector a multidisciplinary system that involves a set of practices that guarantees profitability and/or a neutral environmental impact.

The following is a summary of the current situation regarding fertilizer nutrient use in the major agricultural systems of most South American countries, with particular reference to the commercial production sectors of Brazil and Argentina (FAO, 2003, 2004).

Status of crop production and output target

In general, the agriculture of the region may be divided into two categories:

- An export-oriented commercial sector that aims for maximum economic yields. However, the Mercosur soybean – corn based systems have little in common with the fruit and vegetable systems of the Andean countries, regarding the use of fertilizer nutrients, although both are export-oriented. There are some systems that are a mixture of these two categories - the following discussion concerns the predominant systems.
- Subsistence farming is very common in all South American countries. Due to inequality in the distribution of wealth, there are areas with considerable poverty. A common feature shared by all the countries is that a large number of tenant farmers account for a small proportion of the agricultural land (Figure 1). As regards nutrient management, a common factor of this small-holder sector is, in general, the absence of the use of any fertilizer, apart from manures and/or organic wastes.

Although none of the governments of the region enforce any particular practice concerning the use of nutrients, in many countries and regions within the countries, there are several examples of ecologically-oriented agriculture, which involve control over farm practices through certifying organizations. The period of time over which much land in South America has been cultivated is relatively short. In consequence, in many areas, the nutrient content of soils is high enough for the application fertilizers not to be necessary. The relative absence of pressure from pests and diseases in these relatively unspoiled environments permits an efficient organic agriculture. A large proportion of these organically grown products is exported to Europe and North America.

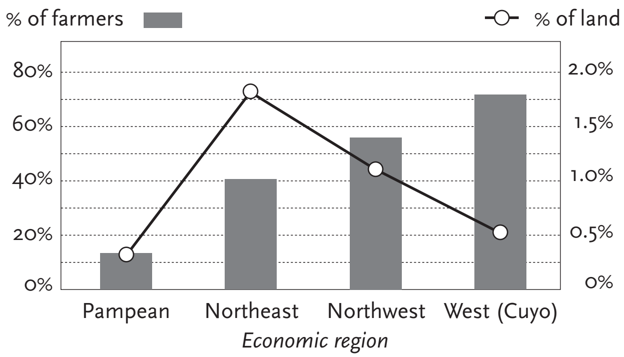


Figure 1. Proportion of smallholders and share of the total agriculture land in the four agro-economic regions of Argentina. The smallholder class comprises farmers who own less than 25 hectares.

The organic farming systems are strictly monitored in accordance with the principles of the International Federation of Organic Agriculture Movements (IFOAM) and related organizations. They can be said to prescribe the fertilizer best management practices (FBMPs) practices that have to be followed.

The most notable characteristic of this mega region is the importance of agriculture in the national economy. The importance of the agricultural sector to the national economy can be measured either in terms of its contribution to the gross domestic product (GDP) or by the proportion of the population employed in agriculture, when compared with other countries with an important agricultural sector (Table 1).

Table 1. Proportion of GDP and employment accounted for by the agricultural sectors of two groups of countries (CIA, 2007).

South America	Ag GDP (%)	Ag labor force (%)	OECD countries	Ag GDP (%)	Ag labor force (%)
Venezuela	3.7	13	Australia	3.8	3.6
Mexico	3.9	18	Canada	2.3	2
Chile	5.9	13.6	France	2.2	4.1
Brazil	8.0	20	Greece	5.1	12
Uruguay	9.3	14	Israel	2.6	1.8
Argentina	9.5	22	Russia	5.3	10.8
Colombia	12.0	22.7	South Africa	2.6	30
Paraguay	22.4	45	USA	0.9	0.7
Average	*9.3*	*21*	*Average*	*3.1*	*8.1*

In addition, many countries are among the world's top producers or exporters of cereals and oil crops (Brazil and Argentina), fruits (Chile), flowers (Colombia, Ecuador), vegetables (Mexico, Costa Rica) or industrial products such as coffee or cotton (Brazil). The production of these crops is usually highly integrated with agribusiness chains.

The importance of agriculture is overwhelming in many rural regions, even if this is not well reflected in the statistics. Vast sectors of the economy of small towns or villages that are not involved directly in agriculture could not exist without it.

Nutrient management, recycling and budgets

South American countries rarely offer agricultural subsidies such as those accorded in many OECD countries. In most cases, fertilizer use is determined more by economic considerations. In this context, commercial sector farmers naturally aim for maximum economic yield and try to avoid the misuse and excessive use of fertilizers.

One exception as regards subsidies is Chile that reimburses farmers for expenditure on liming and on fertilizer use in certain cases that fall within the «Green Box» framework, i.e. agricultural support measures that do not distort trade.

However, nutrient imbalances do occur due either to excessive or to inadequate application of certain nutrients or, most commonly, due to the insufficient restitution of nutrients or low fertilizer rates. The absence or low application of P was very common for many years in Argentina, partly due to an unfavorable price ratio between P fertilizer and grain. This situation lasted for many years and ultimately resulted in serious imbalances as nutrients removed in the exported grain were not replaced (Figure 2). This situation is changing, with a steady trend towards increasing N and P rates, as a result of successful educational programs.

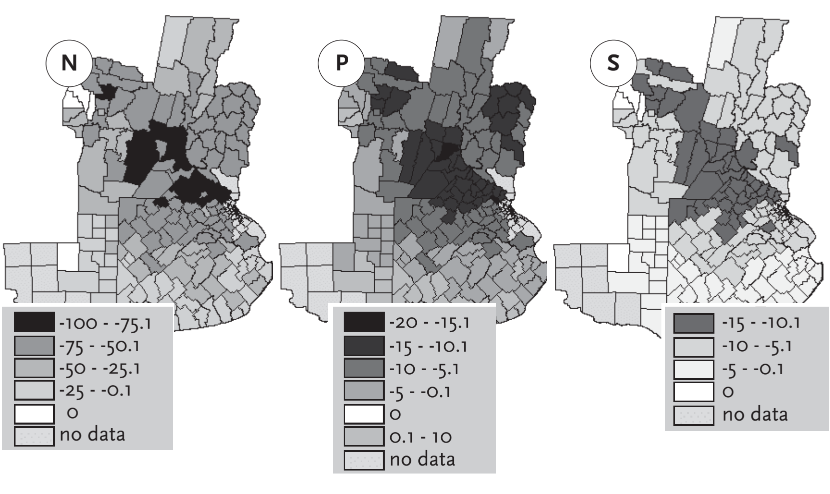


Figure 2. Estimated balances of nitrogen (N), phosphorus (P) and sulfur (S) in Pampean region counties. The balances were estimated as the difference between removal in grain and fertilizer application in soybean, wheat, corn and sunflower (Garcia, 2006).

The over-application of K sometimes occurs where blanket recommendations for K fertilization are implemented. For example, tropical weathered soils in Brazil require high applications of K fertilizers, usually in NPK blends. Good management and recycling of cover crops improves the retention of K in the plant and soil system, reducing the need for the application of K in the fertilization program. If this is not taken into account, there is an over-application of K relative to the quantities removed in the harvested crop.

The over-application of N with an adverse effect on the environment is rare, but it sometimes occurs. It can occur, for example, in areas around cities where vegetable farms are concentrated. The production systems are intensive and a negative environmental impact may occur due to excessive fertilizer use, mainly of N.

South America's farmers seldom recycle nutrients in their agriculture wastes. In the agribusiness chain, there is little coordination between the production of organic wastes, originating from livestock or crops, and their application on field crops. Producers recycle only a small proportion of manures and/or of treated organic wastes of urban origin.

In Argentina, according to a national agricultural survey (INDEC, 2003), in the four major corn provinces, only 0.5% of the area with corn received organic manures, the highest rate of application being Entre Ríos with application on 2.4% of the area. Approximately 15% of US farmers apply different organic manures in conjunction with commercial fertilizers. The proportion reaches up to 30% of the farms in the Lake States region, where there is a more intensive use of manures from dairy farms.

On the other hand, South American farmers are more efficient in their use of mineral N fertilizers than farmers in the United States or the European Union. A large proportion of farmers match demand with supply. Table 2 compares the proportion of farmers in the United States and in Argentina employing practices that influence N use efficiency. Probably due partly to cropping practices, N rates are lower and partial N efficiency is higher in Argentina and Brazil than in certain other cereal producing countries (Table 3).

Table 2. A comparison of N application practices between farmers of Argentina and of the United States in the core states of each country (Christiansen, 2002; Fertilizar 2002-2006).

Nitrogen application practice		USA	Argentina
		% farmers	
Timing	Proportion before planting	41	9
Method	Side dressing, broadcast	60	33
N balance	Negative	21	85

Table 3. Partial factor productivity of N in representative corn growing production areas of major corn exporting countries (Melgar, 2006).

	Corn exports	Average yield in representative states/provinces	Average N rate in representative states/provinces	Partial factor productivity
	million t/yr	t/ha	kg N/ha	kg grain/kg N
USA	46.45	9.15	157.0	58.4
Argentina	10.65	7.16	58.1	123.4
Brazil	2.17	4.88	48.0	101.7
China	7.81	5.04	197.9	26.1
France	7.54	8.29	163.3	50.8

There are large differences between the two groups concerning the adoption of precision agriculture technologies, especially regarding the adoption of variable application techniques. However, this situation may change fairly quickly since the transfer of technology is rapid with globalization and associated advances such as speed information exchange and cost contraction as technological breakthroughs are increasingly adopted. Among the factors that will favor the adoption of precision agriculture by local farmers are:

- Producers cultivate large tracts of land, with a relatively high capital/worker ratio;
- A high level of education of large farmers and of crop consultants;
- Availability of technology from North America and Europe, plus local developments;
- Large farmers must rely on more information;
- Ease of sharing data, analyzing problems and searching solutions through farmer groups.

On the other hand, some factors that could delay the adoption of these techniques are:

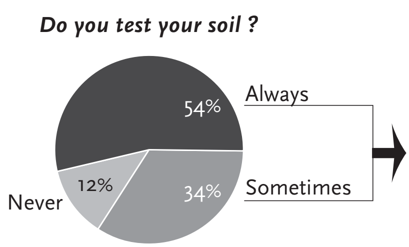
- The higher cost of investment in hardware and software, and the lack of credit;
- Greater production risks due to sudden changes in the tax structure, insurance, etc.;
- A lower soil variability as a result of the shorter period of agricultural practices compared with the northern hemisphere and, thus, a lower accumulated effect of the use of fertilizer or amendments;
- A generalized use of harvest contractors, which can make it difficult to collect quality data.

Fertilizer recommendations

Along with the major advances in the agricultural sectors of South America since the 1960s, most countries developed national institutions for agricultural research. These institutes covered most aspects of crop production and soil fertility management, and relevant information was accumulated systematically over time. Blanket fertilizer recommendations were generated for almost all crops and systems while, at the same time, field trials provided data on which fertilizer recommendations could be based. The extent and dissemination of this information varied between the countries.

The soil types are responsible for large differences in fertilizer practices in tropical regions. This is well illustrated in the cases of Argentina and Brazil. In Brazil, development was not possible without previous liming and generous P and K fertilization. In Argentina, Chile and Uruguay to some extent, the widespread use of fertilizers was delayed until well into the 1980s. Fertilization was a pre-condition for agricultural development in many countries with tropical soils, and this led to major progress in the management of fertilizers.

Today, most systems make an extensive use of soil testing as a tool for making site-specific fertilizer recommendations. A recent survey, conducted among 800 farmers in the main producing provinces of Argentina, revealed that soil test results guide fertilizer use in half of the area sown with corn or wheat, and in 20 % of the soybean areas. Figure 3 shows the overall results in terms of use, timing and frequency (Fertilizar, 1999-2006).



When do you make soil test ?	
Before sowing	68%
Next to fertilization	28%
Other moments	4%

With what frequency do you make it ?	
Once a year	59%
Once every two years	35%
Others	6%

Base: farmers answering always and sometimes

Figure 3. Use of soil tests as primary tool for fertilizer assessment by Argentina's Pampean farmers. Survey of 800 respondents in the core grain producing regions (Fertilizar, 2006).

With a few exceptions, farmers in all the countries and in the regions within each country have access to public or private soil testing services. Education is the main limiting factor preventing the better use of this technology and deriving greater benefits from soil testing in making fertilizer recommendations.

Brazil has a network for monitoring the quality of soil testing throughout the country. At present, there are five quality programs for soil analysis in Brazil (Bernardi and Silva, 2001). Embrapa coordinates the "Analysis Quality of Laboratories of the Soil Fertility Program" - PAQLF. This program was established in 1992. The participation of the laboratories is voluntary. Nationwide, more than 80 soil fertility laboratories in 23 Brazilian states participate in the program. Initially, the objective of PAQLF was to permit evaluation and correction of the analytical quality of the participating laboratories. In 1998, with the adoption of more rigorous quality standards, the program also provided certification of the satisfactory performance of the participants, which could be presented to their customers. However, there are no programs of this type in the other countries of the region, where there are serious discrepancies between the soil tests and technologies used in the different laboratories.

There are substantial differences between Brazil and Argentina, for example, regarding the criteria for interpreting soil tests and making fertilizer recommendations. Due to the major soil types that are characteristic of each country, in Brazil, the predominant criterion is cationic saturation while, in Argentina, nutrient sufficiency is the predominant criterion for farmers and consultants. Environmental differences also result in large differences in the need for liming. The Mollisols and Alfisols are much more resilient to changes in soil fertility parameters due to misuse of fertilizers or imbalances than are Ultisols and Oxisols.

Fertilizer availability

Fertilizer availability is not an important limitation for South American commercial farming. However, availability and choice is often inversely related to the distance from sea ports. An inadequate road and warehouse infrastructure may make fertilizers temporarily unavailable if the requirements were not anticipated adequately.

Traditions also influence market constraints. For example, K is often poorly available for non-Pampean crops of Argentina, and fluid fertilizers such as urea ammonium nitrate (UAN) are not a common fertilizer source in Brazil. The market development of blends for many crops is much greater in Brazil than in Argentina, where the use of single product fertilizers has been historically higher.

Fertilizer use

Most countries of the region show a trend towards improvements in the balance between nutrients applied and removed, although there is considerable variation between countries. While, for example, Brazil and Chile have a longer history of fertilization and therefore, a lower imbalance, in Argentina or Bolivia, there is a large gap between the removal and the replenishment of nutrients.

One factor that is indirectly helping to improve nutrient balances is the strong adoption of the "no-till" system in most field crop production systems of the region. Figure 4 shows the development of this system in Brazil, but the same exponential pattern can be observed elsewhere. No-till systems stress the need for better N use efficiency and proper P and K placement. In turn, this results in more stable production due to a better soil-water relationship and, hence, higher yields and nutrient requirements.

Nutrient balances show a rather positive trend in spite of economic constraints. In fact, for some time, the nutrient balance in Brazil has been positive for all nutrients except N (Yamada and Lopes, 1998). Recent estimates indicate positive balances even for N (Yamada, personal communication). The better knowledge of farmers and professional consultants provide responses to many of the economic pressures placed on modern agriculture (Figure 5).

As yet, little consumer concern about agricultural products has been observed, except perhaps from large urban groups. The demand for higher quality vegetables and fruits is, however, growing as a result of awareness about nutrition and quality. In consequence, the variety and quality of fruits and vegetables offered to consumer on the markets of large cities, with their high purchasing power, are much greater compared with small villages or towns.

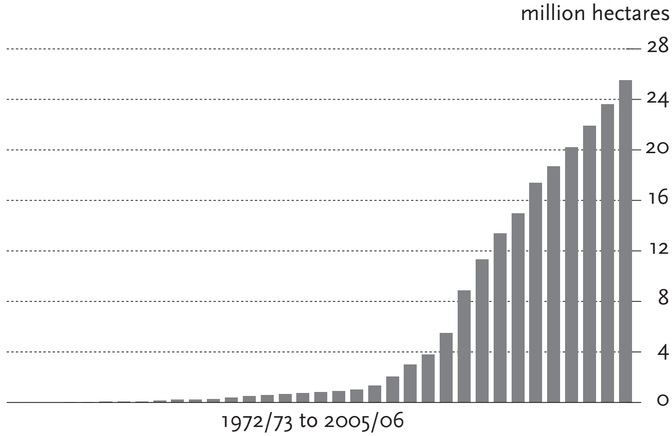


Figure 4. Development of no-till agriculture in Brazil (FEBRADPD, 2007).

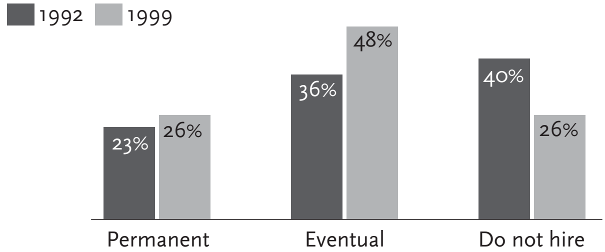


Figure 5. Changes in the frequency of consultation of professional advisory services by Argentinean farmers (White, 2000).

Fertilizer advisory services

National agricultural research institutes were established in South American countries around the end of the 1950s and during the 1960s, with basic and applied research, plus an extension service covering many fields of agronomic science and technology. The institutes included several experimental stations and extension agencies in the different areas of the countries.

These institutes are the main agencies of technology transfer, in the fields of soil management, soil fertility and fertilizer application. Over time, many of these pioneer public institutions were accompanied by private institutions and NGOs. Farmer organizations in Argentina (AAPRESID, AACREA), foundations in Brazil (MT, Agroceres) were major players in transmitting information. In addition, several agricultural universities, although not playing a central role in extension as is the case with the land-grant system in the United States, provide soil testing services to farmers along with recommendations, in most countries of the region.

A special mention needs to be made of industry organizations such as Fertilizar in Argentina and ANDA in Brazil (Asociación Civil Fertilizar, 2007; Associação Nacional para Difusão de Adubos, 2007). Both originated as a result of a demand and were mandated with the transfer of information to farmers on the best use of fertilizers and liming. They received immediate support from public and governmental sectors in order to offset the indiscriminate exploitation of soil nutrients resulting from the large removal of plant nutrients exported with grains, not compensated with their restitution.

After 40 years of activity, having achieved unqualified success in its original mission, ANDA is targeting other, equally important activities. Its main objectives are now to diffuse information on the correct use of mineral fertilizers and to safeguard the image of the fertilizer products and the industry. The Association is the official fertilizer sector representative in dealings with authorities, with a focus on:

- Defending the sector's interests in the development of legislation governing the production, commercialization and use of fertilizers;
- Assisting in the development of policies and regulations concerning mineral fertilizer producers.

Recently a new fertilizer association was formed in Colombia, with the same mission as the industry associations in other countries (Asociación Colombiana de Fertilizantes, 2007).

Legislation

Regulatory norms concerning fertilizers are currently being considered, especially in the framework of Mercosur or the Andean Community.

Unlike the situation in certain other countries, in view of the free enterprise nature of the business, governments do not intervene on price issues. Farmers are free to use whatever fertilizers wish, regardless of the environmental and quality impact.

However, governmental agencies control the quality of imported products. This may impact favorably on the environment by controlling contaminants in fertilizers (Gov. Brazil, 2006), but there is no regulatory intervention on the use of fertilizers in any country.

Conclusion

In the context of a professional agriculture without subsidies, economic rationality helps to prevent the misuse of fertilizer, but ignorance or unfavorable/favorable price ratios of grain to fertilizer can lead to serious imbalances, threatening the sustainability of agriculture.

The issue of FBMPs developed with the consensus of all the stakeholders and adequately promoted could be adopted easily by the farming sector in South American countries, providing the practices are economically sound and the goal of attaining higher yields is not jeopardized.

Environmental awareness is certainly a topical subject. However, a major ecological impact of agriculture does not come from the misuse of fertilizers but rather from deforestation, erosion and inadequate soil conservation.

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Voluntary farm management qualification under the French official "Agriculture Raisonnée" scheme

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France has the largest agricultural economy of all the countries of the European Union, accounting for more than 20% of the gross value in most sectors (cereals, milk, meat, wines …). Agricultural land occupies more than half the territory of France. 550,000 farms, of which 350,000 are professional enterprises, specialize their production according to the agro-potential of soils and climate in the different regions.

Less than 3% of the active population is directly employed in the agricultural sector but, if the agro-industry and related activities are added, more than 6% of the population makes a living from agricultural products. During the past 50 years, French society has adopted a much more urban way of life, but it is still very much concerned about agriculture and its environmental impact on water quality and water resources, landscape, grassland, biodiversity, etc.

"Agriculture Raisonnée"

"Agriculture Raisonnée" (AR) is an official French programme. In 1993, French farmers created the "FARRE" association, with the objective of promoting the integrated farm management (IFM) concept. It was based on self-assessment. It was created at a time when the Ministry of Agriculture wished to promote environmentally friendly practices, prepare French farmers for the application of EU directives and improve the sustainability of the farming systems.

In 2002, after some years of intense debate, a national scheme was adopted to replace the original "Agriculture Raisonnée" scheme. Instead of the self-assessment principle of the original scheme, the new scheme involves 98 measures, which are mandatory and applicable to all types of farm. The text has come into force and a national committee created (CNAR), responsible for establishing an independent auditing process and for improving the content of the scheme, with additional mandatory measures.

The first farmers who volunteered for qualification under this AR scheme received the visit of independent auditors at the end of 2004. By the end of 2006, more than 2,000 farmers had received the AR qualification. They are allowed to state on the food label of their products the mention "Produced on an Agriculture Raisonnée qualified farm".

A whole farm approach

The adjective "raisonnée" refers to the rationale implied in the management of a dynamic farming system. There is a fundamental difference between the management of an industrial process and the management of an agro-ecosystem producing food, feed, fibres, biofuels, etc. Variability is an intrinsic feature of an agro-ecosystem which involves soil heterogeneity, climatic conditions and the diversity that still exists between plants of the same variety or animals of the same breed.

Best available technique (BAT) concept used for industry is not practicable as such in the farming sector. Agricultural practices imply unique choices based on the complex interactions between the farming sub-systems (cropland, grassland, animals, etc.) and the strong impact of climatic conditions.

Soil management and crop nutrition account for 18 of the mandatory measures of the AR scheme. Some of these measures are related directly to existing regulations (storage of fluid fertilizers and manure, field-scale fertilizer plan, etc.). However, most of the obligations go beyond the requirements of regulations. They concern:

- Information used by the farmer (soil maps, soil analysis every six years for each soil type, identification of areas that are sensitive as regards waterways or the water table, erosion, biodiversity, etc.);
- The decision making process (evaluation of results, realistic yield targets for the calculation of the nutrient management plan, etc.);
- Recording and evaluation (records of all nutrient applications at the field level, including organic and mineral fertilization, etc.);
- Training of the farmers and operators (advice from a qualified adviser, maintenance and calibration of fertilizer spreading equipment, etc.);
- Continuous assessment of all aspects of farm management and its environment. These follow-up measures are intended to ensure continuing improvement, with year-on-year progress monitored under the scheme.

Any input that is legally registered is permitted under the scheme, but the use of the various inputs must be carefully calculated and all known impacts on the environment must be taken into account.

Ways to improve nitrogen efficiency

Nitrogen (N) management is a good example of the monitoring applicable to a major nutrient. Integrated nutrient management requires that all sources of available N should be budgeted in order to satisfy plants' needs in both timing and quantity. The complex N cycle is driven by biological soil activity. Losses of mineral N must be limited to a minimum (nitrate in water as well as the emission of various nitrogenous gases to the air).

Benoit Collard, one of the first of the farmers to qualify for the AR scheme in early 2004, manages a 155 ha farm in the chalky Champagne region, 200 km north-east of Paris. The chalky soils are very fertile but can be prone to nitrate leaching into the groundwater. The nitrate concentration has stabilised since the 1990s but can still rise to around 30 mg/l in the local tap water. Nitrogen management has been greatly improved for each crop, with the help of experimental results from the local station of the national agronomic research institute (INRA), applied research institutes and N fertilizer manufacturers.

In February, before the sowing of sugar beet, Benoit Collard pays around €40 to have each field systematically sampled at three depths to assess the quantity of mineral N available in the soil. The soil laboratory delivers a recommendation for N application, using the Azofert® software specifically developed by INRA. Potential N mineralization from the soil and from crop residues, cover crops and all kind of organic matter previously applied, is estimated for the growing period of the sugar beet. Yields are frequently above 80 tonnes of roots per ha. The Azofert® system is also used for N recommendations on potatoes and spring malting barley.

On winter wheat, no N is applied before the end of February. Nitrogen is applied in three to four split applications until May. A calculation of the total N to be applied is made according to the targeted yield, field by field. From this total, 40 kg N are subtracted. A direct assessment of the plant nutritional status using the Yara N-tester® (chlorophyll meter system) helps to decide whether or not to apply these 40 kg N in May in order to maximise the N efficiency for yield and protein content, while minimising the mineral N remaining in the soil after harvest.

There is a N management tool also for melons. Jean-Pierre Duez qualified in 2006 simultaneously for the AR scheme for the whole farm and the EUREPGAP certification for melons only. With his wife, they crop 123 ha in the South of France, some 5 km from the Mediterranean coast. The main crops are wheat, sunflower and rapeseed, but they specialize in melons, salad crops and early cherry production. The groundwater under the farm is used for drinking water for the nearby city of Lunel, near Montpellier. A qualified agronomist himself, Jean-Pierre Duez does not consider that he can be an expert on all the crops. He systematically seeks information and advice from the specialist advisors of producer organisations or cooperatives. For his high-protein varieties of wheat, the farmer measures the need for a fourth application of N, using the Grande Paroisse GPN® system (reflection of light from the foliage). He takes also account of the rainfall and the weather forecast to make his decisions. Fertigation of the melon crop is essential for the quality of the fruit, to maximise water efficiency and protect the environment. Each nutrient in the nutrient solution can be adjusted with precision. The farmer is able to measure on each plot of the farm the N content in the petiole sap of the melon crop. This enables him to adjust each week the N added to the solution, thus avoiding over- or under-supply.

Communication, a crucial issue

It is not only the 2,000 farmers qualified under the AR scheme who have adopted these new management tools. In 2006, more than one million hectares of cropland were sampled between January and March to assess the mineral N in soils. Tools to adjust N fertilization according to measurements taken directly on the crop itself have been used on another million hectares of cereals, mainly soft and hard winter wheat (N sap analysis, chlorophyll meter, reflectance, satellite images, etc.). Some farmers already use precision techniques to adjust N application within the field.

In 2004, the AR scheme was launched with a target of having 30% of all professional farmers qualified by 2010. With only 2,000 farmers qualified by the end of 2006, the target seems far from being reachable.

Farmers have been advised to prepare for more frequent and stricter controls from public officials. There are a number of EU directives (concerning environmental protection, food security, animal welfare, biodiversity, etc.) relevant to the AR measures. If the farmer does not respect a given regulation, the amount of subsidy he receives from the EU is reduced. He may even lose the right to receive this aid if it is found that he has deliberately not respected the regulation.

Good communication is crucial for the success of AR. Criticism of an intensive agriculture that produces surpluses and creates a burden on the environment is still very common in the media. There is a need for a renewal of the relationship between society and its agriculture. It is also important for the fertilizer industry to justify the use of its nutrients in cropping programmes.

Public opinion is becoming increasingly aware that agriculture and forestry can provide renewable raw material to produce biofuels that will replace part of fossil fuel demand. Even if farmers decide to be more proactive and adopt on a large scale practices that enhance the environment, they will still have to communicate this to the public. Membership of the AR scheme would be proof of this engagement.

Voluntary initiatives undertaken by the fertiliser industry of New Zealand

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Summary

The New Zealand fertiliser industry has taken a hands-on, proactive approach to identifying and promoting fertiliser best management practices (FBMPs). The focus has been on improving efficiency and reducing nutrient losses as they apply to a whole farm system, with an emphasis on non-prescriptive, site-specific practices.

This paper discusses how this has been achieved through incorporating best management practices into a code of practice. Related activities of stakeholder buy-in and uptake, promotion, training and implementation are also discussed. The success of this approach is evaluated and some key issues for a successful process identified.

Fertiliser industry involvement in related activities such as fertiliser quality assurance and aerial and ground spreading requirements are also briefly discussed.

Introduction

New Zealand has a technologically advanced and economically important agricultural sector. The regulatory framework and approach to fertiliser use are in general less prescriptive and formal than, for example, is the case in Western Europe. This means there is more scope for developing and implementing FBMPs thereby increasing productivity and nutrient use efficiency, and potentially negating the need for prescriptive regulation or offering a viable alternative based on FBMPs.

Economic and regulatory framework

Agriculture plays a significant role in the New Zealand economy. It generates over 40% of the countries export income and makes up about 9% of the gross domestic product (ref # 1).

Nearly 14 million ha of the total New Zealand land area of 26.7 million ha is used for pastoral agriculture, arable and fodder cropping or forestry.

Land use by primary industries can therefore be expected to have a significant impact on the New Zealand economy and environment.

In addition, New Zealand has a "clean green" reputation and it is in the interests of farmers to maintain this as it influences international market access and can provide farmers with a market premium for their produce.

The most significant legislation for managing the impacts of agriculture is the Resource Management Act of 1991 (RMA). The RMA has the aim of promoting sustainable management of natural and physical resources. When it was implemented in

1991, it replaced 59 Acts including the Fertiliser Act of 1960 and 1982. Under the RMA, fertiliser, along with many other substances, is regarded as a contaminant. Regional authorities are required to address the effects of contaminants applied to soils in their regional plans.

Fertiliser industry

The fertiliser industry consists of two major, farmer-owned, fertiliser manufacturing and importing co-operatives (combined 94% of market) and one smaller importer (6% of market). The two co-operatives employ field staff who provide fertiliser recommendations and nutrient management advice to farmer shareholders.

Role of the fertiliser industry in promoting best management practices

In view of the range of requirements that farmers face when using fertiliser under a range of uniquely New Zealand conditions, the fertiliser manufacturing industry, through the New Zealand Fertiliser Manufacturers' Research Association (FertResearch) deemed it prudent to develop a Code of Practice for Fertiliser Use, which sets out best management practices for fertiliser use (ref # 2).

To gain broad acceptability and provide credibility, the assistance of an independent external consultant was used.

A consultative process was implemented, which resulted in some 150 organisations being contacted. About 50 of these made formal submissions on drafts of the Code. Organisations consulted included government departments, regional authorities, farmer organisations, producer organisations and environmental groups.

The best management practices were incorporated into the Code and formulated to take cognisance of the commercial requirements of farming and the sustainable requirements of land management associated with fertiliser use.

Best management practices, for nitrogen and phosphorus, which are included in the Code, are summarised in Table 1 and Table 2. Fact sheets referred to in these tables are part of the Code and provide additional background information.

Combining best management practices into a Code of Practice for Fertiliser Use has been one of FertResearch's most significant investments.

The first version was produced in 1998, bringing together accumulated knowledge on fertiliser use and best practice, with the aim of improving efficiency in fertiliser use and addressing sustainability issues. The document is presented in four sections designed to provide information on best practice for nutrient management, while addressing the requirements of the Resource Management Act. User guides and fact sheets provide supporting documentation, which help farmers use fertiliser responsibly, comply with the Resource Management Act, and ensure economic production goals can be achieved. Being non-prescriptive and effects-based, it is unique in its approach to addressing issues on a site-specific basis. Documentation and record keeping are part of best management practice and provide information about farm operations and are also an important component of many quality assurance schemes, such as those demanded by some of our overseas markets.

In 2002, a review of the Code was undertaken. The basic approach was unchanged, but additional information was introduced on salient and emerging issues including:

- nutrient budgets,
- nutrient management plans,
- spreading developments,
- cadmium,
- nitrate management,
- greenhouse gas issues.

A further comprehensive review was undertaken in 2006 and is scheduled for completion in March 2007. This review was undertaken against a background of:

- intensification,
- increased fertiliser consumption,
- water quality concerns,
- climate change issues,
- market signals,
- public expectations.

A significant change in approach is in addressing broader nutrient sources rather than an exclusive focus on fertiliser.

Fertiliser use is considered in the broader context of nutrient management. With this approach a nutrient budget is the basis for developing a nutrient management plan and placing nutrient management within the context of a farm management system (Figure 1).

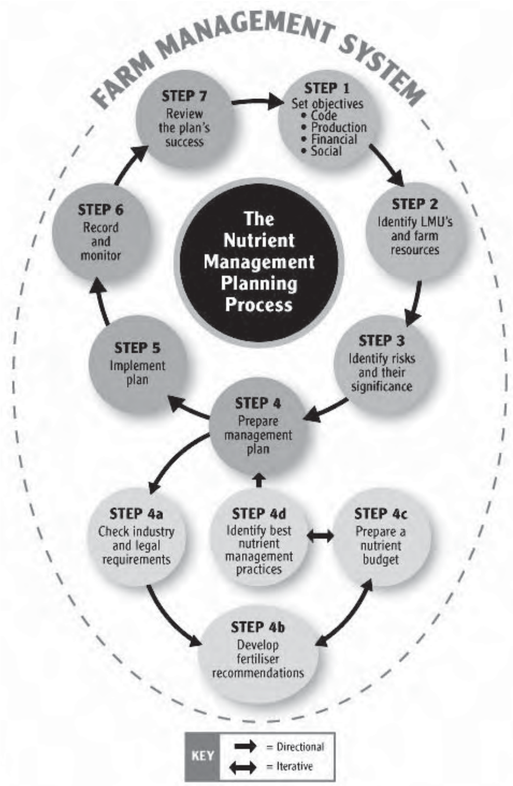

Figure 1. An overview of the nutrient management planning process.

The revised Code of Practice for Nutrient Management will ensure that best management practices for nutrient budgeting and nutrient management planning are being followed.

Related initiatives

In addition to developing the Code of Practice for Nutrient Management, the New Zealand fertiliser industry has played an active role in related best management practice initiatives. These include:

- Fertmark Scheme: a fertiliser quality assurance programme developed in conjunction with the national farmers' association (Federated Farmers of New Zealand) (ref # 3).
- The Fertmark Code of Practice relates to all fertiliser made and sold under the Fertmark programme. It provides assurance that Fertmark registered products, if used properly, do not pose hazards to food safety or animal welfare.
- Spreadmark Scheme: a quality assurance scheme for the placement of fertiliser on farm land (ref # 4) that includes both ground and aerial applications.
- Training course: The Fertiliser and Lime Research Centre at Massey University, in conjunction with the fertiliser industry, have developed courses for the accreditation of advisors responsible for providing safe and effective nutrient management advice (ref # 5).

Achievements and benefits

Compliance with the Code and the implementation of best management practices is a requirement of a number of regional regulatory authorities for fertiliser use to be a permitted activity, without restrictions and prescriptive limits. The Code has also been incorporated into a number of quality assurance programmes. Some of these programmes enable participants to gain access to higher value international markets. In these instances, compliance with the Code as a means of demonstrating the adoption of best management practices may be part of a quality assurance programme audit.

In general, the Code has gained acceptance by regulatory authorities, producer and farmer organisations. It has provided a practical means for farmers to satisfy regulatory and quality assurance programme requirements, and to demonstrate the implementation of best management practices for fertiliser use.

Conclusion

The uptake and implementation of FBMPs varies considerably. Where adoption is poor, there is generally a reversion by authorities to a prescriptive, often restrictive, regulatory environment.

Simply developing FBMPs is not enough. A comprehensive and committed approach is required, including:

- Having a champion. An individual or an organisation should take on the responsibility of 'championing' FBMPs. This role would include raising and maintaining a high profile for FBMPs. Making sure that all stakeholders are aware of them and the benefits that can be derived from successful uptake. Monitoring of FBMPs so that they are up-to-date, reflect the fertiliser services available and address emerging issues. A strong extension component is also important.

- Consultation with key stakeholders. Stakeholders include farmers, regulatory authorities, environmental and community groups as well as market gatekeepers (e.g. supermarkets). Consultation should include all aspects of developing, formulating and implementing FBMPs.
- A practical approach is required. Farmers are unlikely to adopt FBMPs that are not compatible with their farming system, i.e. seen to be impractical.
- Economically viable practices that are expensive to implement and impact negatively on the economic viability of farming business will not be readily taken up by farmers.
- Fertilizer best management practices should be non-prescriptive and allow farmers to select and apply the most appropriate practices for their situation. This will accommodate the site-specific nature of agriculture practices.
- Fertilizer best management practices should be reviewed and updated regularly and include the latest scientific findings and environmental concerns.

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Table 1. Best management practices for nitrogen (N) fertiliser use.

Activity	Best management practices	Fact Sheet
Choice of fertiliser	Use Fertmark registered products	4
Rate of fertiliser application	• Nutrient application rates are determined using some or all of the following factors: · soil and plant tissue analysis · nutrient budgets (including any effluent and/or feed imported to the block) · crop type, yield/quality/stocking rate targets · the need for capital or maintenance applications · previous crop and fertiliser history on the site · soil moisture conditions and expected future weather patterns · local knowledge · feed budgeting/monitoring · soil temperature	2,5,7,8
	• The amount of nitrogen applied per application is limited: · on soils where groundwater lies under permeable sediments (e.g. gravels) · in areas where there is a high water table · on areas where there is subsurface mole and tile drainage	8,9
	• Apply nitrogen fertiliser in split dressings of 50 kg N/ha when 200 kg N/ha or more is required	6,8,9
	• Nitrogen is applied in proportion to other nutrients, according to plant requirements (adding excessive N when other elements limit crop or pasture growth leads to greater N losses)	5
Application technique	• Application equipment is suitable for the conditions and fertiliser type	3,4
	• Only Spreadmark accredited spreading companies (experienced operators and calibrated equipment) should be used	4
	• GPS and GIS technology is used for precise application and for a digital record of fertiliser application locations	3
	• Non-target application of fertiliser is avoided by: · using fertiliser with larger particle sizes (mean size greater than 1 mm) and few or no fine particles · application techniques that direct or specifically place the fertiliser appropriately · application in bands when sowing crop or pasture seeds · choice of fertiliser types that can be applied more precisely (e.g. slurry/liquid) · applying fertiliser only when any significant wind is blowing away from sensitive areas · not applying fertiliser by air when wind speed exceeds 15 km/hr	3,4

Frequency of application	• Nutrient availability is matched to plant demand	6,8
	• Lower rates of N fertiliser are applied more often, at times to match the growth cycle of the crop or pasture and soil moisture conditions, rather than in single large applications	6,7,8
Timing of application	• Nitrogen application is matched to times of high plant growth	7,8
	• Pasture is at least 25 mm high (approx. 1000 kg DM/ha) before N is applied	9
	• In the case of border-dyke irrigation, fertiliser is applied afterwards, provided the soil is not saturated. If the soil is saturated fertiliser application is delayed until ground conditions are suitable	9
	• Nitrogen is not applied when the 10 cm soil temperature at 9 am is less than 6°C and falling (at these low soil temperatures plant nitrogen uptake is slow and there is greater risk of leaching loss)	6,9
	• Nitrogen is not applied after a dry (drought) period until sufficient regrowth has occurred after rain	9
	• Where possible, fertiliser N application is adjusted to complement the release of soil mineralisable N	6,9
	• For information about the effects on stock of high nitrate in grass, contact FertResearch for a fact sheet	-
	• N fertiliser is not applied in mid to late autumn to fallow land unless there is a cover crop	9
	• N fertiliser is not applied when the ground is saturated and/or when tile drains are running	9
	• N fertiliser is applied 4-6 weeks before the feed is required	
Fertiliser use and management measures	• N fertiliser is not applied to severely compacted soils. Soil aeration techniques are used on such soils before fertiliser application	-
	• Pasture is at least 25 mm high (approx. 1000 kg DM/ha) before N fertiliser is applied	9
	• Vegetated riparian buffer strips of sufficient width (10 m) to filter any run-off are maintained adjacent to all waterways	-
	• Urease inhibitors can be used to reduce urea losses to the atmosphere when conditions are conducive to volatilisation	-
	• Nitrification inhibitors can be used: · either with the fertiliser N or · applied across the whole area to help reduce N leaching from urine patches	11

Table 2. Best management practices for phosphorus (P) fertiliser use.

Activity	Best management practices	Fact Sheet
Choice of fertiliser	• Soluble phosphate fertiliser is used where: · rapid plant response is required · soil P levels are required to be increased rapidly · plants are actively growing · there is a low risk of runoff	6,9,13
	• Slow-release phosphate fertiliser is used when: · there is a high risk of runoff and/or · a rapid plant response is not required and/or · soil P levels are adequate and/or · soil pH is less than 6.0 and annual rainfall is greater than 800 mm	6,9,13
Rate of fertiliser application	• Nutrient application rates are determined using some or all of the following factors: · soil and plant tissue analysis · nutrient budgets (including any effluent and/or feed imported to the block) · crop type, yield/quality/stocking rate targets · the need for capital or maintenance applications · previous crop and fertiliser history · soil moisture conditions and expected future weather patterns · local knowledge	5,6,7
	• The amount of phosphate applied per application is limited: · when high rainfall is anticipated or irrigation is planned · on very sandy soils, particularly for soluble phosphate fertilisers · when slope is greater than 25°, and/or pasture is less than 25 mm high (approx. 1000 kg DM/ha) · during winter	6,8,13
	• Soluble phosphate fertiliser must be applied in split dressings if the single application rate would exceed 100 kg P/ha	6,13
	• Phosphate is applied in proportion to other nutrients, according to plant requirements (adding excessive P when other elements limit crop or pasture growth is inefficient and could lead to P losses)	5,6
Application technique	• Application equipment used is suitable for the conditions and fertiliser type	3,4
	• Only Spreadmark accredited spreading companies (experienced operators and calibrated equipment) should be used	4
	• GPS and GIS technology is used for precise application and for a digital record of fertiliser application locations	3

	• Non-target application of fertiliser is avoided by: · using fertiliser with larger particle sizes and few or no fine particles (aerial application) · application techniques that direct or specifically place the fertiliser appropriately · application in bands when sowing crop or pasture seeds · applying fertiliser only when any wind is blowing away from sensitive areas · applying fertiliser only under agreed conditions (e.g. wind speed of less than 15 km/hr)	4
Frequency of application	• Nutrient availability is matched to plant demand, particularly for soluble P products and liquids	5,6
	• Split applications are used where the single application rate would exceed 100 kg P/ha for soluble P or liquid fertiliser	6
Timing of application	• Pasture is at least 25 mm high (approx. 1000 kg DM/ha) before P is applied	-
	• P fertiliser is not applied after a dry (drought) period until sufficient regrowth has occurred after rain	5
	• P fertiliser is not applied when the soil is saturated	5,6
Fertiliser use and management measures	• P fertiliser is not applied to severely compacted soils. Soil aeration techniques are used on such soils before fertiliser application	-
	• To avoid fluoride toxicity to stock, pastures top-dressed with P fertiliser are not grazed for 21 days or until 25 mm of rain has fallen	12
	• Only P fertilisers which comply with the industry limit of 280 mg of cadmium per kg of P are used	12
	• Vegetated riparian buffer strips of sufficient width (10 m) to filter any run-off are maintained adjacent to all waterways	-

Fertcare® – putting best practice into stewardship

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Abstract

The use and adoption of best management practice (BMP) for fertilizer use in Australia is predominantly being driven by environment and food safety concerns rather than productivity issues. However, as both environmental risk and economic productivity are closely linked to efficiency of nutrient use, BMP adoption is likely to have a net positive effect on the fertilizer industry.

This paper gives an overview of environment and food safety issues related to fertilizer use in Australia. It describes the regulatory environment and discusses the philosophy adopted by the fertilizer industry in addressing these issues, and achieving full engagement in the development and delivery of public policy. The focus has been on the development of a comprehensive product stewardship program rather than on BMPs per se, but builds on the principle of providing advice on the best available management practices.

The management of eutrophication of surface waters is the highest profile public policy issue for the fertilizer industry in Australia – with phosphorus and nitrate run-off and leaching being issues across the country. In addition, the contribution of nitrogen fertilizers to greenhouse gas emissions is currently the subject of further study and improved management practices. Contaminants such as lead and cadmium that represent a food chain risk have already received considerable attention from both Government and the fertilizer industry. However, the use of various industrial by-products as 'fertilizers' and 'soil ameliorants' continues to be of concern.

In order to become fully engaged in the development and implementation of public policy in these areas, the fertilizer industry has made significant commitments to effective product stewardship through the development of the Fertcare training and accreditation program. The process of developing and implementing this program, and its value in effectively leveraging the fertilizer industry's participation in public policy will be discussed. Whilst the program is not portrayed as a BMP program it is clearly about providing advice on best management practices.

Context and policy

Australia has a strong environmental movement, including a political party–the Greens–and environmental issues are major policy areas for both State and Federal Governments. The role of agriculture is central to many environmental debates both as a custodian of much of the land mass of Australia and as a contributor to the health and quality of land, air and waterways.

There are a number of environmental issues that arise when plant nutrients, either native to the soil or applied as fertilizers, move out of the farm production system. Eutrophication of waterways, pollution of groundwater and acidification are all significant issues where fertilizers are clearly identified as a contributing factor.

Greenhouse gas emissions from soil nitrogen (N) are a significant contributor to Australia's total net greenhouse gas emissions.

Impurities in fertilizer products, notably heavy metals and fluorine, can present a food safety concern. Their accumulation in soils adds an environmental dimension to the problem.

All of these issues have a public profile in Australia, and there is a significant amount of detailed information from credible sources that is very accessible to the public. The level of public information and public concern ensures that high level public policy will be developed to manage these issues.

Regulation of fertilizers, agriculture, the environment and land use in Australia is primarily a State and Territory responsibility, leading to eight sets of regulations, and often resulting in significant differences between jurisdictions. The fertilizer industry, in contrast, operates at a national scale and is, therefore, confronted with managing multiple sets of rules and procedures with multiple agencies. The adoption of credible codes of practice that detail BMPs for issues relating to quality, description, labelling and use of fertilizers offers the industry a potential tool in achieving national uniformity in meeting community and, therefore, Government expectations.

The Australian fertilizer industry provided 5.6 million tonnes of product to users in 2005, supplying 952,174 tonnes of elemental N, 454,531 tonnes of elemental phosphorus (P) and 184,347 tonnes of elemental potassium (K). The beneficial use of nutrients has enabled the steady growth in agricultural productivity that has allowed Australian farmers to compete effectively in world food markets.

Nutrient inputs to Australian agriculture are a significant part of input costs, totalling at least AU$2.5 billion in 2005. The importance of export markets to Australian agriculture and the resulting competitive pressures create an economic landscape in which costs are under constant scrutiny and must remain internationally competitive. As well as cost pressures, international markets are increasingly imposing conditions for food quality, including impurities, and environmental considerations in the production system.

The significant size of the fertilizer market and the coexistence of farmland and natural ecosystems mean that there is a clear risk that fertilizers may contribute to adverse environmental impacts. Measures to manage these risks must also consider the underlying economic imperatives.

Impurities

The heavy metals lead, cadmium and mercury represent potential risks to human health if they enter the food chain in sufficient quantity. While each of these elements can be present in various fertilizers as impurities, plant uptake is only likely to be significant for cadmium. Whilst there is some risk of lead contamination through the use of foliar fertilizers, particularly trace elements, monitoring of produce in Australia has clearly shown that cadmium is the heavy metal of concern.

In 1991, FIFA and the Horticultural Research and Development Corporation (HRDC) funded a three year project by the Commonwealth Scientific and Industrial Research Organization (CSIRO), to study the effect of fertilizers on cadmium levels in vegetables. This was the industry's first major investment in an issue of such national concern, and one that has lead to a significant change in policy directly affecting the industry.

FIFA continues it's involvement in heavy metal policy development through its involvement in the National Cadmium Minimization Strategy. FIFA is an active member of a stakeholder group, the National Cadmium Management Committee that co-ordinates the strategy. The committee is made up of representatives of the farming community, CSIRO, State and Federal Government departments of agriculture, environment and public health, as well as FIFA. The committee co-ordinates activities of the strategy and reports to the national Primary Industry Standing Committee, which is composed of the relevant Federal and State Government Department CEOs.

Under this strategy, the industry has:

- Reduced cadmium levels in fertilizers through the selection of raw materials (particularly in relation to phosphate rock for single super phosphate manufacture);
- Produced low cadmium single super phosphate for use in higher risk situations;
- Helped to develop maximum permitted concentrations of cadmium in fertilizers; and
- Through the committee, produced targeted information packages on BMP for those agricultural industries where cadmium risks are greatest (potatoes and leafy vegetables on sandy and or acid soils).

Cadmium inputs to Australian agriculture have been reduced by 75% as a direct result of these strategies.

The industry has also been active in promoting uniform product description laws amongst the Australian States to provide appropriate consumer information in the form of analyses of heavy metal content and product use warnings.

Information on the management of cadmium in Australia, including BMP brochures can be found at www.cadmium-management.org.au.

Information on food standards for cadmium in Australia can be found at www.foodstandards.gov.au.

A consequence of selecting low cadmium phosphate rock has been an increase in fluorine concentration in singe super phosphate. Initial modelling in Australia and New Zealand suggests that, in the medium term (50 years), current use rates could lead to problems in dairy cattle and milk supplies. FIFA is monitoring the development of data in New Zealand that will further elucidate this issue.

Surface water quality

Nitrogen and P concentrations in waterways and oceans have a significant impact on fauna and flora composition. Significant changes in the concentration of N and P in waterways are therefore of major environmental concern, particularly in ecologically valuable areas such as the Great Barrier Reef and its rivers and estuaries.

The Australian Government has developed a comprehensive program of auditing and reporting on the state of the Australian environment – the Australian Natural Resources Audit and the State of the Environment Reports. FIFA member companies contributed to collection of data for these initiatives by providing soil test and fertilizer use data. As a result of these reports, there is a lot of publicly available data from a reputable source on several environmental issues of relevance to the fertilizer industry, and particularly on surface water eutrophication.

Figure 1 shows a rating of Australian catchments where nutrient levels exceed the desired water quality for environmental health. The areas on the map where nutrient levels are a major or significant issue represent more than 80% of Australia's agricultural land.

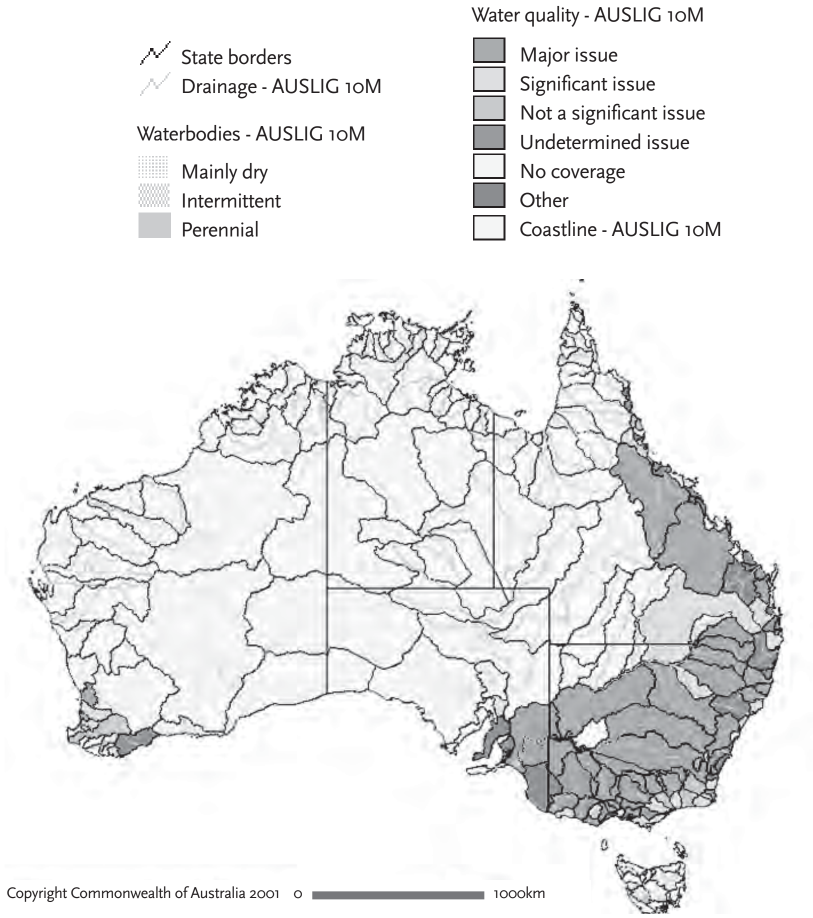

Figure 1. Water quality exceedence (Australian Natural Resources Atlas, 2001).

A very public outcome of eutrophication is the occurrence of algal blooms in inland waterways that prevent use for recreational, domestic and livestock purposes. These blooms can be toxic and occur across wide areas on a regular basis.

Groundwater quality

There are parts of Australia where groundwater resources are used for human consumption. Nitrate (NO_3) leaching into these aquifers could represent a human health risk and would be an issue of high public concern should it occur. At this stage, current levels of concern are low.

Soil acidity

Soil acidity is a significant environmental issue in Australia. Whilst fertilizers play a role, the acidification of soil is an inherent part of productive agriculture. Soil acidity is a high profile subject amongst the farming and agricultural science community but is not yet high on the public agenda.

Nutrient depletion

Nutrient depletion is identified in the Australian Natural Resources Audit as a bigger issue than salinity or acidity – in terms of land management. Some Australian farming systems rely solely on the natural fertility of the soil, without replacing the nutrients lost through harvest. In such systems, plant cover can be insufficient to protect the soils from wind and water erosion – resulting in extensive soils loss to waterways.

Whilst there are limited circumstances in Australia where fertilizer is over applied, there is a large net deficit when nutrient removal in agricultural produce is compared with nutrient application as fertilizers. This means that, for much of Australia, the effective management of environmental impacts of fertilizer use may be a significant increase in total fertilizer use.

Information on the Australian Environment including issues of surface water quality, acidity and nutrient depletion can be found at The Australian Natural Resource Atlas (http://audit.ea.gov.au/anra/).

Greenhouse gas

Global warming is an issue of very high public concern that is constantly in the news. Whilst the public expectation is that Governments need to act, the complexity of the issue confounds clear policy direction.

Nitrous oxide (N_2O)emissions from agricultural land have been identified as a major contributor (3.4% of total net emissions), but the confidence in this estimate is very low (Table 1).

More information on greenhouse gas in Australia is available at the Australian Greenhouse Office (www.greenhouse.gov.au/index.html).

While each of the above issues have varying degrees of risk and impact, the Fertcare product stewardship program described below, aims to minimise the detrimental contribution made by fertilizers to each of the issues by ensuring that BMP advice is provided at all levels in the industry.

Table 1. Agriculture sector CO_2-equivalent emissions, 2000.

Greenhouse gas source and sink categories	CO_2-equivalent emissions (Gg)				% of total net national emissions
	CO_2	CH_4	N_2O	Total	
Total net national emissions (Kyoto)	404,577	108,468	30,701	550,049	100
4. Agriculture		73,625	23,656	97,281	17.7
A Enteric fermentation		62,748		62,748	11.4
B Manure management		2,048	1,286	3,334	0.6
C Rice cultivation		400		400	0.1
D Agricultural soils		NE	18,716	18,716	3.4
E Prescribed burning of savannas		8,220	3,564	11,784	2.1
F Field burning of agricultural residues		209	89	298	0.1

NB: one giga gramme (Gg) is equivalent to one thousand metric tonnes
Source: Australian Greenhouse Office, Department of the Environment and Heritage, May 2005

Industry approach

As most of the environmental and food safety risks occur at the point of use, the industry has implemented a comprehensive product stewardship program. Fertcare aims to meet the industry's responsibilities for food safety and environmental protection, and facilitate its involvement in public policy development and implementation.

Fertcare

Fertcare is an accreditation program based on training, quality assurance and certification. Developed with funding assistance from the Australian Government's Natural Heritage Trust and National Landcare Program, it is the centrepiece of the industry's commitment to managing environment and food safety issues.

Fertcare training

Fertcare trains industry staff in the competencies required to meet their direct responsibilities for food safety and environmental risk management and, in particular, the competency to warn, advise and or refer customers to information about the risks and how to manage them. The management strategies are equivalent to BMPs and, where relevant industry BMPs exist, these are referenced in the training materials. It also develops awareness of occupational health and safety issues associated with fertilizer and soil ameliorant products.

Fertcare is a three level training program delivered by registered training organisations (RTOs) that meets national competency standards under the Australian Qualifications Framework. Individuals can attain certificates of competency by successfully completing the courses, and these may be used as part of a formal qualification (eg. Certificate Level III in Rural Operations).

The training program is focused on food safety and environmental risk management but, to do this effectively, it provides appropriate background knowledge and contextual reference at each of the levels (A, B and C). Specific occupational health and safety (OHS) issues associated with fertilizer storage, handling and use are also discussed.

The training material covers understanding and managing risk directly, and providing appropriate warning, advice and referral to customers. It is clear that the Level B course, in particular, will significantly improve participants' understanding of nutrient related issues, and improve their ability to communicate effectively with customers. An incidental benefit is that the background knowledge gained and the ability to communicate it effectively will add to participants' sales skills.

The three levels of training have specific objectives and characteristics. After completing a Fertcare training course, participants should have an understanding of what each of the levels of training involves, and be confident to draw on the skills and knowledge of colleagues who have completed a different level course.

The training material is given local relevance through the delivery and assessment processes, which require participants to gain an understanding of local issues, policies and programs, including local BMPs.

Level A

Level A has a strong focus on environment and food safety risk management, particularly in relation to handling, transport and storage. Level A is targeted at the operational level. The core module includes a basic understanding of fertilizer and soil ameliorant products including:

- physical identification,
- understanding labels,
- storage and handling characteristics, and
- the main environment and food safety risks.

Level A also has three elective modules of which at least one must be completed:

- spreading,
- storage, and
- transport.

A fourth module for aerial operators is under development.

Level B

Level B is focussed on developing underpinning knowledge of nutrient issues relating to environment and food safety. It provides basic education in plant nutrition designed to enable personnel to improve communication with their customers, and provide warnings and simple advice. Importantly, Level B emphasises the need to refer customers to Level C trained staff where appropriate. It is envisaged that Level B training will be combined with company specific training to deliver effective sales skills, as well as meeting stewardship objectives. Level B will also cover logistics and OHS issues at an awareness level. The major subject areas covered at a medium level of complexity are:

- soils and nutrients,
- fertilizers,

- application,
- environment and food safety,
- regulation,
- sampling,
- logistics, and
- OHS issues.

Level C

Fertcare training covers only some of the competencies required at the advisor (C) level. The other competencies should have been attained through other education and training programs and will be assessed through a process of 'recognition of prior competency'. In this regard, Level C has two components.

Level C1 provides training that covers a detailed and complex knowledge of:

- environmental issues,
- fertilizer environmental stewardship review methodology,
- food safety issues,
- sampling,
- the regulatory framework and label requirements, and
- awareness of OHS and stewardship issues in transport, storage, handling and application of fertilizers.

Level C2 is the recognition of prior competency (ROPC), and Fertcare accreditation includes assessment of competency in:

- soil, nutrient and fertilizer knowledge, and
- systematic development of interpretation and recommendations based on sound science.

Fertcare quality assurance

To maintain accreditation under the Fertcare program, all trained personnel are required to participate in a biennial refresher process. This will include updates on technical knowledge, reminders of key issues, and self assessment of how the Fertcare skills and knowledge have been applied. In addition, there are specific quality assurance measures for advisors and for premises that store bulk fertilizer.

Advisors

To become an accredited Fertcare Advisor, Level C training and ROPC must be satisfactorily completed. In addition, participants must then meet the requirements of a third party biennial audit of the fertilizer recommendations they have made. The audit process will ensure that advisors are adopting a systematic approach to providing:

- Appropriate evaluation and advice based on soil physical, chemical and biological factors that may impact on plant and nutrient behaviour and management;
- Appropriate evaluation and advice on soil or plant nutrient status and implications for productivity and environmental outcomes;
- Appropriate recommendations for application of products taking into consideration the users' expectations and management, the available response data and environment and food safety risks;

- Recommendations that are clear to the end user and include choice of product, rate and method of application, frequency of treatments and timing of treatments;
- Recommendations that give appropriate qualification of the basis for the suggested approach where data or methods are limited; and
- Explicit reasons and explanation for any variations from the best available response data and scientific consensus in the recommendations made.

Premises

Premises that store bulk fertilizer are required to undergo a biennial audit that assesses the management of environmental risk and product-specific OHS. Premises managers are required to develop a management plan following a simple risk assessment process, and the audit assesses the plan and its implementation.

Fertcare certification

The Fertcare Accu-Spread program assesses the width and uniformity of distribution of fertilizer spreading equipment. The spreading machine is driven over a set of collection trays, the contents of which are then individually weighed. A graph of the distribution and the co-efficient of variation at various distances of overlap (Figure 2), are then created. Machines are certified to spread at overlap (bout) widths where the co-efficient of variation is less than 15%.

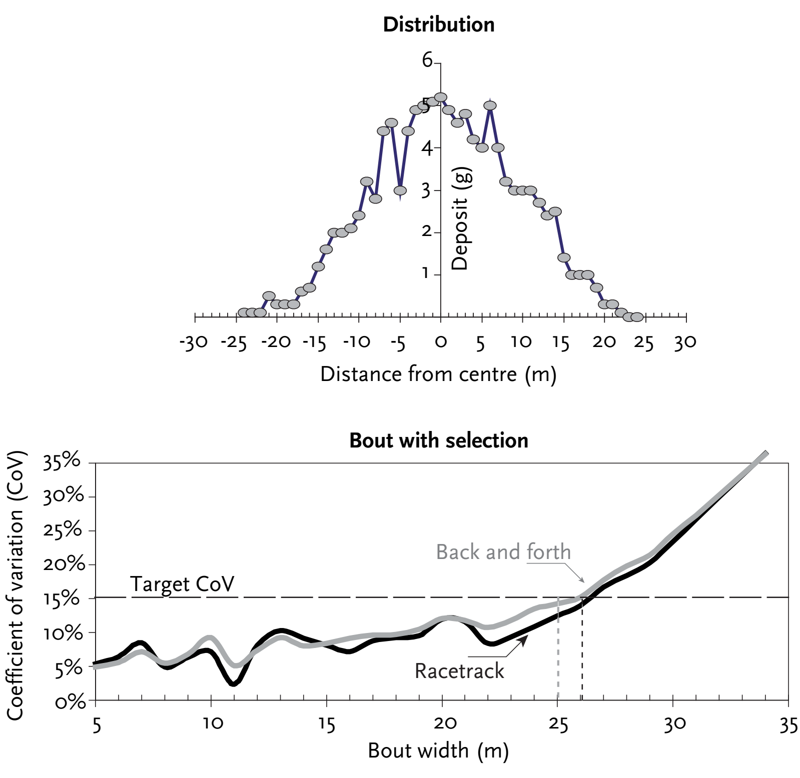

Figure 2. Fertcare Accu-Spread program print out for a well adjusted broadcast spreader.

Fertcare accreditation

The training, quality assurance and certification activities are brought together in the Fertcare Accreditation program. The program licenses businesses to use the Fertcare logos based on their compliance with the program targets for training, quality assurance and certification. The industry is committed to achieving 100% coverage of eligible staff, premises and contract spreading equipment by the end of 2008 (Table 2). Eligible staff are those involved in providing advice on fertilizer and soil ameliorant use, either in a sales or advisory role, and those involved in the storage, handling, transport and application of fertilizers and soil ameliorants.

Table 2. Fertcare accreditation program targets.

Measure	2005	2006	2007	2008
Eligible staff Fertcare trained	20%	45%	70%	100%
Trained staff refreshed/quality assured			100%	100%
Eligible premises quality assured		50%	100%	100%
Spreaders Accu-Spread certified	50%	75%	100%	100%

Source: Fertcare implementation handbook, unpublished

The intention is that the Fertcare logos (Figure 3) will become recognised as symbols of expert, up to date and independently audited advice and service, and sought out as part of a farmers' quality assurance program

Figure 3. The Fertcare logos.

A publicity and promotion plan is underway to explain the value of the program to the fertilizer industry, farmers, government agencies and regional natural resource management bodies. The program was officially launched on October 12, 2005 by the Australian Government Minister for Agriculture, Fisheries and Forestry, the Hon. Peter McGauran MP.

Quality control, independence and credibility

To gain acceptance amongst a range of stakeholders as a mark of quality advice and service, the program has been developed in consultation with those stakeholders, using significant input from external organisations and individuals with relevant expertise and high credibility. In particular, a technical committee made up of fertilizer industry technical staff and independent public sector scientists was used to approve all training materials, and ensure that the best available science and management practices were included.

A list of contributors is provided at Appendix 1.

The involvement of the Australian Government in guiding and funding the project has also contributed significantly to the program's credibility.

In addition, the training programs for each Fertcare level have been 'mapped' to new and existing national competencies, under the Australian Qualifications Framework. Fertcare is delivered by appropriately qualified third parties under the control of Registered Training Organisations (RTOs). The RTOs also ensure course participants are independently assessed and fully meet the competencies required.

Progress and targets

The members of FIFA estimate that there are 3,000 staff eligible for training within the industry. AFSA estimates that there are at least 1,000 contract fertilizer spreading trucks in Australia.

Training at Level A has been available since 2000, with Level B and Level C introduced during 2004. More than 1,100 personnel have successfully completed training to the end of 2006, comprising around:
- 420 at Level A,
- 360 at Level B, and
- 350 at Level C1.

Just under 200 spreader trucks are currently Fertcare Accu-Spread certified.

Advisor recognition of prior competency and audit programs have just completed development, and are now being introduced. The premises audit process is under development, and will be available from July 2007.

Delivery modes

The three levels of training each focus on using the skills and knowledge acquired. Workbooks and role plays require participants to put the knowledge into the context of their local environment and job roles.

However, the three levels are delivered in different modes to reflect the likely learning styles of the participants.

Level A is conducted in the workplace as a face-to-face session followed up by on-the-job evaluation. Presentations are supplemented by short videos, and the emphasis is on practical activities.

Level B is a computer based self paced learning module where the learning material is covered by an audio tutorial with associated pictures and text and an accompanying work book. Participants can also opt to print the material. The learning phase is followed by a workshop, which focuses on practice and evaluation of the knowledge and skills learned through hands on activities and role plays.

Level C is text based detailed information, a series of workbook challenges and case studies followed by an evaluation workshop that includes further case studies and role plays.

Costs

The program is run on a cost recovery basis with a small margin to fund maintenance of course materials. Delivery is by commercial organisations, and prices are subject to normal commercial processes. However, a typical Fertcare training course will cost the participant around $500, and will involve a full day at a regional location, plus around 20 hours of preparation, research or on-the-job assessment.

Costs for accreditation are currently $50 per premise and Fertcare Accu-Spread certification costs $450 per machine. The costs for Level C ROPC and audit and for premises audit are yet to be finalised.

These represent significant costs to fertiliser businesses, which range between multi-million dollar companies and single-spreader operators. With 3,000 staff and 1,000 machines, the direct training and certification costs to the industry would be around $2 million, with the effective cost likely to be at least double this.

Evaluation

The primary aims of the Fertcare program are to effectively manage the environment and food safety risks associated with fertilizers, and to support the industry's role as an effective partner in public policy development and implementation. Whilst numbers of personnel, equipment and premises will give a clear picture of the progress of implementation of the Fertcare program, they do not measure effectiveness against these objectives.

The Australian Government is funding an evaluation of the effectiveness of the program in changing farmer practices, focussing on the Great Barrier Reef catchment and greenhouse gas issues. The results will be used to improve the program, and will be presented at the Australian Fertilizer Industry Conference in August 2007.

In a previous evaluation of the program, workshops were run in catchments of the Great Barrier Reef across a range of agricultural industries. The workshops were facilitated by a consultant and involved Level C trained advisors in the delivery. Growers were provided with soil and plant analyses for their properties, and the implications of the results to environmental and productivity outcomes were discussed. Growers completed a survey about their nutrient management practices, prior to the workshops, and it was planned to do a second survey one year after the workshops to assess actual practice change. Unfortunately, Cyclone Tracey completely disrupted normal activity in the following year, and the follow up survey had to be postponed, and will be completed over the next three months. The results will be combined with the consultants report to provide a comprehensive review of the program's effectiveness.

Engagement in public policy

In August 2004, the Australian Fertilizer industry organised an international conference with two themes: environment and quarantine. 350 people attended, which was the maximum capacity of the venue. Senior staff from the Department of the Environment and Heritage and the Department of Agriculture Fisheries and Forestry attended, with some making presentations to the conference. Several State Departments of Agriculture and or Environment were represented, and a meeting of the National Cadmium Management Committee was held during the conference.

In public forums like the industry conference, in smaller meetings and in personal communication, the various levels of Government have expressed very strong support for the Fertcare program, and see it as an opportunity to help achieve public policy goals. This is confirmed by FIFA's growing involvement in a range of public policy development forums:

- Represented on the Fertilizer Working Group, which coordinates State policy on fertilizer issues;
- Involved with the National Cadmium Management Committee for a number of years;
- Involved in two industry liaison groups for the Reef Water Quality Protection Plan;
- Consulted early in the development of the Western Australian Algal Management Strategy;
- Commitment from the Victorian Environment Protection Authority in the development of the Fertcare premises quality assurance program;
- Approached by the Department of the Environment and Heritage (DEH) to assist in managing issues with excess levels of heavy metal contaminants in imported trace element products, resulting in FIFA's implementation of a code of practice for purchasing, developed in consultation with DEH.

On 12 October 2005, the Australian Minister for Agriculture Fisheries and Forestry officially launched Fertcare Accreditation on the lawns of Parliament House, and urged everyone involved in agriculture to get behind the program.

Conclusion

Fertcare is a comprehensive and credible program that will significantly lift the skills and knowledge of the Australian fertilizer industry with regard to environment and food safety management. It is likely to have a real effect on fertilizer use practices that will reduce risks and improve the efficiency of use of fertilizer inputs. This will result in less movement of nutrients from both fertilizer and native sources from farming systems into the wider environment. Whilst not promoted specifically as a BMP program, it is an effective means of ensuring that the Australian fertilizer industry consistently promotes BMP at all levels of advice to its customers.

Fertcare is an effective means of assisting in the implementation of public policy:

- It will provide 3,000 trained personnel who can deliver information and advice to all fertilizer users across Australia;

- It will ensure that detailed nutrition advice provided by Fertcare advisors is consistent with the best available scientific information with regard to both productivity and environmental outcomes;
- It will provide a mechanism to ensure that rural distribution premises do not become point sources of nutrient pollution;
- It will provide assurance that contract fertilizer spreaders are operating effectively, and that the operators can manage environmental risks.

Fertcare has significantly enhanced the credibility and standing of the fertilizer industry, and enabled significant involvement in the development and delivery of public policy relating to fertilizer.

The contributing factors to success

The clear public statement of the issues by reputable parties was a significant factor in achieving a strong and uniform view within the industry. Subsequent public statements of likely policy options in the Great Barrier Reef catchment, new powers in the South Australian Agricultural and Veterinary Chemicals Act 2002, and the instigation of an Algal Management Strategy in Western Australia, confirmed the industry's view that the issues must be dealt with, and that the development of Fertcare was timely.

A number of positive implications from dealing effectively with nutrient related environmental issues were identified early in the development of the industry position. Nutrient depletion, a significant issue in Australia, has clear positive implication for the fertilizer industry. In general, improving fertilizer use efficiency, which improves the economic benefit of using fertilizers, is consistent with reducing environmental risk. Managing issues of food safety is clearly of benefit to an industry reliant on food producers.

The successful history of the National Cadmium Management Strategy created a receptive background for the partnership with Government approach adopted for the development and implementation of the Fertcare program, and for the industry's broader engagement with public policy on environmental issues.

Funding support from the Australian Government to develop materials and programs was significant in speeding up the rate of development; it also added credibility and reinforced the decision to pursue a cooperative approach to the issues. The Government support has also contributed to efforts to communicate with stakeholders such as the regional natural resource management groups.

In a very competitive industry, the cost of the program, is a significant consideration. The public commitment by the industry to achieve 100% compliance with the accreditation program was a significant factor in giving all participants the confidence to make this investment. This commitment has been a powerful argument in describing the potential benefits of the program in helping to achieve public policy objectives.

Within the industry, the availability of appropriate training to suit all levels of job complexity, from logistics through to detailed advice, and the linking of the levels to each other, has created a very positive view of the program – everyone is included. The delivery modes have proven overwhelmingly successful, with very positive feedback from course participants. The effect of the training in improving participant's ability to add value to the customer relationship, from both a productivity and environmental management perspective, gives it intrinsic value to the fertilizer businesses.

The involvement of stakeholder representatives, particularly from the public sector, added significantly to the quality of the program and to its acceptance outside the industry.

The decision to use an external qualifications framework with the attendant quality controls, record keeping and approvals processes gives the program instantly recognised credibility.

Nearly half of the recent external funding for the program has been for activities to promote the program to relevant stakeholders, including the fertilizer industry, farmers, government agencies and independent consultants. Understanding of the program and acceptance of its quality and value by these stakeholders will be a critical factor in the success of the program.

The Fertcare program is not about developing BMPs but it is clearly an effective mechanism for ensuring that advice on BMP is consistently delivered to farmers by all levels of the fertilizer industry.

Relevant literature

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Appendix 1. Stakeholder involvement

Project Steering Group (strategic direction)		
Peter Arkle	Policy Officer	National Farmers Federation
Jenny Brownbill	Consultant	Agrifood Industry Skills Council
Colin Boldra	Accreditation Manager	Agsafe
Donald Carter	Past National President	Australian Fertilizer Services Association
Margaret Clarke	Program Manager	Chemcert
Shane Dellavedova	National President	Australian Fertiliser Services Association
Tim Ogden	Policy Officer	Department of Agriculture Fisheries and Forestry
Kirsten Rappolt	Marketing Manager	Incitec Pivot Limited
Alistair Steven	Fertilizer Manager	AWB Landmark
Simon Veitch	Director	Department of Agriculture, Fisheries and Forestry
Nick Drew	Executive Manager	Fertilizer Industry Federation of Australia
Training Committee (technical quality)		
Colin Boldra	Accreditation Manager	Agsafe
Andrew Cannon	Fertilizer Manager	Elders
Cameron Gourley	Science Leader	Victorian Department of Primary Industries
Cathy Lescun	Consultant	Cathy Lescun Consulting
Craig Goodhand	Training Manager	Elders
Shane Dellavedova	National President	Australian Fertiliser Services Association
Donald Carter	Logistics Committee Chair	Australian Fertiliser Services Association
Garry Kuhn	Product Stewardship Manager	Incitec Pivot Limited
Jonnie White	Agronomist	Agrow Canpotex
Martin Shafron	Environment Manager	Fertilizer Industry Federation of Australia
Nigel Bodinnar	Technical Services Manager	Incitec Pivot Limited
Peter Flavel	Technical Services Manager	Hi-Fert
Eddy Pol	Technical Services Manager	CSBP
George Rayment	Principal Scientist	QLD Department of Natural Resources & Mines
Sandy Alexander	Agronomy Manager	Summit Fertilizers
Andrew Spiers	Agronomy Manager	Hi-Fert
Peter Verrion	Program Manager	Bendigo Regional Institute of TAFE
With additional input from		
Richard Eckard	CRC for Greenhouse Accounting	Melbourne University
Mike McLaughlin	CSIRO Division of Land & Water	

Principles, dissemination and performance of fertilizer best management practices developed in China

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Abstract

This paper summarizes the problems and challenges in food security faced by China. The paper discusses fertilizer best management practices (FBMPs) which have been developed, based on the principles of integrated nutrient management, with the objectives of optimizing high yields, efficient resource utilization and environmental protection. It first outlines fertilizer use and production at the national level, and presents information necessary for the development of FBMPs. Principles, performance and dissemination of the developed FBMPs in the main cropping systems in China are then addressed. Finally, constraints that the farmers are facing in adopting FBMPs are discussed.

Fertilizer consumption in China since the 1950s

China has a long tradition, over thousands of years, of using organic materials to maintain relatively high yield levels and prevent soil fertility from declining. Before 1949 almost no chemical fertilizer was utilized in China, but now the situation has changed greatly. The rapid increase in population and living standards has increased demands on agricultural production, and the nutrients required have outstripped the supply from organic manures.

Chemical fertilizers were introduced in the 1950s, and their use has increased rapidly (Figure 1). The inputs of fertilizer nitrogen (N), phosphorus (P) and potassium (K) increased almost linearly from 8.9, 2.7 and 0.4 million metric tonnes (Mt) nutrients in 1980 to 24.8, 11.8 and 6.8 Mt in 2004. The ratio of $N:P_2O_5:K_2O$ in chemical fertilizers applied changed from 1:0.30:0.04 in 1980 to 1:0.48:0.27 in 2004, with an increased input of 180%, 340% and 1767% for N, P and K over this 24-year period. Total consumption of chemical fertilizers in China exceeded 55.3 Mt in 2005 (National Bureau of Statistics of China, 2006), nearly 35% of the total global consumption (estimated using the global consumption data for 2005, Heffer and Prud'homme, 2006). Average fertilizer application per unit area of cultivated land reached 356 kg/ha in total (228 kg/ha for N and 76 kg/ha for P_2O_5) rates that were higher than those in most countries, and as much as 200% above the global average. Concomitantly, the contribution to total nutrient supply from organic manures decreased from almost 100% in 1949 to only 35% in 2001. For example, applied organic manures accounted for 18% of N, 28% of P and 75% of K overall in 2000.

Fertilizer production, which reached 51.78 Mt in 2005, was able to meet 94% of market demand. Fertilizer production has increased quickly at a growth rate of 1 Mt of nu-

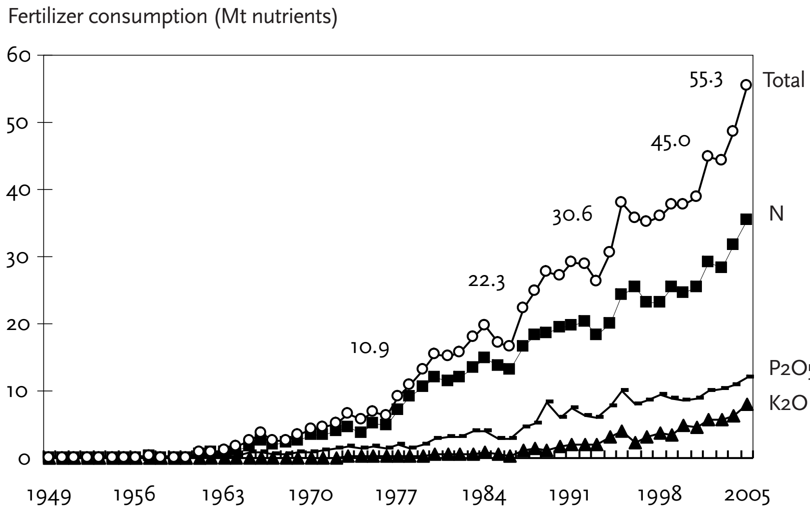

Figure 1. The trends in fertilizer consumption in China from 1949 to 2005. N.B. The consumption is the apparent consumption of whole China; it is calculated using production + imports - exports. Data are from the Statistics Bureau of China.

trients annually over the last half century. This was largely due to government support. For instance, the Chinese government adopted several support policies for the fertilizer industry, including direct financial support, cheaper raw materials such as coal, natural gas and electricity, cheaper and preferential transportation by train, and favourable tax rates for production and trade. It is estimated that the total financial support from government was 40.3 billion Yuan in 2005 (Zhang *et al.,* 2007a; Wang, 2006).

Despite the increasing consumption of fertilizers since the 1950s, both over-use and under-application of fertilizers, and especially of N and P, occur in different areas and cropping systems even today. According to a recent survey by the Chinese Ministry of Agriculture, about one-third of farmers over-apply N and one-third use levels of N on their crops that are too low. Evidence is mounting that both over- and under-application of fertilizers can contribute to losses of crop yield, poorer food quality and environmental harm. It is therefore a major challenge to develop technological and political strategies and policies that further increase grain yields while increasing nutrient use efficiency and protecting the environment.

The need to develop fertilizer best management practices

Since the establishment of the People's Republic of China in 1949, the growth of agricultural production has been one of the main accomplishments of the country. By 1999, China was successfully feeding 22% of the global population with only 9% of the world's arable land, and per capita food availability reached the levels of developed countries. Increasing the amount of inputs (e.g. fertilizer and water) has played a crucial role, accounting for about 50% of the yield increase.

Notwithstanding the achievements in agricultural production, there are still major challenges ahead. On the production side of the food sector, annual growth rates are declining gradually. For example, the growth rate of cereal yields decreased from 2.2% in the 1970s to 1.1% in the 1990s, and grain production showed almost zero growth between 1996 and 2000. Furthermore, grain production declined from 508 Mt in 1999 to 430 Mt in 2003 (National Bureau of Statistics of China, 1996-2003). On the demand side, China has to produce more food to feed an increasing population, which is predicted to reach a plateau of 1.6 billion within 50 years. According to the projections, food production has to increase by 150-200 Mt and crop yields have to increase at an annual rate of 1.4% within the next 30 years. Improving living standards will also drive demand for high-value food products.

On the resource utilization side (e.g. fertilizers), as mentioned above, Chinese farmers use 35% of the world's total fertilizers on farm land that accounts for only 9% of the total arable land in the world. In terms of N, the average application rate amounts to 193 kg/ha for rice, 190 kg/ha for wheat and 188 kg/ha for maize, rates that are higher than their equivalents in the other major producing countries. However, nutrient utilization efficiencies (e.g. partial factor productivity) in rice, wheat and maize production systems in China are considerably lower. For instance, the partial factor productivity of fertilizer in maize cropping systems was 17 kg/kg in China, 27 kg/kg in the USA and 70 kg/kg in Argentina (Table 1). The situation is further exacerbated by the loss of agricultural land at a rate of approximately 1% annually through rapid industrialization

Table 1. Fertilizer application rates and partial factor productivity on grain crops of major countries.

Crop	Country	Chemical fertilizer application rate (kg/ha)			Yield per unit land (t/ha)	PFP (kg/kg)
		N	P_2O_5	K_2O		
Rice	Japan	78	92	72	6	27
	Rep. of Korea	110	70	80	7	26
	China	193	67	54	6	20
Wheat	Japan	117	93	74	4	13
	France	80	80	70	7	31
	China	190	106	28	4	12
Maize	USA	150	70	90	8	27
	Argentina	50	25	2	5	70
	China	188	63	25	5	17

Note: PFP is the abbreviation of partial factor productivity of (N+P_2O_5+K_2O) on grain crops
The data from China are from the "Cost and Profit of Primary Products of China" compiled by the Ministry of Development and Reform of China, 2006
The data on fertilizer use of other countries are from Fertilizer Use by Crop (FAO,2004)
The data on grain yield represent the average of four years from 1997-2000 and are from the FAO Statistics Database, 2006.

and urbanization, by an increasing shortage of available water and by environmental deterioration. China is faced with low fertilizer manufacturing efficiency and shortages of raw materials for N fertilizer production such as coal, natural gas and electricity, and of P and K resources. In the case of P, current P resource use efficiency is only 39%, i.e. from every 10 kg P in the source rock only 4 kg of P fertilizer are produced (Zhang *et al.*, 2007b). China will exhaust its high-grade P rock resources by 2014 if fertilizer use continues to increase at the current rate (Zhang *et al.*, 2007a).

On the environmental side, irrational fertilizer utilization has led to environmental pollution. For example, losses of N and P through leaching and run-off have led to drinking water pollution, which affects 30% of the population, and result in eutrophication in 61% of the lakes in the country. Agricultural production also produces considerable emissions of nitrogen oxides.

The Chinese government regards agriculture as the primary field of development of the national economy in the 21st century. For China, the optimal path of agricultural development is to improve the ratio of resource utilization and to protect the environment while guaranteeing the grain supply. However, concerns about China's food security and agricultural production have raised a number of questions. Will China continue to be able to feed its increasing population? What is the best approach for improving grain production with efficient resource utilization and environmental protection?

Principles of the fertilizer best management practices: integrated nutrient management

Sustainable agricultural production incorporates the idea that natural resources should be used to generate increased output without depleting the natural resource base. However, despite past achievements in crop production in China, both over- and under-application of fertilizers, de-coupling between crop and animal production and poor management of resources have led to low resource efficiency and damage to the environment. The overall strategy for further increasing crop yields to feed the growing population and maintain the yields in a sustainable way should focus strongly on integrated nutrient management (INM).

In the integrated approach, the strategy is to emphasize the integrated use of nutrients from fertilizers, wastes (from both agriculture and industry), and soil and environmental sources such as atmospheric deposition and irrigation water. China produces large amounts of organic wastes. This is especially true for livestock production and the amount of organic waste from this source reached about 4,000 Mt in 2000. However, organic manures are applied to only 47% of the agricultural land area. Furthermore, other sources of nutrient inputs have been ignored. For example, N inputs from rainfall were up to 60-90 kg/ha in the wheat-maize cropping system in Huiming, and inputs from irrigation reached 180-250 kg/ha in the tomato production system in Shouguang, Shandong province.

On the nutrient management side, N management emphasizes the synchronization of N supply and crop N demand. The N fertilizer applications can be split to match crop requirements at different growth stages, based on the total fertilizer N rate required at the specific sites; to minimize N losses from the soil-plant system. This requires dynamic monitoring of root zone nutrient concentrations at different growth stages of crops in order to realize the synchronization of crop nutrient uptake, soil nutrient supply and fertilizer input. Additional fine-tuning by top-dressing is achieved using N-kits and a chlorophyll meter (SPAD) or a leaf color chart (LCC).

Fertilizer P or K management focuses on maintenance of adequate soil available P or K levels to ensure that neither P nor K supply limits crop growth and N use efficiency. Therefore, maintenance fertilizer P or K rates are recommended through constant monitoring of the soil nutrient supply capacity (Wang *et al.*, 1995).

In the integrated approach, the strategy of nutrient management should also be integrated with sound soil management practices and other farming techniques such as high-yielding cultivation systems (Zhang *et al.*, 2005).

Dissemination and performance of fertilizer best management practices

Three channels have been used for communication with farmers and growers: (1) more than 120 experimental bases or stations established throughout the main crop production areas in China, for research and extension purposes; (2) official extension service systems operated by central and local governments; (3) effective cooperation with the fertilizer industry.

With support from the Chinese Ministry of Agriculture and the National Natural Science Foundation of China, a large-scale project has been in operation since 2002. It features integrated nutrient management systems for 12 cropping systems at more than 120 sites across the country (Figure 2). Many experimental stations have played an important role in both the development and the dissemination of FBMP techniques. For

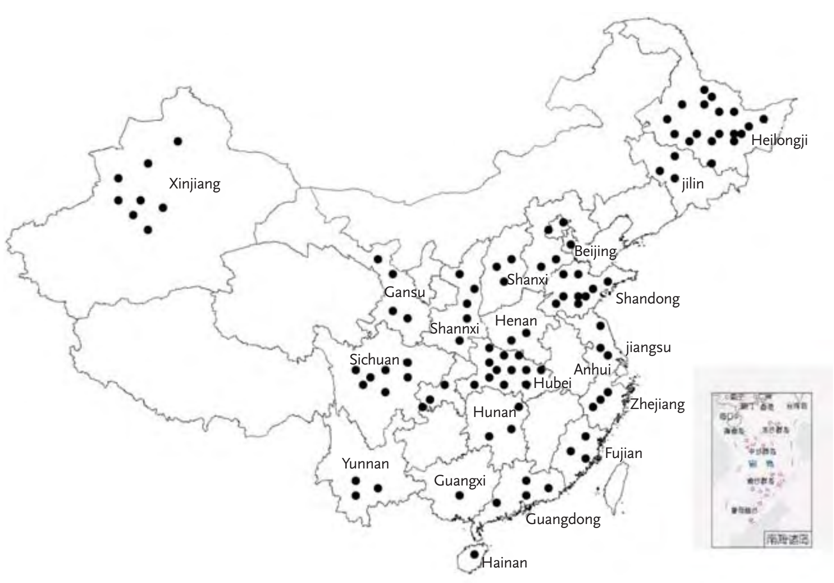

Figure 2. Distribution of experimental and extension bases or stations across 12 cropping systems throughout China.

instance, farmers have been organized in a special association at Jianyang in Sichuan province. By joining the farmers' association, farmers can participate in the development of the FBMP techniques, receive training and share experience and information with each other, while the local government gives some subsidy to those farmers who use FBMPs during the first year. This has greatly facilitated the development and dissemination of FBMPs in this part of the country.

Effective cooperation with the fertilizer industry has substantially benefited dissemination of FBMPs. For instance, in cooperation with Sinochem, an 'R&D center of Sinochem and China Agricultural University (CAU) was established in 2003. It focuses on new types of fertilizer, their use, fertilizer market investigations, on-farm surveys of fertilizer application, and the training of staff in both the fertilizer industry and the official extension service.

The main measures adopted in FBMP extension include: (1) holding farmers' field days using interactive education methods that focus on problem solving in the field, and on nutrient management case studies tailored to local audiences; (2) issuing technical manuals, leaflets and publications as resource materials for FBMP training of farmers and/or technicians; (3) establishing a website (www.fertrdc.cau.edu.cn/cnnm) designed for nutrient management planners; (4) producing special compound fertilizers suited to different crops in the typical climatic zones in China.

Current evidence indicates that FBMPs offer benefits to farmers. As shown in Table 2, the FBMPs have realized the multiple objectives of reducing fertilizer use, improving grain yield and quality, and increasing resource use efficiency as well as reducing environmental pollution. Compared with farmers' traditional treatments, FBMPs have on average saved 20-40% of the N, increased yields by 2-12%, increased N recovery rates by 10-15% and decreased N losses by 10-50%, over nine cropping systems across the country.

Table 2. The potential of N saving, yield increase, N recovery rate increase and N loss decrease in FBMPs compared with farmers' traditional treatments in different cropping systems in China.

Cropping system	N saving (%)	Yield increase (%)	N recovery increase (%)	N loss decrease (%)
Wheat/maize rotation	41-59	5-10	12-15	43-69
Rice	22-32	8-12	10-15	40-50
Vegetables	30-50	2-10	5-15	40-65
Cotton	20-30	5-8	10-15	10-30
Oilseed rape	10-30	5-30	8-15	-
Rice/wheat rotation	30-50	8-20	8-30	30-50
Intercropping	20-50	0-10	8-13	20-45
Tobacco	10-30	0-10	7-20	40-50
Apple	10-50	5-15	2-12	-

Constraints to the dissemination and implementation of fertilizer best management practices

The current effectiveness of the extension system for disseminating agricultural techniques is rather poor, and there are serious difficulties such as lack of investment and poor training of technicians (Research Centre of Rural Economy, Ministry of Agriculture, 2005). According to a recent survey, farmers obtained more agricultural knowledge and experience from their neighbors than from the extension personnel. The low efficiency of the extension services has substantially influenced the low contribution (34.1% during the '8th Five-Year' Plan from 1990 to 1995) of science and technology to agricultural development (Fan and Guo, 1999). In recent years, although non-governmental agro-technological services have been developing rapidly, their impact on the dissemination of agricultural technology is still very limited. Despite the establishment of agrochemical services by numerous fertilizer enterprises, their services have focused mainly on fertilizer sales rather than on FBMPs.

According to the statistical data (National Bureau of Statistics of China, 2005), there were about 250 million rural households with an average of 0.6 hectares of sown area in 2004. The potential for effective extension to these small-holdings is restricted to a certain extent since the use of commercial products is proportionately very low owing to the small areas involved (He, 2000). On the other hand, the 17,000 staff in the soil and fertilizer management sector of the extension system could not meet the technological demands of 250 million small-holders. Hu and Li (2004) indicated that, in 2001, the ratio of agro-technological extension workers to rural laborers was about 1/800, which is lower than in Europe (1/431) or North America (1/325). It was therefore difficult for most farmers to have access to agricultural technicians and technology transfer.

Poor education and lack of agricultural knowledge by farmers in China is another constraint to the extension of FBMPs. According to a survey conducted by the National Bureau of Statistics of China, the proportion of the population educated to a level above senior high school is only 20%, and this figure is lower for rural people. Poor education and lack of training has limited farmers' understanding of the importance of fertilizer management and its impact on the environment. For example, although about 70-80% of farmers knew that fertilizer application rates should be related to soil fertility and target yield levels, most of them did not know how to determine satisfactorily the fertilizer rate and application time. Improving education and the technological training of farmers will therefore make an important contribution to improvements in the impact of agricultural extension programs.

Perspectives

It appears that the FBMPs are a feasible solution to tackle or alleviate, to a certain extent, the problems that the country is facing in both food production and environmental protection within the next 20-50 years. As shown in the present study, these new nutrient management systems could reduce N fertilizer inputs by 20-40%, increase N recovery by the crop and raise grain yields by 2-12% compared to traditional practices.

However, there is still a long way between research on experimental plots and technology adopted widely by farmers. Despite the savings in N fertilizer use, current FBMPs did not lead to yields that are significantly higher than those obtained using farmers' practices. This makes farmers less enthusiastic about adopting FBMPs. Thus, efforts must continue to achieve higher yields along with efficient nutrient use and environmental protection.

Successful FBMPs depend on a concerted effort by a multitude of actors. Government has an important role to play. This role involves committing resources to national research and extension programs that contribute to sustainable nutrient and soil management, for example farm subsidies that create an environment conducive to the adoption of sustainable resource use and yield-increasing technologies.

On the fertilizer production side, a strong emphasis is needed on measures to improve fertilizer manufacturing efficiency, e.g. reducing the number of small-scale fertilizer production units and improving or innovating manufacturing processes. In addition, interaction between farmers, researchers, extension services and the non-governmental sector involved in research and dissemination of integrated nutrient and soil management techniques should be further strengthened.

Acknowledgement

We thank Dr. P. Christie (The Queen's University of Belfast) for revising the paper.

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Voluntary initiatives and regulations for fertiliser best management practices in India

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India is basically an agrarian country. The country supports nearly 17% of world's population on less than 2.5% of the land area. Due to the high and rapidly growing population, the agricultural policies in India have centered on national food security. The introduction of fertiliser-responsive high-yielding varieties (HYVs) proved to be a turning point in Indian agriculture. The country has witnessed rapid agricultural growth, particularly after late 1960s (Table 1).

Table 1. Growth of fertiliser consumption in India.

Year	Fertiliser consumption ($N+P_2O_5+K_2O$)		Gross irrigated area	Food grain production
	million tonnes	kg/ha	million ha	million tonnes
1969-1970	1.98	11.04	36.97	99.50
1979-1980	5.26	30.99	49.21	109.70
1989-1990	11.57	63.47	61.85	171.03
1999-2000	18.07	94.90	78.81	209.80
2000-2001	16.70	89.30	75.87	196.81
2001-2002	17.36	92.80	77.94	212.85
2002-2003	16.09	86.01	72.97	174.77
2003-2004	16.80	89.80	76.82	213.19
2004-2005	18.40	96.51	N.A.	198.36
2005-2006	20.34	106.69	N.A.	208.30

The metamorphosis of a nation from begging bowl to food grains surplus in less than three decades is, indeed, a remarkable achievement. Factors such as the increases in the area of HYVs, irrigated areas and fertiliser use, supported by favourable policies, made the greatest contribution to this progress. The Sivaraman Committee Report (1966) laid the foundation of a modern fertiliser policy. It emphasized the need to encourage the use of fertiliser-responsive HYVs, to promote the balanced use of fertilisers and to provide credit to farmers for the purchase of agricultural inputs. The country emerged as the third largest user and producer of fertilisers in the world.

Fertiliser consumption - uneven growth

Although fertiliser consumption has increased rapidly, the growth has not been uniform over time and space. In 2005-06, the per hectare fertiliser consumption varied from less than 3 kg/ha in the states of Arunachal Pradesh, Nagaland and Sikkim to more than 200 kg/ha in Punjab, Tamil Nadu and Andhra Pradesh. Three products, urea, diammonium phosphate (DAP) and muriate of potash (MOP) dominate the range of fertiliser products. Urea accounts for 81% of total N consumption and DAP for 60% of P consumption. Six crops (rice, wheat, cotton, sugar cane, rapeseed and mustard) consume about two-thirds of the fertiliser applied.

The benefits of the «Green Revolution» which enabled India to become self-sufficient in food grains are showing signs of diminishing. Some of the important challenges to be faced by Indian agriculture are:

- depletion of land and water resources,
- stagnation of food grain production and productivity,
- soil degradation (nutrient mining),
- increased secondary- and micro-nutrient deficiencies,
- low and declining fertiliser use efficiency,
- declining farm profitability.

Soil fertility depletion

Indian agriculture has entered an era of multinutrient deficiencies. Deficiencies of at least six nutrients–nitrogen (N), phosphorus (P), potassium (K), sulphur (S), zinc (Zn) and boron (B)–have become fairly widespread (Table 2).

Table 2. Extent of nutrient deficiencies in India

Nutrient	Samples deficient (%)
Nitrogen	89
Phosphorus	80
Potassium	50
Sulphur	40
Zinc	48
Boron	33
Iron	12
Manganese	5

The decline of soil fertility is largely because of increased crop removal and the inadequate and imbalanced use of fertilisers. At present, there is a negative annual balance of 8-10 Mt (million metric tonnes) of nutrients ($N + P_2O_5 + K_2O$) between the quantity of nutrients removed in crops and the quantity added through fertilisers. Continuous depletion of soil nutrient reserves is posing a threat to sustainable agriculture in India. The stagnation of food grain production and productivity during the past 5-6 years is a matter of serious concern, and the depletion of soil fertility is one of the major reasons for this stagnation.

Fertiliser best management practices - the emerging need

One of the main problems in Indian agriculture continues to be low crop productivity. Fertiliser consumption has increased significantly during in last three years. However, this increase in fertiliser consumption has not resulted in increases in crop productivity, due to the increasing deficiency of secondary and micronutrients and the continuing depletion in soil fertility. The requirement of 300 Mt of foodgrains by 2025 will have to be met essentially from increases in crop productivity, in view of the limited scope for increasing the cultivated area. Low fertiliser use efficiency and declining factor productivity are of serious concern and underline the need for developing fertiliser best management practices (FBMPs).

Principles of fertiliser best management practices

Balanced, efficient, integrated, profitable and environmentally friendly use of fertilisers are the basic principles of FBMPs. Balanced fertilisation must include information such as the nutrients that need to be applied and their amounts, the fertiliser product to supply the nutrient and the time and method of application. Once the product has been selected, it should be applied at the right time in the right way - a good fertiliser is not a substitute for faulty application. The integrated use of chemical fertilisers, organic manure and biofertilisers improves fertiliser use efficiency. Any factor, decision or event which improves the yield per kg of nutrient improves the profitability of the fertiliser use. Important components of FBMPs are:

- Application of chemical fertilisers to correct deficiencies of soil nutrient as identified by soil testing;
- Use of all available sources of plant nutrients, including organic manures and biofertilisers as well as chemical fertilisers;
- Application of soil amendments on acidic or alkaline soils;
- Adequate availability of plant nutrients in soils to meet the requirements of plants at their critical growth stages;
- Adequate soil humus to improve the physico-chemical and biological properties of soils.

Partners and key players

In India, a number of agencies - central and state governments, the Indian Council of Agricultural Research (ICAR) and its institutes, the fertiliser industry, several international organizations, NGOs and industry associations - are engaged in developing and promoting FBMPs.

Government initiatives

Most of the governmental programmes in India have aimed at increasing fertiliser consumption in a balanced manner, using a 4:2:1 NPK consumption ratio as a guideline. ICAR and State Agricultural Universities (SAUs) have generated valuable information on various aspects of fertiliser management, with special emphasis on the judicious use of fertilisers under different agro-climatic conditions. The results of long-term fertiliser experiments (LTFE) have highlighted the role of balanced fertilisation. They have demonstrated that, with the continuous application of N alone, there is a great risk of reducing the soil content of organic carbon, adversely affecting soil quality and crop productivity.

After the decontrol of P and K fertilisers in August 1992, the Government of India introduced the concession scheme for P and K fertilisers in order to improve the NPK consumption ratio. A task force on the balanced use of fertilisers has been set up and its report has been submitted for consideration by the government. The recommendations of the task force, if accepted, will go a long way to promoting the balanced use of fertilisers in India.

Regulatory framework

The Government of India identified the need for the regulation of fertilisers as early as 1957, when the annual consumption of fertilisers was less than 0.2 Mt NPK. In 1957, fertiliser was declared to be an essential commodity under the Essential Commodities Act (ECA). The government enacted the Fertiliser (Control) Order (FCO) in 1957, essentially to regulate the sale, the price and the quality of fertilisers. A revised FCO came into effect on September 25, 1985. In addition to the ECA and the FCO, other legislative measures that are applicable to fertilisers in India are the Fertiliser (Movement Control) Order (FMCO) of 1973, the Standards of Weight and Measures (Packaged Commodities) Rules of 1977, the ECA Supply Plan of 1982, the Environment (Protection) Act of 1986 and the Consumer (Protection) Act of 1986.

The main objective of the fertiliser legislation is to ensure the timely and adequate availability of good quality fertiliser throughout the country at affordable prices and in a balanced form. The government regulated the supply of fertilisers through seasonal allocation of fertilisers to different states to ensure adequate distribution. The government fixes the maximum retail prices (MRP) and it is not permitted to sell fertilisers at prices higher than the MRP.

A good example of using legislative measures to promote the balanced use of fertilisers was an early provision in the FCO of 1957 stipulating that a fertiliser dealer should have at least 20% of his stocks of fertilisers in the form of K fertilisers. This clause was removed in the FCO of 1985 since the use of K had become common in the soil/cropping systems. To promote integrated nutrient management in March 2006, the government included organic manure and biofertilisers in the FCO.

To encourage the use of sulphur, specifications for S were included in the FCO in 2003. Two straight S fertilisers i.e. S 90% (powder) and S 90% (granular) were covered. In December 2006, the government included customized fertilisers in the FCO to encourage site-specific nutrient management (SSNM). To expedite registration of new products, the government has introduced a new category of provisional fertilisers in the FCO (clause 20a). Three companies in India, National Fertilisers Ltd., Indogulf Fertilisers and Shriram Fertilisers and Chemicals Ltd., have been given provisional permission to manufacture neem-coated urea, whose high N use efficiency is proven.

The regulatory framework aims to ensure that the use of fertilisers does not have adverse effects on the soil and the environment. Impurities such as biuret, sodium chloride (NaCl) and heavy metals (lead, cadmium, arsenic, etc.) are kept below the permissible levels in fertiliser products. The fertiliser manufacturers have to ensure that the effluents and gases released from the manufacturing plants do not have any adverse effect on the soil or the environment.

Environmental safety

The per hectare fertiliser consumption in India is 106 kg/ha and, at this level, environmental pollution is not an issue. The studies undertaken in India to correlate the nitrate pollution of ground waters with the use of fertilisers do not indicate that an increased nitrate content in ground water is due to increased use of fertilisers (Table 3). However, in areas with a high fertiliser consumption, the studies were required to monitor the nitrate concentration in ground water on a time series basis.

Table 3. Nitrate content of ground waters in India.

District/State	Total samples	Samples having NO_3>45 mg/l (%)	Fertiliser consumption (kg/ha)
Barmer/Rajasthan	351	63	3
Gulbarga/Karnataka	529	49	66
Nagpur/Maharashtra	47	21	75
Mehsana/Gujarat	200	19	96
Satara/Maharashtra	1,001	16	123
Kurnool/Andhra Pradesh	143	18	185
Faridabad/Haryana	200	23	203
All India	4,496	29	106

Fertiliser industry initiatives

India has witnessed impressive growth in fertiliser consumption during the past four decades. A number of programmes have been initiated by the fertiliser Industry to educate farmers on the balanced and efficient use of fertilisers. The emphasis of the industry's programmes has changed over time according to the needs:

- Beginning of the planned era: create awareness of fertilisers;
- Sixties: fertiliser as a component of a package of practices;
- Seventies and eighties: enlarge the fertiliser consumption base;

- Nineties: promote balanced fertiliser use (NPK);
- Current decade: promote balanced, efficient and integrated use of nutrients to maintain soil health (IPNS approach).

Fertiliser companies are conscious of the fact that just making fertilisers available is not enough to increase its use. Convincing farmers of better returns and enabling them to make farming a profitable venture are equally important. Besides their involvement in various national programmes and international collaborative projects, fertiliser companies have initiated measures such as village adoption, crop demonstrations, soil testing, farmers meetings and general welfare schemes, to make the transfer of technology more rapid and effective.

In India, there are about 0.3 million fertiliser dealers, who are in a position to guide farmers. The fertiliser industry is putting a lot of emphasis on dealer and farmer training. Almost all the fertiliser companies organize series of dealer training programmes to up-date dealers' knowledge on various aspects of the balanced and efficient use of fertilisers. Some of the programmes and activities being undertaken by the fertiliser industry to promote the balanced and efficient use of fertilisers are:

- **Fertiliser demonstrations**: two plot demonstrations, block demonstrations, front line demonstrations and critical input package demonstrations;
- **Field programmes**: farmers' meetings, field days, crop seminars, soil testing, special campaigns;
- **Agricultural extension programmes**: village adoption, area development projects such as land reclamation, watershed management and other area specific projects, biofertilisers, micro irrigation; the use of agricultural implements, forestry projects, etc.;
- **Research and development**: modified forms of fertiliser (urea super granules, neem coated urea, zincated urea, fortified value-added products, soil and crop specific customized fertilisers);
- **Farmer service centers**: all major companies have established farmer service centres (FSCs) to provide all the agriculture inputs under the one roof, along with technical advice; at present, there are over a 1000 FSCs that have been established by various companies including IFFCO, KRIBHCO, CFCL, GSFC, GNFC, IGFL, NFL, RCF, ZIL, TCL & DSCL's Hariyali Kisan Bazar.;
- **Information technology**: e-services (E-Chaupal) of ITC, information KIOSKS of IFFCO, CFCL, GNFC;
- **Training**: dealer training programmes, training and farm visits.

Collaborative initiatives

Balanced fertilisation with sulphur

The Fertiliser Association of India (FAI), in collaboration with The Sulphur Institute (TSI) and the International Fertiliser Industry Association (IFA), started a project on "Sulphur in Balanced Fertilisation" in 1997 in order to identify S deficient areas and evaluate crop response to fertiliser S. The results of the project revealed that S deficiency is widespread in India, with an average of 46% of arable land soil deficient in S and 30% potentially deficient.

Balanced fertilisation with potassium

Indian Potash Limited (IPL), in collaboration with the International Potash Company (IPC), launched the Potash Promotion Project (PPP) for a period of three years beginning in April 2003. In this project, the approach was to promote existing state fertiliser recommendations for increasing K consumption and narrow the N:K consumption ratio.

Dealers training

FAI, in collaboration with the International Potash Institute (IPI), is organizing a series of dealers training programmes to promote the balanced and integrated use of fertilisers. Training programmes on fertigation are being organized to increase fertiliser and water use efficiency.

Soil health enhancement campaign

FAI, with the help of its member companies, launched a nation-wide campaign on Soil Health Enhancement in 2006-07. The response to the campaign was very encouraging. A number of activities covering soil testing, preparation of soil health cards, conducting demonstrations on the balanced and integrated use of fertilisers, organizing training for fertiliser dealers, farmers, etc. were undertaken by the fertiliser companies. More than 240 thousand soil samples were collected from farmers' field in different states of the country. A large number of farmers' meetings and crop demonstrations were organized to educate farmers on the balanced, efficient and integrated use of fertilisers (Table 4).

Table 4. Activities undertaken by fertiliser companies in the 'Soil Health Enhancement Campaign'.

Fertiliser company	Number of soil samples analysed	Farmers' meetings	Crop demonstrations	Field days
CFCL	48,824	101	43	16
IFFCO	53,455	1,726	351	137
Indo Gulf	22,461	272	1,224	120
KRIBHCO	9,213	75	68	-
NFCL	7,527	711	752	-
RCF	26,131	-	-	-
SFC	3,584	2,070	882	212
Others	70,694	1,214	651	20
Total	241,889	5,169	3,971	505

Successes and failures

The efforts of the government and the fertiliser industry have been very successful in increasing the demand for fertilisers at the farm level. The estimated increase of about 25% in NPK consumption and improvement in the NPK consumption ratio during the past three years is a significant achievement. However, a similar achievement has not occurred with other limiting nutrients such as S, Zn and B. The state governments and the fertiliser industry have done commendable work as regards soil testing and the distribution of soil health cards to all the farmers of the states. The fertiliser industry succeeded in analyzing more than 240 thousand soil samples during 2006-07, under the Soil Health Enhancement Campaign. Although India has a good network of 544 soil testing laboratories, supported by a vast extension system, the fertiliser industry has failed to convince farmers to use fertilisers based on soil testing.

The states of Uttar Pradesh, Tamil Nadu and West Bengal have revised their general fertiliser recommendations, but similar measures have not yet to be taken by other states. To promote the concept of integrated nutrient management, ten fertiliser companies are producing and marketing biofertilisers. Some companies have also started the production of vermicompost. The production and marketing of neem-coated urea is a significant contribution to improving N use efficiency of paddy. Some companies are considering the production of soil and crop specific customized fertilisers after their inclusion in the FCO.

Future needs

Appropriate pricing policy

Fertiliser policy plays an important role in the development and promotion of best management practices. It should address issues related not only to trade but also to the balanced and efficient use of fertilisers, the development of more efficient products, economic and environmental aspects. In this context, the following recommendations of the Task Force on Balanced Use of Fertilisers, which are under consideration by the government, are relevant:

- Expand soil testing facilities in the country, in the public and private sectors;
- Accelerate efforts by state governments and the industry to promote the use of all sources of organic nutrients and to provide financial assistance for increasing their production;
- Encourage development of alternative products with better efficiency, fortification of major fertilisers with appropriate secondary and micronutrients, customized and value added fertilisers;
- Provide the necessary regulatory mechanisms for ensuring the quality of fertilisers;
- Implement policy measures based on nutrients instead of on products as at present.

Value added/fortified products

Products and practices which improve fertiliser use efficiency should be encouraged. The development of more efficient N fertilisers, such as neem-coated urea, needs to be encouraged by providing a price incentive to the fertiliser manufacturers. The fertiliser industry should be pro-active in developing soil and crop specific customized fertiliser for different agro-ecological regions.

Amendments in the Fertiliser Control Order

Several new fertilisers have been included in the FCO in last five years, but the registration of new products is a lengthy process. A system providing rapid approval of new fertilisers, which have proven efficiency and wide applicability, should be put in place. This would provide healthy competition in the fertiliser industry to innovate and produce various new fertiliser products having better nutrient use efficiency.

Integrated nutrient management

It must be recognised that the nutrients needs of Indian agriculture are now greater and more varied. No single nutrient source, be it fertiliser, organic manures or biofertilisers, is adequate to meet the needs of crops. The integrated use of all available sources of plant nutrients is needed to check soil nutrient depletion and maintain soil fertility and crop productivity. There is a need to develop crop rotations involving legumes to benefit from biological N fixation.

Integrated nutrient management should take account of soil constraints (acidity or sodicity) and, in acidic soils, the application of amendments should precede that of fertilisers. Research efforts are needed to identify the crops and soil types where a particular nutrient source would be more appropriate. Intensive farmer training should be organized to educate them on preparation of compost, based on standard scientific methods.

Rejuvenating extension services

Farmers' knowledge regarding the right product, dosage, time and method of application is inadequate, leading to the inefficient use of fertilisers. Extension systems should be rejuvenated and reoriented with focus on poor farmers and low fertiliser consumption areas. Extension agencies should ensure that farmers use fertilisers in accordance with soil and crop requirements. The facilities of existing soil testing laboratories need to be expanded in order to analyze for secondary and micronutrients.

Conclusion

It is forecast that, by 2025, India will require 45 million tonnes of nutrients ($N+P_2O_5+K_2O$) to produce 300 million tonnes of food grains for an estimated population of 1.4 billion. The dependence on fertilisers and other nutrient sources will increase if the rising food demand of the ever-growing population is to be met. National food security will remain a priority for the agricultural and fertiliser policies in India. Considering the low per hectare fertiliser use and crop yields, India has a good potential to increase crop productivity by increasing the use of inputs. Food grain production could be increased by 60 Mt just by adopting FBMPs and better water management. At the present low level of fertiliser consumption, in terms of kg/ha, environmental concerns due to fertiliser use are not an issue in India.

Fertilizer best management practices in Pakistan

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Background and socio-economic set up

Agriculture contributes about 22% to the Gross Domestic Product (GDP), employs 44.8% of the labour force and is major source of foreign exchange earnings. About 65.9% of the country's population living in rural areas is directly or indirectly linked with agriculture for their livelihood. Thus, whatever happens to agriculture is bound to affect not only the country's growth performance but also, to a large extent, the country's population. In the last three decades of the 20th century, Pakistan witnessed an unprecedented technological and economic transformation, which started in the late 1960s with the advent of the Green Revolution. The key elements in improving agricultural production were the combination of a technology package (high-yielding varieties, water, fertilizer), an improved policy environment, investment and infrastructure development in agriculture. The population of the country is about 155 million, growing at about 2% per annum. There are 6.6 million farms, with an average farm size of about 3 ha. The total cropped area is 22.5 million hectares (Mha), which has not shown any increase since 1992-93. The expansion of the cropped area will depend on the availability of irrigation water, which is less than the demand. Therefore, the major emphasis in the future will be on improving crop productivity per hectare through best fertilizer management and crop husbandry practices. This paper reviews fertilizer use practices, crop production and the rationale for developing fertilizer best management practices (FBMPs).

State of agriculture and fertilizer use

Crops sown and source of irrigation

Pakistan is located in the semi arid, sub-tropical region and a large part of the country is located in the Indus plain. Of a total cropped area of 22.5 Mha, 18.8 Mha (85%) is irrigated and the rest is rainfed. Of the irrigated area, 7.0 Mha is served by river canals, 7.7 Mha by canals and tubewells and 3.46 Mha by tubewells only. The soils are calcareous alkaline with a low organic matter content. There are two cropping seasons: Kharif (summer) and Rabi (winter). Major Kharif crops are cotton, rice, sugarcane and maize. The major Rabi crops are wheat and oilseed. Other crops include potatoes, onions, chillies and pulses, which are grown in both seasons or are sandwiched between the two. A variety of fruit and vegetable crops are grown. Table 1 shows the area, production and yield of major crops. The yields of the important crops have improved over the years, but they are still at about 40 to 60% of their economic yield potential.

Table 1. Area and yield of major crops and average annual growth (Government of Pakistan, 2005).

			Growth (%)	Yield (kg/h)a		Growth (%)
	1992-93	2004-05		1992-93	2004-05	
Wheat	8,300	8,358	-	1,947	2,586	2.38
Rice	1,973	2,519	2.06	1,622	1,994	1.74
Maize	867	981	1.03	1,364	2,894	6.47
Sugar cane	885	966	0.73	43,000	49,000	1.09
Cotton	2,836	3,192	0.99	543	760	2.84

Fertilizer use

The consumption of fertilizers has increased substantially since 1966-67 (Figure 1). This figure shows that nitrogen (N) use has increased steadily since its introduction, but that growth in phosphate (P) use has been inconsistent. The total annual use of potash (K) is negligible, and so is that of micronutrients. The total fertilizer use in the country is about 3.8 million tonnes (Mt) nutrients, of which N, P and K account for 77%, 22% and 1% respectively. The national average nutrient use is about 169 kg/ha, but it is seriously imbalanced and used inefficiently. This imbalance use coupled with poor fertilizer management practices leads to inefficient use of plant nutrients.

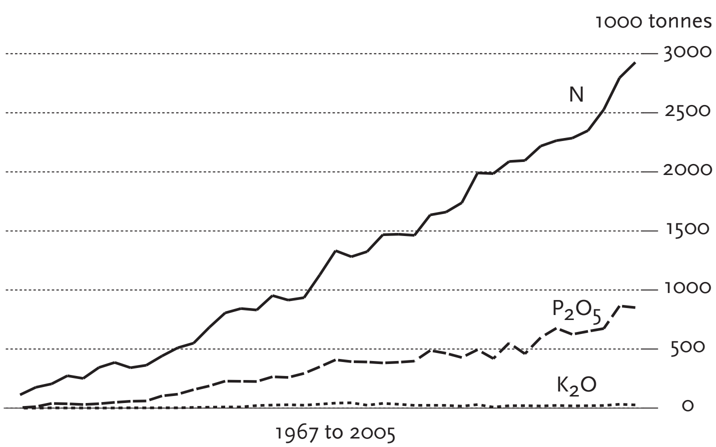

Figure 1. Fertilizer use development (NFDC, 2006).

Fertilizer use efficiency

Fertilizer use efficiency in farmers' fields varies according to the different cropping conditions. The utilization of N has been estimated to vary from about 30% in flooded (lowland) rice to about 40 to 50% in irrigated crops grown under upland conditions. The low efficiency of N fertilizer under rice and upland crops stems from various mechanisms, of which ammonia volatilization is the most important under Pakistani conditions. Urea consumption amounts to about 5.5 Mt costing US$ 1.0 billion. With an average N use efficiency of 40%, the loss is about US$ 600 million, plus the cost to the environment. Nitrogen use efficiency (NUE) measured as the amount of food produced per unit of N applied (partial factor productivity) has continued to decline during the past two decades (Figure 2). The current NUE for cereal crops in Pakistan is about half of the world average. The NUE can be increased to 60% on well-managed farms. The utilization of P fertilizer by the first crop is only 15 to 20%. Most zinc (Zn) fertilizer is fixed by calcareous soils, and only a small fraction remains available.

Figure 2. Fertilizer N use efficiency.

Fertilizer best management practices

Principles of fertilizer best management practices

The principles of FBMPs are to:

a) Create awareness among farmers of the need to use optimum and balanced fertilizer applications in order to improve crop productivity and their profitability;
b) Provide planners and policy makers with a sound understanding of the role of fertilizers in sustainable crop production and poverty alleviation;
c) Promote the integrated use of plant nutrients for sustainable agricultural growth and environmental protection;
d) Restore and enhance soil fertility and minimize losses of applied nutrients.

Balanced fertilizer use – key to improve efficiency and productivity

Balanced fertilizer use and efficient nutrient use are two key aspects of FBMPs. Despite rapid increases in fertilizer use, it remains skewed in favour of N. Yet a farmer may make a balanced fertilizer application and still not achieve high efficiency. There are other crop husbandry factors which may have an impact on the overall efficiency of applied fertilizers, such as:

- poor seed bed preparation,
- poor quality seed,

- improper seeding or delayed sowing,
- unsuitable crop variety,
- inadequate irrigation / drainage;
- weed infestation,
- pests and diseases, etc.

Adoption of best management practices supports fertilizer use efficiency.

The National Fertilizer Development Centre (NFDC), jointly with the Food and Agriculture Organization of the United Nations (FAO) and the World Phosphate Institute (IMPHOS), has been demonstrating and promoting the balanced use of plant nutrients at farm level. In these trials, the yield increase with the balanced use of fertilizers was substantially higher compared with that from N alone (Table 2).

Table 2. Effect of balanced fertilization on yield of major crops (NFDC, IMPHOS and FAO, 2006).

Crop	Yield (kg/ha)		Percent increase
	N only	NPK	
Wheat	2,521	4,120	63%
Paddy (Basmati)	2,800	4,494	60%
Maize	2,110	5,084	140%
Sugar cane	56,515	126,334	123%

The potential impact on crop production of balanced fertilizer is important. The potential additional yield with a 50% adoption of balanced fertilizer use could translate into an average increase of 30% of national crop production, with a total financial gain of US$ 1.4 billion.

Rate of fertilizer application

As regards site-specific fertilizer use, there are about 60 soil testing laboratories in the public and private sectors. Surveys have shown that scarcely 5% of the farmers use the facilities of soil testing laboratories. Most of the farmers use their own experience and/or that of fellow farmers, taking into account the expected profitability, their access to credit and to markets. General fertilizer recommendations issued by research, extension and the fertilizer industry are distributed widely. In formulating generalized recommendations for any crop, the produce price, crop response and cost of fertilizer are taken into account. Based on crop response data, the provincial and national organizations in the country formulate fertilizer recommendations, which provide a useful guideline.

Method and time of fertilizer application

The most effective methods and time of fertilizer application depend on the type of nutrient, product quality, soil type, crops to be grown, source of irrigation and the physiological stage of crop growth. The broad guidelines for different nutrients are summarized below:

Nitrogen

The general FBMPs developed for N are:

- Have a realistic yield goal to avoid over-use of N. The recommendation should take into account the type of soil, the crop and the source of irrigation.
- Apply N in two to three split applications for all the major crops, depending on the soil and the physiological stage of crop growth. Three split applications are recommended for light textured soils and long duration crops/varieties.
- At the sowing of the crop, N should be applied banded; the top dressed second and third split applications should be irrigated immediately to minimize volatilization losses.
- On rice, half of the N should be incorporated into mud-wet soil followed by flooding to check volatilization. The remaining half should be applied at the panicle initiation stage.
- For cotton, one third of the N should be applied at sowing by band placement and the remainder in two split applications at the first irrigation and at the pre-flowering stage.
- For other crops, N should be applied in two to three split applications; preferably, the first application should be banded.
- In the event of severe disease, use smaller split applications or omit top dressing.
- In the case of crops following legumes, the N rates can be reduced by 20 to 40 kg/ha, depending on the biomass of the legume crop.

Phosphorus

- One third of the P fertilizers should be mixed with two parts of well-decomposed and moist farmyard manure for 12 hours before application to soils.
- Apply the P through banding at the side of seed.
- Phosphate fertilizer dissolved in water and applied with first irrigation improves efficiency by 20 to 30%.
- If the Rabi (winter) crop is fully fertilized with P and the soil test value is higher than 15 mg/kg, reduce the P application to the succeeding crop.

Potash

- Band with P at sowing.
- Two split applications on light textured soils.

Micronutrients

- Boron and zinc should be banded with the major nutrients, or broadcast after mixing with five times their volume of well-pulverized soil.
- Micronutrient fertilization of cotton can also be applied as a 0.1% foliar spray 45, 60 and 90 days after sowing.

Integrated plant nutrient supply – the best mix

Farmers are encouraged to use all other sources of plant nutrients, such as organic and biofertilizers, to complement and supplement chemical fertilizers.

Foliar application of nutrients

Foliar application is used only for micronutrients and growth regulators.

Role of the fertilizer industry in developing and promoting fertilizer best management practices

The fertilizer industry has been accused of marketing strategies based on selling more bags and not promoting best management practices. This was partly true in the introductory stages. Over time, however, the industry has not only improved the availability of the products throughout the country but also has established efficient advisory services. Farmers' education and training programmes include crop demonstrations, extension activities, publication of fertilizer/crop literature, TV documentaries, etc. Soil testing laboratories have been established, permitting soil-based recommendations and balanced fertilizer use. Recently, the fertilizer industry has also begun to issue information on best management practices regarding fertilizer rates, method of application and time of application, with adaptation to different agro-climatic zones.

The fertilizer industry is also collaborating with national research and development institutes in the development of new technologies and their promotion. However, there is a need to improve industry/research/extension/university interactions.

Adoption of fertilizer best management practices by farmers

Fertilizer use development in Pakistan is reaching a maturity stage. It is now the second and third generation of farmers who have been using fertilizers since their introduction. However, FBMPs are adopted only by progressive farmers. Their yields are very high compared with those of average farmers (Figure 3). The surveys conducted by NFDC show that, though over 90% of the farmers have adopted fertilizer use, fertilizers are not applied in balanced doses, at the right time and using methods that are conducive to maximum output. Their use is mostly imbalanced and inefficient. There are number of constraints, such as the farmer's lack of knowledge, product availability, economic conditions, credit, profitability, weather, family obligations/competing requirements, etc.

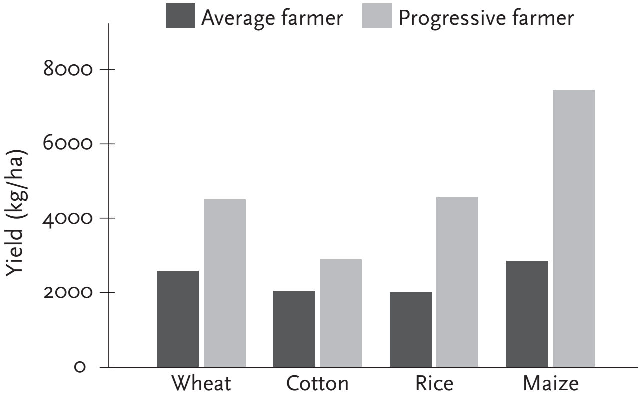

Figure 3. Adoption of FBMPs by farmers (NFDC and other research organizations).

The way forward/future plans

There is a need for a strong interaction between the stakeholders in the development, promotion and adoption of FBMPs, such as policy makers, planners, researchers, extension workers, the fertilizer industry, financial institutions, fertilizer dealers and, above all, farmers. It is important for policy makers to be aware of the importance of FBMPs for sustainable growth in agriculture and protection of the environment. The researchers have to fine-tune the techniques. The extension services, the fertilizer industry and NGOs should work hard with the farmers to demonstrate and convince them to adopt FBMPs. The role of financial institutions for advancing credit with technology backup is very important.

As regards technological development, there is a need to develop complex, slow- and controlled-release fertilizers for site-specific nutrient management. The FBMP developments related to precision agriculture, conservation agronomy and biotechnology must be shared between developed and developing countries.

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Fertilizer best management practices in Southeast Asia

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Countries in Southeast Asia for the purposes of this case study include Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand, and Vietnam. Rice, oil palm, and maize are the three most important agricultural crops in the region (Figure 1) (FAO, 2007). These three crops account for 75-80% of the fertilizer consumption in Southeast Asia.

Rice production increased slightly from 162 million metric tonnes (Mt) in 2004 to 167 Mt in 2005. Maize production increased slightly from 25.7 Mt in 2004 to 26.2 Mt in 2005. Maize is also expected to gain further importance because of a high demand for animal feeds in the region and beyond. Oil palm fruit bunch production has increased sharply with an average growth rate of 13% during the 10-year period 1996-2005. The total oil palm fruit bunch production increased from 136 Mt in 2004 to 145 Mt in 2005. Indonesia is the top producer of maize and rice among the eight Southeast Asian countries (FAO, 2007). In 2005, rice production was 54 Mt and maize production was 12 Mt in Indonesia. Malaysia and Indonesia dominated the oil palm sector with a production in 2005 of 76 Mt in Malaysia and 64 Mt in Indonesia (FAO, 2007).

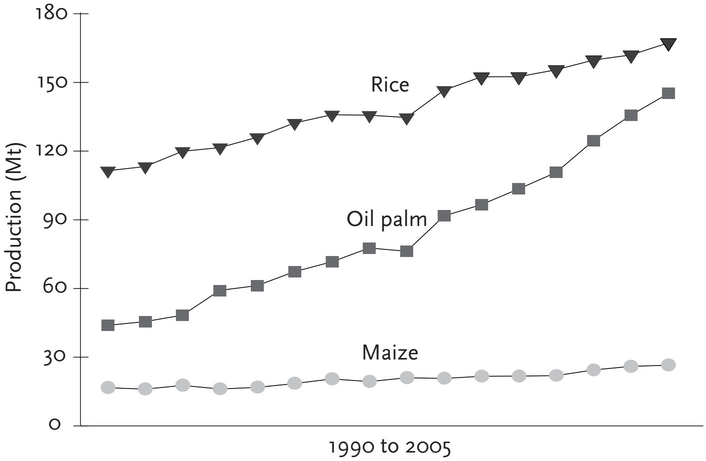

Figure 1. Total production of rice and maize (Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Thailand and Vietnam) and oil palm fruits (Indonesia, Malaysia, Philippines and Thailand) in Southeast Asia from 1990 to 2005 (FAO, 2007).

Relatively greater use of fertilizer N compared to P and K continues in Southeast Asia (Figure 2), but fertilizer P and K demand is expected to rise in the future due to yield increases and area expansion, particularly for oil palm. Fertilizer K consumption in Malaysia and Indonesia, for example, continues to increase. In 2005, fertilizer K consumption in both Malaysia and Indonesia increased by 50,000 tonnes.

Of the eight Southeast Asian countries, Indonesia is the largest consumer of fertilizer N and the second largest consumer of fertilizer P and K. Most fertilizer in Indonesia is consumed by rice and oil palm. Overuse of fertilizer N in rice is common so that consumption is expected to slightly decrease in coming years. Indonesian farmers have used substantial amounts of fertilizer P in rice since the green revolution days, and recommended fertilizer P rates were lowered in the 1990s followed by a decline in P use in the mid 1990s. Fertilizer K consumption has substantially increased since 2000 because of a strong demand in oil palm plantations.

Vietnam is the second largest consumer of fertilizer N and the largest consumer of fertilizer P. Fertilizer consumption in Vietnam increased markedly in the 1990s driven by a substantial intensification in rice production. Vietnam is today the second largest rice exporter after Thailand. Crop diversification is increasing substantially. Other important crops include coffee, maize, vegetables and sugarcane.

Malaysia is the largest consumer of fertilizer K. Most fertilizer in Malaysia is consumed by oil palm. Further expansion of oil palm is limited due to a lack of suitable land, and further increases in fertilizer consumption will be associated with increased intensification of oil palm production.

Most fertilizer in the Philippines is consumed by rice, maize, fruits and vegetables. Fertilizer consumption has remained largely unchanged since 1990. Unbalanced fertilizer application is common.

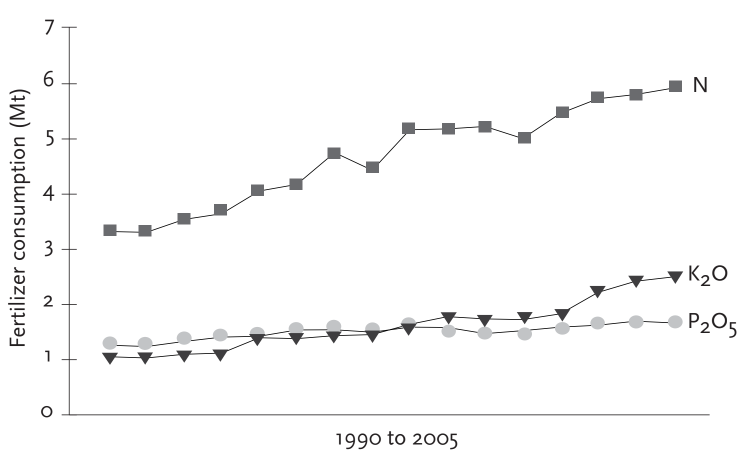

Figure 2. Fertilizer N, P and K consumption in Southeast Asia (IFA, 2006).

Fertilizer consumption in Thailand is quite stable. Rice is by far the greatest fertilizer consumer followed by maize, sugarcane, fruits and vegetables.

Fertilizer consumption in Cambodia, Lao PDR and Myanmar is small.

Fertilizer best management practices for irrigated rice

Rice is the most important crop in terms of fertilizer use, especially N, in Southeast Asia. Rice farmers often apply fertilizer N at rates and times not well matched to the needs of the crop for supplemental N. For example, the application of fertilizer N by farmers during early vegetative growth soon after transplanting or direct seeding often exceeds the needs of rice for N, whereas the application of N at the critical growth stage of panicle initiation (about 60 days before rice harvest) is often insufficient to match crop needs. Balanced fertilization — particularly with K, S and Zn — to ensure nutrients other than N are not limiting yield is becoming increasingly important to achieving increased profit for farmers and higher efficiency for fertilizer N use.

Site-specific nutrient management (SSNM) as a plant-based approach for supplying rice with essential nutrients to optimally match the needs of the crop is fortunately becoming increasingly known to research and extension workers and increasingly being disseminated to farmers across Southeast Asia (IRRI, 2007). The SSNM approach provides the principles and practices for:

- Estimating the total amount of fertilizer N, P and K required by a rice crop;
- Prescribing an amount of fertilizer N in the first N application near crop establishment;
- Dynamically adjusting the within-season rates of fertilizer N to match the spatial and temporal needs of the crop for N;
- Farmer-participatory tailoring of fertilizer management to field-specific conditions.

Estimating crop need for fertilizer

The SSNM approach is based on the direct relationship between crop yield and the need of the crop for a nutrient, as determined from the total amount of the nutrient in the crop at maturity. A yield target provides an estimate of the total nutrient needed by the crop. The portion of this requirement that can be obtained from non-fertilizer sources such as soil, crop residues, organic inputs, atmospheric deposition and irrigation water is referred to as the indigenous nutrient supply. Because rice grain yield is directly related to the total amount of nutrient taken up by rice, indigenous nutrient supply can be determined from the nutrient-limited yield, which is the grain yield for a crop not fertilized with the nutrient of interest, but fertilized with the other nutrients to ensure they do not limit yield.

The fertilizer N needed by a rice crop can be estimated from the expected increase or response in grain yield due to fertilizer N application and the expected efficiency of fertilizer N use by the crop as shown in Table 1. The grain yield response with fertilizer N application is the difference between the yield target and yield without fertilizer N (N-limited yield). The yield target is the yield attainable by farmers with good crop and nutrient management and average climatic conditions. The agronomic efficiency of fertilizer N (AE_N), which is the increase in yield per unit of fertilizer N applied, is used as the measure of the efficiency of fertilizer N use.

Table 1. Guidelines for estimating total fertilizer N required for rice, based on yield response to fertilizer N and efficiency of fertilizer N use.

Efficiency of fertilizer N use (kg grain increase/kg applied N) →	15	18	20	25
Expected yield response (t/ha) ↓	Fertilizer N rate (kg/ha)			
1	65	55	50	40
2	130	110	100	80
3	195	165	150	120
4		220	200	160
5			250	200

Experiences in Asia indicate that an AE_N of 25 kg grain increase/kg N applied is often achievable in the tropics with good crop management in high-yielding seasons, and an AE_N of 18 to 20 kg grain increase/kg N is achievable in the tropics with good management in low-yielding seasons. An AE_N of 15 kg grain increase/kg N is a realistic target for environments where existing fertilizer N management practices are very inefficient with AE_N in farmers' fields of about 10 kg grain increase/kg N or less.

As a general rule for modern rice varieties with harvest indices of 0.45 to 0.55, apply about 4 kg P_2O_5/ha per tonne of grain harvested to match the export of P_2O_5 with harvested grain when most of the crop residue is retained in fields after harvest and little or no manure is applied to fields. For example, apply about 20 kg P_2O_5/ha for a grain yield of 5 t/ha. When all crop residues are removed from fields after harvest and P input from organic amendments is negligible, apply about 6 kg P_2O_5/ha per tonne of grain harvested to match the export of P_2O_5 with harvested grain and straw and maintain soil P fertility. For example, apply about 30 kg P_2O_5/ha for a grain yield of 5 t/ha.

In the case of K, apply about 3.5 kg K_2O/ha per tonne of grain harvested to match the export of K_2O with harvested grain when all crop residues are retained in fields after harvest. For example, apply about 17.5 kg K_2O/ha for a grain yield of 5 t/ha. When all crop residues are removed from fields after harvest, apply about 12 kg K_2O/ha per tonne of grain harvested to match the net export of K_2O with harvested grain and straw and maintain soil K fertility. For example, apply about 60 kg K_2O/ha for a grain yield of 5 t/ha.

Disturbing nutrient inputs during the crop growing season

For best effect, farmers should apply fertilizer N several times during the growing season to ensure that the N supply matches the crop need for N at the critical growth stages of tillering, panicle initiation and grain filling. With the SSNM approach, guidelines for fertilizer best management practices (FBMPs) are provided by crop growth stage.

Early vegetative phase

This phase covers the period from before crop establishment up to 14 days after transplanting (DAT) for transplanted rice or up to 21 days after sowing (DAS) for wet-seeded rice. During this period, apply:

- Only a moderate amount of fertilizer N because the need of rice for supplemental N is small during that phase of slow initial plant growth;
- All of the required fertilizer P because P is important for early crop growth, especially for root development and tillering;
- At least half the required fertilizer K because it can contribute to greater canopy photosynthesis and crop growth;
- All of required zinc (Zn) and sulfur (S) fertilizer.

Use the following guidelines for the early application of N before 14 DAT or 21 DAS:

- Typically apply about 20 to 30 kg N/ha in seasons with yield response to N between 1 and 3 t/ha;
- Apply about 25 to 30% of the total N in seasons with yield response to N >3 t/ha;
- Eliminate early application when yield response to N is ≤1 t/ha;
- Do not use the leaf color chart (LCC) with the early N application;
- Reduce or eliminate early N application when high-quality organic materials and composts are applied or the soil N-supplying capacity is high;
- Increase the N application up to 30 to 50% of the total N for transplanted rice when old seedlings (>24 days old) and short-duration varieties are used;
- Increase early N application in areas with low air and water temperature at transplanting and for low tillering and large panicle type varieties.

Apply all fertilizer K before 14 DAT or 21 DAS, when the total fertilizer K requirement is relatively low (≤30 kg K_2O/ha). On sandy soils or when larger amounts of fertilizer K are required, apply about 50% of the required fertilizer K before 14 DAT or 21 DAS.

In case of S deficiency, apply about 2.5 to 3 kg S/ha per tonne of anticipated crop yield before 14 DAT or 21 DAS. In case of Zn deficiency, apply about 5 kg Zn/ha as zinc sulfate before 14 DAT or 21 DAS. Alternatively, for transplanted rice apply zinc sulfate in the nursery seedbed or dip seedlings in 2 to 4% zinc oxide suspension before transplanting.

Late vegetative phase

Rice plants require N during the tillering stage to ensure a sufficient number of panicles. The critical time at active tillering for N application is typically about midway between 14 DAT or 21 DAS and panicle initiation. The need of the rice crop for fertilizer N can be determined by leaf N status, which is related to leaf color. Dark green leaves have ample N, whereas yellowish green leaves are deficient in N. The LCC is a simple and inexpensive tool to rapidly assess leaf N status based on leaf color (Witt *et al.*, 2005b; IRRI, 2007). The standardized LCC is 14 cm long, made of high-quality plastic, consisting of four color shades from yellowish green (No. 2) to dark green (No. 5).

Reproductive phase

Panicle initiation (about 60 days before harvest of tropical rice) is a critical stage for ensuring the supply of N and K are adequate to match the needs of the crop. An insufficient supply of N at panicle initiation can result in loss of yield and profit through reduced number of spikelets per panicle. The LCC can be used to guide the application of fertilizer N to maintain an optimal leaf N content for achieving high rice yield with effective N management. As a rule of thumb, the more yellowish green the leaf color, the greater the need of the crop for fertilizer N. The need for fertilizer N at active tillering and panicle initiation also increases in proportion to the response in grain yield to fertilizer N. Table 2 provides guidelines for variable N rate management at active tillering and panicle initiation, based on yield targets and plant N status as determined with the LCC. The fertilizer N rates in Table 2 can be fine-tuned and tailored to accommodate location-specific crop-growing conditions and rice varieties.

An insufficient K supply at panicle initiation can result in loss of yield and profit through reduced spikelets per panicle and reduced filling of grain. Apply at panicle initiation up to 50% of the total fertilizer K requirement when the total fertilizer K requirement is >30 kg K_2O/ha. In the case of sandy soils, typically apply up to 50% of the total fertilizer K requirement, even when the requirement, is ≤30 kg K_2O/ha.

Table 2. Guidelines for the application of fertilizer N to rice with the leaf color chart (LCC) at active tillering and panicle according to yield target and N-limited yield (adapted from Witt *et al.*, 2007).

Approximate yield without fertilizer N–N-limited yield (t/ha) ↓	Yield target (t/ha) →		5	6	7	8	9
	LCC reading	Leaf color	Fertilizer N rate (kg/ha)				
4	LCC ≤ 3	Yellowish green	35	45	45-60*	60	◄
	LCC = 3.5	Intermediate	25	35	35-45*	45	◄
	LCC ≥ 4	Green	0	0	25	25-35*	◄
5	LCC ≤ 3	Yellowish green	--	35	45	45-60*	60
	LCC = 3.5	Intermediate	--	25	35	35-45*	45
	LCC ≥ 4	Green	--	0	0	25	25-35*
3	LCC ≤ 3	Yellowish green	45	45-60*	60	60	◄
	LCC = 3.5	Intermediate	35	35-45*	45	45	◄
	LCC ≥ 4	Green	0	25	25-35*	25-35*	◄

* Use the lower rate at active tillering and the higher rate at panicle initiation

Ripening phase

Nitrogen absorbed during the ripening phase, in the presence of adequate solar radiation, enhances the grain filling process. Inbred rice normally does not require fertilizer N at heading or flowering if the N application at the critical growth stage of panicle initiation was adequate. Hybrid rice and large panicle type (panicle weight type) rice in high-yielding seasons often require a fertilizer N application at early heading. As a general guideline, do not apply fertilizer N at early heading or flowering except in the following cases:

- For hybrid rice, apply about 20 kg N/ha at early heading when the expected response to fertilizer N is ≥3 t/ha and leaf color is yellowish green (LCC value 3).

- For large panicle type rice, apply about 25 kg N/ha at early heading when the expected response to fertilizer N is ≥3 t/ha regardless of leaf color.

Fertilizer best management practices for maize

Fertilizer best management practices for maize comparable to the SSNM approach for rice are in an advanced stage of development through a regional project coordinated by the Southeast Asia Program of IPNI-IPI. The SSNM approach for maize is scheduled for publication in 2008. As with SSNM for rice, SSNM for maize provides the principles and practices for:

- Estimating the total amount of fertilizer N, P and K required by a rice crop;
- Prescribing an amount of fertilizer N in the first N application near crop establishment;
- Dynamically adjusting the within-season rates of fertilizer N to match the spatial and temporal needs of the crop for N.

As with rice, the fertilizer N needed by a maize crop can be estimated from the expected response in grain yield due to fertilizer N application and the expected agronomic efficiency of fertilizer N use by the crop.

Fertilizer best management practices for oil palm

Fertilizer comprises a high portion of the variable cost in intensively managed plantation crops such as oil palm. There is often considerable innovation and receptivity to new technologies. The opportunities for promotion and adoption can be quite high, and new technologies can be implemented at large scale. Key principles of crop and nutrient management include:

- Decision making based on relevant information;
- Development of management units based on soil and plant surveys;
- Best management practices for optimal economic yield;
- Plant-based determination of nutrient needs and
- 'Need-based' fertilizer use for effective and environmentally sound nutrient use (Witt *et al.*, 2005a).

Ingredients to successful promotion and adoption

Farmers in Southeast Asia often lack sufficient knowledge on the most effective use of fertilizers for their fields. Their resulting ineffective use of fertilizer can limit their profit from farming and, in the case of rice, it can increase the susceptibility of their crop to diseases and pests. The SSNM approach for rice is now being widely promoted through partnerships with research and extension organizations, non-government organizations and the private sector in order to empower farmers with decision-making skills for their specific rice-growing conditions. Dissemination of a complementary SSNM approach for maize will soon follow, drawing upon experiences and successes with the promotion and dissemination of SSNM for rice.

Based on our experiences with rice, maize and oil palm, key ingredients to the successful development, promotion and adoption of FBMPs include:

- sound, science-based concepts,
- involvement of key stakeholders from the beginning,
- strong partners across research and extension,
- consistent, clear and unbiased messages for end users,
- participation and empowerment of farmers,
- strong institutional links,
- long-term funding.

The effective uptake by farmers of relatively knowledge-intensive technologies such as FBMPs requires the communication of consistent and clear messages to farmers. This necessitates that farmers receive comparable messages from all technical experts, extension workers and media they encounter. One of the challenges in disseminating SSNM for rice has been avoiding confusion to extension workers and farmers arising from contrasting information and recommendations from different organizations and technical resource persons. An important ingredient to success is, therefore, to involve stakeholders and partner organizations from the onset, and to develop consensus among organizations on the science-based messages to be disseminated.

Because of inherent spatial and temporal variation, the 'best fertilizer management practice' can often vary within fields, among fields and between seasons and years. Technical experts or extension workers must be sufficiently familiar with the inherent scientific principles and concepts so that they can provide farmers with improved decision making on the selection of the 'best practice' for their specific field locations and seasons. The dissemination of FBMPs therefore requires effective training of researchers, local extension workers, fertilizer retailers and farmer leaders on techniques and guidelines for enabling rice farmers to use the 'best' nutrient management practices for their specific rice-growing conditions.

We strive through the process of disseminating SSNM to empower farmers with greater decision-making skills for their specific rice-growing conditions. Field visits and farmer meetings are encouraged together with the use of simple observational tools such as nutrient additional plots. We plan in the future to develop more effective ways for farmers to utilize knowledge of their historical use of fertilizer P and K, their straw management practice, yield targets, and simple field observations to help them identify improved nutrient management practices for their specific rice fields.

Site-specific nutrient management for rice and maize would not exist today without the past strong commitment of the donors and project partners to research on developing new, science-based concepts. Such commitments to research must continue. Site-specific nutrient management for rice and maize would not exist today without the strong partnerships among national and international organizations across the Southeast Asia region. Site-specific nutrient management for rice and maize would also not exist today without the long-term commitments in funding from donors. The current dissemination of SSNM of rice builds upon a decade of research and partnerships across Asia beginning with the development and testing of a plant-based concept followed by on-farm evaluations, adaptive research for tailoring recommendations to local needs and conditions, training, building awareness at provincial and national levels, and developing clear and consistent messages for local extension and farmers.

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Global assessment of the situation of fertilizer best management practices

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Global warming, protecting the environment and safeguarding natural resources are of great public concern. In consequence, agriculture is becoming increasingly regulated with, in the case of fertilizers, restrictions on how much plant nutrient should be used and how it should be applied. The global fertilizer industry as the major source of plant nutrients is obliged to assist its clients, the farmers, by providing the means and tools to enable them to best manage nutrients.

There are countless fertilizer recommendations aiming to increase farm output and income and - to a certain extent – also to protect the environment. However, the wide array of recommendations is certainly not conducive to effective communication with the public and with legislative bodies when further rules and regulations regarding agricultural production and fertilizer use are being formulated and implemented. What seems to be needed is a proactive response, with one voice, and a forward-looking program in which a framework is given on how to manage fertilizer nutrients most effectively and to protect the environment, as well as providing the means for income generation and the production of sufficient and affordable food, feed, fiber and energy.

Since agriculture is confronted with continuously changing demographic and agronomic developments, the framework for best management of fertilizer nutrients has to be a living document, flexible and amenable to revision and updating.

Some of the major demographic challenges can be summarized as follows:

- The global population is still growing and, thus, also the demand for food in general;
- Urbanization is still advancing, accompanied by dietary changes, towards more animal protein, processed food and higher quality food;
- The population is aging rapidly, a population that requires less calorific food but more fruits and vegetables;
- Consumers increasingly demand more "environmentally-friendly food"; the "bio" aspect is assuming a predominant role when selecting food at the market;
- Consumers, especially in industrialized countries, are becoming increasingly suspicious on how their food is produced. They ask for greater transparency and traceability, which requires more documentation and recording on the part of the farmers;
- Last but not least, the growing globalization in food trade not only transfers more plant nutrients across national borders, but consumers want to impose their local rules and regulations on farmers abroad;

The agronomic changes are as challenging as the demographic developments:

- The cropped area is declining because of increasing urbanization, and this calls for increasing productivity in order to compensate for land loss;
- Access to irrigation water also is declining with the consequent need to improve water use efficiency;

- Land productivity is starting to decrease, predominantly caused by unbalanced fertilization and resulting soil nutrient mining;
- Land degradation, declining water tables and desertification in certain countries restrict further progress in yield and quality;
- A high degree of wastage of agricultural produce requires even higher output to meet growing demand;
- Emerging competition for land between food crops and energy crops also results in the need for higher yields of food crops from the remaining land;
- Labour shortages in agriculture leads to a demand for "smart inputs" (e.g. nutrients, growth regulators, repellents, etc. in a single application) and increased mechanization.

The standard of crop production and nutrient management varies considerably worldwide

There is a close relationship between the appropriate fertilizer recommendations and nutrient management and the level of crop production.

Agricultural systems may be classified approximately into four groups, as follows:

1. **Subsistence agriculture**
   Self-sufficiency with or without a small surplus for the market is the dominant management structure. Low educational levels and the low purchasing power of the farmers result in poor nutrient management. If fertilizers are used at all, their use is often unbalanced and the rate too low. The plot sizes are often too small for a standard bag of 50 kg fertilizer. A resulting poor crop canopy results in nutrient losses from erosion and/or run-off. Widespread soil nutrient mining reduces fertility, and the usually very low nutrient use efficiency results in the possibility of losing a substantial part of the applied N in the form of atmospheric emissions.
   Fertilizer recommendations are usually very simple (bags per acre). A lack of knowledge and insufficient advice aggravate poor nutrient management. Irregular fertilizer supply, uncertain in time and quantity, comprising mostly straight fertilizers with a high nutrient concentration, make precise nutrient management difficult. Lack of funds, unfavourable crop/fertilizer price ratios are further obstacles to the needed application of nutrients. The absence of fertilizer regulations permits the sale of adulterated and/or less effective materials.
   Public advisory services are often non-existent or ineffective; assistance from the private sector and/or international agencies is normally sporadic and not ubiquitous.
   More advanced fertilizer recommendations in form of fertilizer best management practices (FBMPs) in general are not issued, although international research centres develop easy-to-handle management tools such as leaf colour charts or omission plots to improve nutrient use efficiency.
   Most of the developing countries, especially in Sub-Saharan Africa, belong to this category.
2. **Crop management in transition, often mixed with commercial estate/plantation farming**
   Prominent representatives of this group of countries are Argentina, Brazil, Indonesia, but also China, India, countries of West Asia/North Africa and Russia. The commer-

cial sector is export-oriented and confronted with strict quality norms and non-tariff barriers.

The focus on exports introduces the quality factor, which, in turn, affects nutrient management. More care is taken to estimate the nutrient budget although the nutrient balance often remains inadequate because of the large quantities of nutrients removed in the exported crop. Food crops are frequently under-fertilized. The nutrient use efficiency remains rather low in this category, resulting in substantial nutrient losses to the environment. Management of crop residues is still rather erratic.

Better advisory services, especially those provided by the private sector, aim to improve the nutrient balance. The public sector in contrast appears to be weak. More advanced site- and crop-specific fertilizer recommendations based on field trials are available, although there is still limited access to soil tests and plant analysis.

Fertilizers are, in general, better available in quantity and timeliness, and are more affordable. Fertilizer regulations are already in place in a range of countries, and these provide better protection for the farmers. However, imports and prices are still controlled, especially for straight N, P and K fertilizers. The use of appropriate NPK mixtures is limited as is the availability of secondary and micronutrients. In some countries, there are still legislative restrictions and/or slow approval procedures for the use of new fertilizers such as custom mixed fertilizers and organic products.

3. **High-tech farming based mostly on voluntary adoption**

   Farmers in this category, as in the USA and Canada, aim for sustainable, maximum production, in terms of both yield and quality. Nutrients are applied to improve both plant growth and quality. Care is taken with the nutrient budget and to maintain well balanced fertilization. High yields and supply of crops for the market result in a high nutrient turnover and a large export of nutrients removed with the harvested crops.

   The environmental aspect of nutrient management is receiving increased attention. Improved control of nutrient losses to the environment is favoured by synchronizing nutrient supply with the crop's nutrient demand. More care is being taken with crop residue management. Also, the integration into nutrient management of nutrients supplied from organic sources is becoming common practice.

   Site- and crop-specific fertilizer recommendations based on soil tests and plant analysis are widely available. "Precision" nutrient management is becoming widely adopted.

   There are hardly any limitations on the availability of fertilizers, in terms of type, quantity, quality and timeliness of supply. Farmers usually have good access to custom mixed fertilizers.

   In general, fertilizer use is fairly well balanced because, on one hand, of the high level of instruction of the farmers and, on the other hand, the wide spectrum of available information. Access to the internet is common practice. The availability of high-quality and custom mixed fertilizers favours the application of nutrients in a well balanced manner. However, economic considerations and mounting pressure from the public, in particular from environmental groups, are impacting fertilizer use.

   Fertilizer advisory services are predominantly based on a strong private sector, which offers a wide range of information and management tools. The public sector is still well structured and reputed but is tending to withdraw.

Legislative intervention is increasing, although less restrictively than in EU. The focus is on the statutory control of the environmental fate of nutrients, especially of N and P.

4. **High-tech farming with substantial government involvement**
   This category is particularly prevalent in the EU countries, as well as in Australia and New Zealand.
   The profitable production of top quality crops is the aim of most farmers also in this in this category. However, increasing social and administrative pressure and regulations on farm management and a rapidly growing market for so-called "bio-products" increasingly impact nutrient management in crop production:
   - Production has to be compatible with environmental considerations and, in order to comply with regulations, the production of "healthy" food may even be at the expense of yield;
   - Fertilizer use is under strict control in terms of time of application and quantity; exceeding the permitted levels of N and P can result in a fine;
   - The documentation and monitoring of nutrient use and movement is becoming mandatory, based on fertilizer recommendations and information on the nutrient contents of crops and manure;
   - Environmental groups are becoming more involved in nutrient management measures;
   - The integrated approach to farm and nutrient management, i.e. the integration of plant protection, irrigation, animal husbandry, social welfare, etc., is becoming common practice.

   The level of education of the farmers is usually good; they have access to a wide spectrum of information, and the availability of high quality and custom mixed mineral fertilizers helps farmers to comply with statutory requirements and consumer demand.

It is the expectations of the public that encouraged the preparation of codes of conduct in the form of fertilizer best management practices.

Attempts have been made to prepare manuals which explain how to best use fertilizers in a way that is efficient and economic and that respects the environment. A range of recommendations for FBMPs has been issued, substantiated by research and tested through farmer implementation, adapted to local conditions. Some examples are:

- the Australian "Cracking the Nutrient Code";
- the New Zealand's "Code of Practice for Fertilizer Use";
- the French Reference Code for "Agriculture Raisonnée";
- the European Integrated Farming Framework by EISA;
- the UK "Whole Farm Nutrient Plan";
- Fertilizer Best Management Practices issued by FAR, USA;
- the TFI/PPI Fertilizer Product Stewardship, USA.

Similar documents are under preparation for example in Brazil, China, India and Russia. There is no knowledge of the existence of such documents in areas with a predominantly subsistence agriculture.

It is common practice for FBMP documents to be developed in a concerted manner with the different partners. For example, the UK "Whole Farm Nutrient Plan" has been jointly developed by the private sector (AIC, PDA), the relevant governmental body (DEFRA), environment agencies (FACTS) and integrated farming organizations (LEAF).

The objectives of those country/region-specific FBMPs can be summarized as follows:

- To create understanding and awareness of the fate of nutrients, the risks linked to nutrient use, the potential of nutrients to pollute the environment and the misuse of natural resources. This refers in particular to:
  - leaching of nutrients, especially nitrate,
  - accumulation of nutrients due to overuse and/or inadequate and uneven application,
  - nutrient loss through run-off and erosion,
  - atmospheric losses of nutrients, especially volatile N forms,
  - soil nutrient mining due to imbalanced fertilization, i.e. removing more nutrients from the soil than are added through mineral and organic fertilizers.

  Apart from harm to the environment, the loss of nutrients is also a financial waste, a loss of potential yield and income and higher costs for society as a whole, for example in water treatment or mitigating the impact of global warming.
- To mitigate physical risks associated with operational activities, such as transport, loading/unloading, storage and application.
- To take account of the risks associated with agronomic activities. In short, fertilizer nutrients have to be applied following the guiding principles:
  - right product(s),
  - right rate,
  - right time,
  - right place.
- To take account of environmental and social objectives, for example concerning groundwater, surface water, soils, neighbourhood, biodiversity, air and farm produce.

The adoption of FBMPs differs according to the farm management systems:

- For farms that are subject to tight statutory regulation, FBMPs have the advantage of being integrated into quality assurance programs, land use policies and support to meet regulatory requirements. Fertilizer best management practices also promote the traceability of nutrients and transparency. It can also be argued that FBMPs can support acceptability on the global market.
- For farms operating under less stringent statutory regulations, acceptance and adoption depend on whether FBMPs are economically feasible and logistically compatible with the farm systems and with enterprises that compete for labour, management and resources. Awareness that FBMPs could be a management tool for increased fertilizer use efficiency, improved farm income and reduced risks supports their adoption. The farm size and the educational level of the farmer also seem to be related to their acceptance.
- Bureaucracy, countless documentation, auditing and the need to ensure economic viability while reducing nutrient loss and minimizing environmental impacts are substantial restraints to the adoption of FBMPs.
- Resistance to change from traditional ways that are perceived to have worked well in the past also constrains the adoption of the more advanced FBMPs.

- For countries with a subsistence agriculture and those in transition, there is a whole range of constraints to the adoption of FBMPs. Some of these are:
  - the huge number of recipients,
  - widespread illiteracy, misinformation and poor education,
  - lack of knowledge, combined with inefficient extension services,
  - the side-effects of misuse are not known,
  - other constraints such as lack of irrigation, pest and disease control, labour availability etc.,
  - farmers' limited financial resources,
  - often inadequate returns due to an unattractive price/cost ratio,
  - unsatisfactory fertilizer supply in terms of kind, quality and timing,
  - often a high diversity of crops and cropping systems, climate and soils,
  - shortage of funds for soil and plant testing, soil mapping and research,
  - lack of private-sector involvement in advisory services and the education of farmers.

Despite the constraints described above, there is also a wide range of benefits to be obtained from the development and adoption of FBMPs, since they:

- Help to optimize and economize on fertilizer use by reducing losses and thus improving use efficiency;
- Contribute to wealth creation for the country and individual farmers by developing and implementing new nutrient management techniques that realize the agricultural potential in a sustainable way;
- Translate plant nutrient research into best practice;
- Create new technologies, knowledge and value-added products that optimize sustainable agricultural output;
- Contribute to a better understanding of the relationship between nutrient management and land use;
- Provide a model for balancing nutrient inputs, agricultural outputs, environmental sustainability and people's health and well-being;
- Improve the relationship between the farmer and the consumer by creating confidence through transparent operations;
- Create confidence in the fertilizer industry as a sector that takes into account the economic expectations of its clients (the farmers) and the environmental concerns of the public opinion;
- Provide access to high value niche markets;
- Contribute to improved soil health and hence sustainable crop productivity.

Is a global fertilizer best management practices framework feasible?

It is clear that, while FBMPs have a useful function in the country where they have been developed, it is questionable whether they are transferable to countries with a different agro-ecological situation. However, there is a need to communicate to the public and politicians, with one voice, the concern to protect the environment and to safeguard natural resources, in particular with respect to nutrient management.

It is therefore proposed that a global FBMP framework should be developed as a document that demonstrates the concern and commitment of the fertilizer industry as regards environmental issues. Just as industry has ISO standards to make production, supply and services safer, more efficient, transparent and environmentally friendly, a global FBMP framework could fulfill an analogous purpose in agriculture, as a kind of quality management system.

The FBMP framework should also serve also as a guide to the development of regional FBMPs based on science and site- and crop-specific conditions. They could contribute to income generation, rural development and food security.

The regional FBMPs derived from the framework should be based on the following principles:

- They should be developed in a concerted action by all stakeholders, i.e. the fertilizer industry through its associations, governments, research, extension, farmers' organizations and environmental groups;
- Government participation should help to prevent stringent, disproportionate and exaggerated statutory directives and regulations with respect to fertilizer use;
- They should integrate nutrient management with related agri-disciplines (e.g. irrigation, pests and disease management);
- They should contain provisions for training (both for farmers and dealers), monitoring, audit and review systems, in order to be traceable and transparent in their operating and agronomic activities.

Regional FBMPs derived from the global framework should take account of the following points:

- Be specific enough to cope with diverse crop and climatic conditions;
- Be flexible and amenable to revision and updating;
- Be based on good research and sound data;
- Meet regulatory requirements;
- Contribute to protection of the environment and conservation of natural resources.
- Adoption should be in the context of the economic sustainability of crop production;
- The introduction of FBMPs should be accompanied by appropriate educational material and programs.

In the spirit of sustainable product stewardship, the fertilizer industry could play a leading role in the development of the framework and the consequent FBMPs throughout the world. In regions with predominantly small farms and/or low education level (in particular in developing countries), this should be by:

- Providing fertilizers in a rational and economic way in the context of the financial limitations;
- Promoting legislation and regulations that permit liberalization of the fertilizer sector.
- Working closely with governments to liberalize policies and thus facilitate the development and sale of custom mixed fertilizer grades and their supply to farmers. This would provide economic benefits and would be conducive to environmentally friendly practices;

- Fostering through industry's associations, in close contact with extension services and research entities, further education, training, demonstrations, field days, field trials, etc.;
- Providing information material through various channels and platforms (printed, electronically, media);
- Assisting, through their outlets, the monitoring and recording of operational and agronomic activities related to nutrient management;
- Promoting soil testing and plant analysis, the establishment of soil fertility indices and maps, etc.;
- Providing a platform for educating farmers, which could be used also by other sectors.

Conclusion

There is an evident need to express with a single voice the concern of the fertilizer sector to meet the expectations and demands of the public and to respect statutory rules and regulations. Individual fertilizer recommendations do not serve this purpose. This also applies to country- or regional-specific FBMPs, in view of their local approach. A global framework for individual FBMPs, developed in a concerted way with the other stakeholders, could provide a guiding document to policy makers when formulating legislation on agricultural and environmental issues. This document could also act as a proof of good stewardship in relation to the production, distribution and use of fertilizers. And last but not least, a global framework could improve and strengthen public confidence that agriculture and the related agri-business sectors, including the fertilizer industry, aim to provide the consumer with affordable and healthy food while preserving the environment and natural resources.

Possible entry points for action, an FAO overview

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The Codex Alimentarius Commission

The Codex Alimentarius Commission was created in 1963 by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) to develop food standards, guidelines and codes of practice under the joint FAO/WHO Food Standards Program. The main purposes of this program are to protect the health of consumers, ensure fair trade practices in the food trade, and promote coordination of all food standards work undertaken by international governmental and non-governmental organizations. FAO and WHO complement the Commission's activities in a number of practical ways, helping developing countries apply the standards, strengthen their national food control systems, and maximize international food trade opportunities. FAO and WHO provide scientific advice developed by expert committees, particularly in the area of risk assessments.

Codex standards typically address product characteristics under government regulation. For instance, there are maximum residue limits (MRL) for pesticides and more general standards for food additives, contaminants and toxins. The general standard for labeling pre-packaged foods can be applied wherever those products are traded.

The Codex General Principles of Food Hygiene introduces the use of the Hazard Analysis and Critical Control Point (HACCP) food safety management system. In addition, a code of practice covering the use of veterinary drugs provides general guidance in this area.

In summary, Codex guidelines fall into two categories:

- principles that set out policy requirements in key areas,
- guidelines for applying the general standards.

The free standing Codex principles further address such issues as food additives, contaminants, food hygiene and meat hygiene:

- the addition of essential nutrients to food,
- food import and export inspection and certification,
- the establishment and application of microbiological elements,
- microbiological risk assessments,
- risk analysis of biotechnologically derived food.

Promoting a sound regulatory framework

In many countries, effective food control is undermined by widely fragmented legislation, multiple jurisdictions, and weaknesses in surveillance, monitoring and enforcement. Sound national food control and regulatory systems are pivotal for ensuring the health of domestic populations and safety of internationally traded foods. As such, the establishment of effective national regulatory frameworks is of paramount importance. With facilitation provided by FAO and WHO, developing countries will be assisted in achieving higher levels of food safety and nutrition that are in line with international principles. Considering the perils involved with food importation, it is especially important to successfully negotiate bilateral agreements that guarantee the integrity of national regulatory systems; thus ensuring that imported foods conform to national requirements.

Good agricultural practices initiative

The concept of good agricultural practices (GAPs) requires the application of available knowledge in using natural resources to produce safe food and non-food agricultural products in a human manner, while maintaining social stability.

The FAO GAPs initiative is intended to assist farmers, food processors, retailers, consumers and governments to play a part in the search for sustainable agricultural production systems that are socially viable and economically profitable, while protecting human health and well being, animal health and welfare and the environment.

Although methodologies such as integrated pest management (IPM) and conservation agriculture have evolved to address specific production issues, the agricultural sector still lacks a unifying framework to guide national debate and action on policies and methods to achieve susta nable agriculture. Clearly defined GAPs could provide the basis for collaborative international and national action for developing sustainable agricultural production systems.

Accordingly, governments and private institutions need to enact appropriate supportive policies. This will enable farmers to respond to the incentives of improved market access and added value by adopting those production methods that satisfy the demands of both processors and consumers. In order to achieve this, they require unambiguous guidance on requirements and how they can be satisfied. While farmers must be efficient and competitive, they must also receive adequate prices for their products.

Therefore, responding to the needs of farmers, processors and consumers, the GAP initiative aims to:

- Develop a framework of guiding principles for developing GAPs, engaging both the public and private sectors;
- Channel existing knowledge, options and solutions into effective risk management guidelines for use as policy instruments;
- Raise awareness and stimulate action within the sustainable agriculture and rural development (SARD) initiative.

To that end, FAO has initiated discussions to identify the potential roles of governments and other stakeholders. In so doing, the organization seeks agreement on the principles of GAPs with a corresponding strategy for moving forward. FAO's role is to support the local, national and international quality assurance schemes or codes of practice, which are voluntary and market driven.

Integrated plant nutrition systems

FAO has focused attention on the need for large-scale adoption of integrated plant nutrition systems (IPNS) or integrated nutrient management (INM). In order to translate this approach into field interventions, functionaries at all levels must attain a clear understanding of the associated concepts, phrases and terms.

Integrated plant nutrition systems maintain and enhance soil productivity through a balanced use of mineral fertilizers, combined with organic sources of plant nutrients. Therefore, IPNS are ecologically, socially and economically viable, and can lead to sustainable increases in both soil productivity and crop yields. In addition, they focus on the seasonal or annual cropping system (as opposed to individual crops), on the management of plant nutrients in the whole farming system, and on the concept of village or community areas versus individual fields.

Strategic approach to international chemicals management

Adopted by the International Conference on Chemicals Management (ICCM) on February 6, 2006 in Dubai, UAE, the strategic approach to international chemicals management (SAICM) is a policy framework for international action on chemical hazards. SAICM was developed by a multi-stakeholder and multi-sectoral preparatory committee, and comprises three core texts:

- The Dubai Declaration, which expresses the commitment to SAICM by Ministers, heads of delegation and representatives of civil society and the private sector;
- The Overarching Policy Strategy, which sets out the scope of SAICM, the needs it addresses, the objectives for risk reduction, knowledge and information, governance, capacity building and technical cooperation, as well as underlying principles and financial and institutional arrangements;
- A global plan of action, which sets out proposed work areas and activities for implementation of the strategic approach.

Global plan of action

The SAICM global plan of action has been structured into work areas and associated activities. It also serves to guide stakeholders at the global, regional, national and local levels. Priorities and timelines often differ between countries owing to the differing capacity for executing certain measures. However, governments and other stakeholders are expected to adopt flexible programs to build and sustain adequate and comprehensive management structures that take into account their national circumstances, in line with the stated objectives.

General priority is given to the following objectives:

- Measures to support risk reduction;
- Strengthening knowledge and information;
- Governance: strengthening institutions, law and policy;
- Enhancing capacity building;
- Addressing illegal international traffic;
- Improved general practices.

The case of Madagascar: SAICM pilot project

CropLife Madagascar is an organization that draws together agrochemical, importers and distributors. It is further involved with the cycle of chemicals from import and manufacturing to the end users. Considering the variations in law enforcement, developing countries benefit from such voluntary initiatives on chemical management.

Under the project, a platform made up of relevant stakeholders–including Ministry of Agriculture, Ministry of Commerce, international organizations such as the Japanese Aid Organization, USAID, FAO, the European Union–has been created in order to monitor the future of the fertilizer sector.

Some of the issues discussed under this public–private partnership initiative encompass:

- Criteria over the appointment of professionals who will work with their fellow fertilizer operators;
- Product control to ensure that nutrient contents stated in import documents match the prescribed standards;
- Proper packaging and labeling require the names of both importer and manufacturer to be clearly stated for ease of tracing;
- Industry must ascertain that appropriate training through the distributors supports the storage and application of chemical fertilizers;

This case highlights how industry involvement can facilitate a regulatory framework, where formal regulations are lacking.

Fertcare Program: joint initiative between the Australian Fertilizer Services Association and the Fertilizer Industry Federation of Australia

Fertcare is a national training and accreditation initiative for all fertilizer and soil amelioration industry businesses and staff. The program assists customers in importing, manufacturing, storing, handling or distributing fertilizers, and advising on fertilizer use.

Food safety is an important issue that elicits concern from all stakeholders. As such, the Australian community is committed to controlling impurities in food products. The Fertilizer Industry Federation of Australia (FIFA), in collaboration with the Australian Fertilizer Services Association (AFSA), has committed to ensuring that Fertcare becomes the industry standard. All eligible staff, spreaders and premises will therefore comply with Fertcare. Accordingly, training will be delivered at three levels that cover the knowledge and complexity expected at the logistics, sales and advisor functions.

Regulations

A number of countries, particularly developing ones, have legislation that serves to ensure that the physical and chemical qualities of commercial fertilizers meet government specifications. In developed countries, however, such requirements are not necessarily mandated. For instance, in the United States, fertilizers are sold as long as they satisfy the “Truth in Labeling” requirement.

Regulators monitor truth in labeling—taking and testing samples—based on complaints as well as inspections. Agencies can arrange for other organizations—private companies or universities—to help with laboratory tests. Depending on the regulations, the agency may also maintain lists of registered importers, dealers and registered products.

One of the basic institutions for promoting and maintaining a competitive fertilizer market is a private fertilizer trade association. These associations provide information and services to members, and also act as spokesperson in dealings with regulators, legislators and other government bodies.

The public and private sectors often possess complementary expertise and overlapping interest in good regulations and effective implementation. This offers scope for public–private cooperation. The government should therefore create a framework within which a fertilizer board may contribute to research, regulation and export promotion. It should ensure that all parties, including producer organizations, have equal market access.

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Strategies for controlling nitrogen emissions from agriculture: regulatory, voluntary and economic approaches

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Contribution from the European Centre of the International Nitrogen Initiative

Introduction

The International Nitrogen Initiative (INI) is a global project supported by the Scientific Committee on Problems of the Environment (SCOPE) and the International Geosphere Biosphere Programme (IGBP) that addresses the problems associated with too much or too little nitrogen (N) in the environment. In some areas of the world, such as large parts of Africa and South America, there is a shortage of N in its reactive forms (Nr), which limits food production. By contrast, across most of Europe, North America and S.E. Asia, there is a substantial excess of Nr, which leads to a wide range of environmental problems. Overall, there has been a massive global increase in available Nr from agriculture in the last 100 years. As shown by Figure 1, this increase is much larger than the increase in the agricultural area or the production of Nr from NOx emissions from fossil fuel consumption.

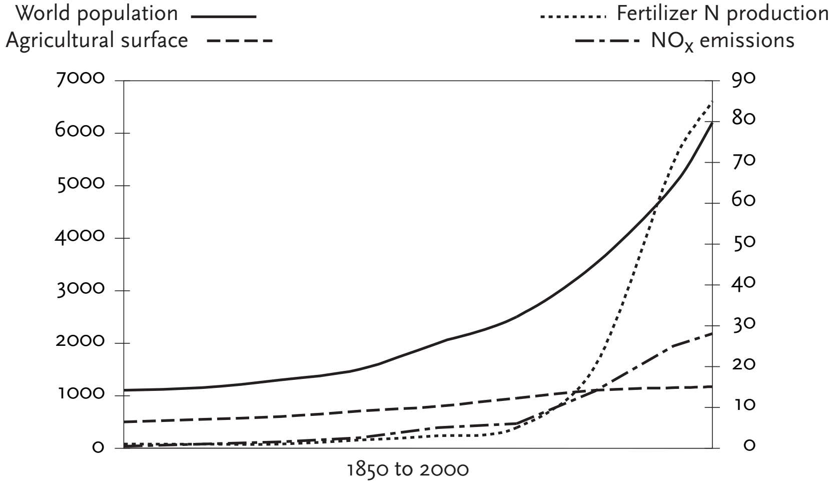

Figure 1. Global estimates of agricultural fertilizer N production (Tg) compared with NO_x emissions (Tg), agricultural surface area (Mha) and world population (millions).
NB: one tera gramme (Tg) is equivalent to one million metric tonne

Although fossil fuels are very important drivers in the N-cycle and relevant for a range of different effects, agriculture is one of the key drivers of the global N problem, the primary input being the fixation of unreactive di-nitrogen (N_2) to form ammonia (NH_3) in the Haber Bosch process and its variants (Smil, 2001). Most of the ammonia so produced is then utilized to manufacture urea, ammonium- and nitrate-based fertilizers. These chemical N products are essential to sustain global food production. With the low fertilizer prices over the last decades, it has been convenient in many countries to apply fertilizer N at rather high rates, leading to significant losses to the environment.

A major problem faced in managing excess N is that the N cycle is both extremely leaky when inputs are large and involves many different N forms, which can be lost at several different stages. Figure 2 shows the classical "leaky pipe" diagram of N input and transformation in soils. Losses of Nr occur both to air and water, including ammonia (NH_3) volatilization, nitric oxide (NO) and nitrous oxide (N_2O) emissions, nitrate (NO_3) leaching and dissolved organic nitrogen (DON). Further, even where "low emission" fertilizers are applied, substantial emissions occur following the use of the crop products in animal production. In particular, when fertilized crops and grasslands with high protein contents are used to feed livestock, a relatively large fraction of the N intake via animal feed ends up as animal manures. The animal manures contain part of the Nr in highly mobile forms, leading to major losses via NH_3 volatilization, and also via nitrification, denitrification (including N_2O emissions), and NO_3 leaching. These represent a loss of Nr as an economic commodity, as well as pollutant inputs to the environment. Together with biological N fixation, fertilizers are the dominant Nr source, so that it is vital to consider fertilizer N production in relation to its overall life cycle and eventual fate.

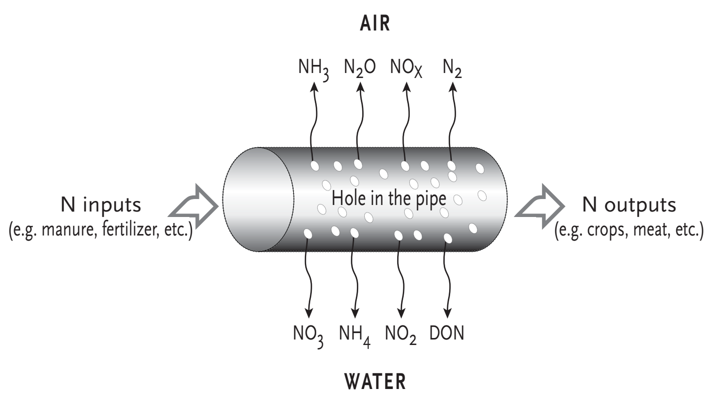

Figure 2. Conceptualization of N use in agriculture and losses to the environment. The N cycle in agriculture can be considered as a "leaky pipe" where losses occur to both air and water in a wide range of different N forms, in addition to the target of transforming N into crop and meat products.

With these interactions in mind, the flow of excess N has been considered as a "cascade" (Galloway *et al.*, 2003) through different forms and environmental compartments, as illustrated in Figure 3. The main target use of fertilizer N is on crops and grassland, through which significant losses of different N pollutants occur. Use of this Nr in livestock agriculture substantially increases the emissions of these pollutant forms of N. A wide range of environmental effects follows, including acidification and eutrophication of soils (with adverse effects on semi-natural biodiversity and soil quality), formation of particulate matter in the atmosphere (with effects on human health, visibility and global radiative balance), eutrophication of surface and ground waters, and formation of greenhouse gases (including nitrous oxide, as well as interactions with methane and carbon dioxide). The dispersal of Nr through the environment leads to a cascade where one particular N atom contributes to several environmental effects. Thus, a Nr atom emitted as NH_3 may react to form particulate matter, be subsequently deposited to a forest affecting biodiversity and then enrich the forest soil, before being re-emitted as NO or N_2O.

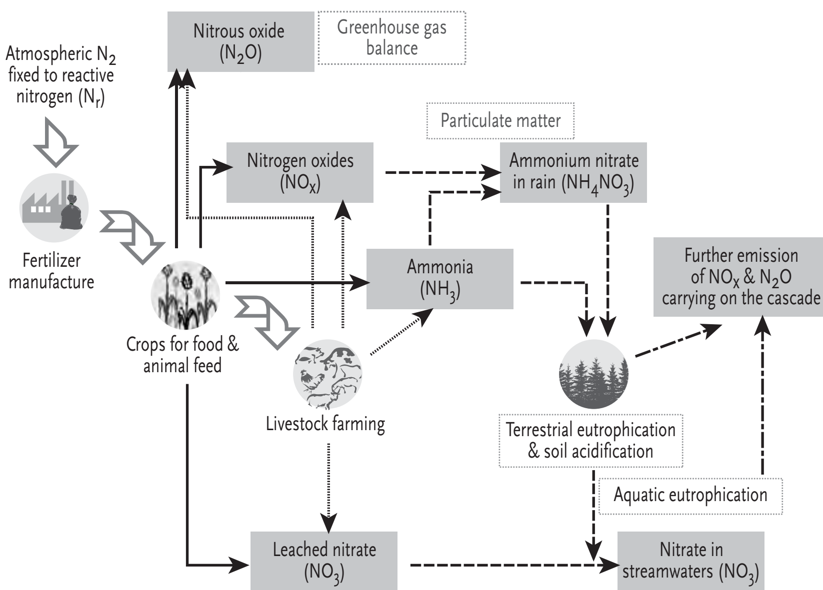

Figure 3. Illustration of the N cascade from fixation of atmospheric N for fertilizer production, with successive losses N in different forms as N is transformed and transported through the environment. Priority environmental concerns are shown in white boxes.

The N cascade emphasizes the importance of considering the ultimate fate of fertilizer derived N. A key problem for fertilizer manufacturers is that Nr becomes increasingly uncontrollable as it passes through the cascade. Emissions during fertilizer manufacture are typically well controlled. Similarly, the production of an effective fertilizer product, with good advice on best management practices, can reduce direct emissions from fertilizer application to crops and grass. By contrast, once the crops (containing the fertilizer N) are eaten by livestock, animal manures become a much harder and more variable product to control. Finally, once lost in to the environment, there are few techniques available to manage the N. These interactions illustrate how it is vital for the fertilizer industry, as a key source of the N input, to take a whole-systems approach to developing fertilizer best management practices (FBMPs) and increasing N use efficiencies that includes the use and fate of organic manures (e.g. Laegreid *et al.*, 1999) and the environmental consequences.

The International Nitrogen Initiative represents a 15 year plan of three successive 5 year phases: Phase I: Assess knowledge on N flows and processes (2005-2010); Phase II: Development of region-specific solutions (2010-2015); Phase III: Implement scientific, engineering and policy tools to solve problems (2015-2020) (see www.initrogen.org).

Thus, the focus of the present INI phase is on scientific development, with a forward look towards investigation of approaches for better management of N in the environment. In the present context of developing a consensus on FBMPs, we are asked to address the pros and cons of regulatory versus voluntary approaches. In this short paper, we reflect on the issues from the perspective of European N scientists engaged in both the quantification of N fluxes and the discussion on future policy approaches.

Existing regulatory approaches to European control of nitrogen

To date, Europe has taken a largely regulatory approach to controlling different forms of N in the environment (Figure 4). The striking thing about the implementation of existing legislation is the high degree of separation in regulations between different N forms, sources and effects.

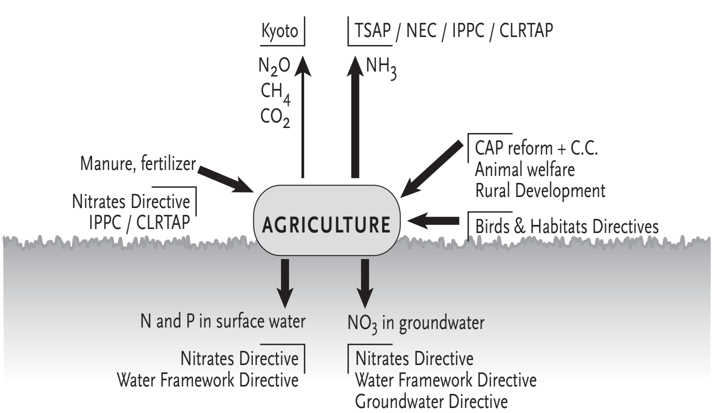

Figure 4. Summary of different European regulations and policies affecting N and agriculture.
Key: CAP, Common Agricultural Policy; C.C., Cross Compliance regulation; TSAP, Thematic Strategy on Air Pollution (2005); NEC, National Emissions Ceilings Directive; CLRTAP, UNECE Convention on Long Range Transboundary Air Pollution; IPPC, Directive on Integrated Pollution Prevention and Control; Kyoto, UNFCCC Kyoto Protocol (1977).

The current regulations have largely proceeded from a focus on protecting against specific environmental threats. Thus, the Framework Directive on Ambient Air Quality (96/62/EC) and its first Daughter Directive (1999/30/EC) include limits to concentrations of NOx and particulate matter (PM10). They then specify that Air Quality Management Areas (AQMAs) need to be established where these concentrations are exceeded. In both cases, the main sources are considered to be urban emissions from transport, industry and domestic heating. However, emissions of Nr from agriculture in the form of both NO and NH_3 will contribute precursors that significantly raise background levels. Hence, while AQMAs focus on urban mitigation strategies, the quality of rural air from agricultural areas substantially affects the achievability of the urban targets.

The focus for regulating emissions of NO and NH_3 has been through international agreements under the Convention on Long Range Transboundary Air Pollution (CLRTAP), and the 1999 Gothenburg Protocol (UNECE, 1999). Together with further commitment within the EU under the National Emissions Ceilings Directive (NEC, 2001/81/EC), this protocol has set national limits for emissions of sulphur dioxide (SO_2), NO and NH_3 for 2010. Europe-wide, the main NO_x emissions are from transport and industry. As a result, little attention has been placed on the contribution of agricultural soils and organic manures to NO_x emissions, even though they can affect the balance of photochemical ozone production in a region. By contrast, because around 90% of European NH_3 emissions result from farm sources, the Gothenburg Protocol has placed the spotlight firmly on reducing agricultural Nr emissions.

The actual national ceilings under the Gothenburg Protocol and the NEC were negotiated to a large extent in relation to the degree of modelled environmental effects. This was expressed through the accumulated area of "critical load exceedance", being the area for which total N or acidifying deposition exceeds the critical values below which significant adverse effects are not believed to occur. The benefit of this approach is that it is linked to scientific underpinning and thereby provides some degree of fairness between countries. On the other hand, it should be noted that some countries obtained exemptions in order to further develop their agricultural sectors. In addition, the ambition level was not so high, and by 2010 there will still be very large areas across Europe where the critical loads for N remain exceeded. This implies that there will still be significant adverse effects of agricultural NH_3 emissions on biodiversity and water quality, in addition to a significant contribution to particulate matter formation, associated with shortening of human life expectancy.

The main mandatory measure of the Gothenburg Protocol and the NEC was the establishment of the national ceilings. However, it was also mandatory for parties to adopt Codes of Good Practice (CGP) to reduce NH_3 emissions. Following the actual codes is voluntary, and these are tailored to national conditions, while drawing on the guidance developed by the UNECE Expert Group on Ammonia Abatement (EGAA, 2001). There was also significant debate in developing the Gothenburg Protocol on whether to include a complete ban on urea fertilizer (due to its much higher emissions than from ammonium nitrate based fertilizers). Although this proposal was rejected, the Protocol did agree on a full ban on ammonium carbonate fertilizer, the emissions of which are even higher than those from urea. This ban was rather easy for Europe, since there is very little use of ammonium carbonate fertilizer in this region, the main use of which is in other areas of the globe, especially China. In practice, a greater use of urea is expected over the next decade (replacing ammonium nitrate), which will actually increase NH_3 emissions. The case for controlling urea emissions therefore remains an important topic, especially since switching to ammonium nitrate based fertilizers remains one of the cheapest measures available (per kg NH_3-N abated) in modelling of cost-curves.

Leaching losses of NO_3 from agriculture have been regulated under the Nitrates Directive (91/676/EEC). This directive sets limits on the use of fertilizer N and animal manure N (limited to 170 kg N/ha/year) in nitrate vulnerable zones (NVZs), which need to be declared by Member States where surface or ground water concentrations of NO_3 exceed 50 mg/l, or where NO_3 concentrations are increasing over time. There is now substantial experience across Europe in different implementations of this directive, with the European Commission engaged in several infraction proceedings against Member States, where the Commission considers that the directive has not been properly implemented.

To date, the implementation of the Nitrates Directive has proceeded rather independently of legislation related to NH_3, while there has been no direct legislation aimed at reducing NO emissions from agricultural soils, or measures to reduce N_2O emissions from agriculture (Under the Kyoto Protocol, the overall focus is to reduce total greenhouse gas emission, without specific targets for N_2O).

A criticism of the current N-related regulations is that they look separately at different parts of the N cycle. Although the services of the European Commission have sometimes stated that implementation of the Nitrates Directive would have largely "solved the ammonia problem", this must be considered as unrealistic. Reduction of Nr fertilizer inputs under the Nitrates Directive will indeed reduce NH_3 emissions. However, other measures, such as increased winter storage of manures, will have increased NH_3 emissions. Already in Denmark and the Netherlands, springtime NH_3 concentrations in the atmosphere have been seen to increase substantially as a result of the nitrates policy, with uncertain environmental consequences (Erisman *et al.*, 1998).

One example of a more-integrated aspiration in existing European legislation is the Directive on Integrated Pollution Prevention and Control (IPPC, 96/61/EC). IPPC addresses all emissions of pollution, noise levels and energy usage for specified controlled installations, including large pig and poultry farms above certain animal-place thresholds. An industrial approach is used, with emissions being reduced by the requirement to use best available techniques (BAT), and such farms are required to hold an IPPC permit in order to operate. In practice, the emphasis in the pig and poultry sectors has been on reducing NH_3 emissions. In addition, vagueness in the Directive has led to substantial variation in the degree to which the approach is really integrated, as well as the ambition level of what is considered BAT. For example, in some Member States, IPPC is considered to apply only to the installation itself (the buildings), and low-emission housing techniques are followed by completely unregulated manure application to fields. This is a problem, since NH_3 saved at an early state of manure handling can be emitted later if low-emission techniques are not applied throughout.

A useful point of IPPC is that the permitting requirement provides a review process that allows the links with other directives to be implemented. By contrast, the directive is limited in that it is not able to manage N in its full rural context. For example, in order to receive a permit to operate, an IPPC farm must be shown not to adversely impact on special areas of conservation (SACs) and special protection areas (SPAs). Together, these make up the "Natura 2000" network of sites designated under the EU Habitats Directive (92/43/EEC). This review provides a very important mechanism to ensure protection of the Natura 2000 network, which represent the priority areas for the protection of European biodiversity. By contrast, in most European countries (and under EU law), there is little regulation on Nr emissions to air from cattle and sheep farming activities. This is despite the fact that cattle farms actually emit more NH_3 than pig and poultry farms in the EU-27, and often occur in the vicinity of many SACs and SPAs. This can lead to antagonisms between industry sectors when different rules apply for the same amount of pollution generated.

In addition, it seems that there is currently a loop-hole in European legislation that is relevant to the effects of atmospheric NH_3 deposition. Under the Habitats Directive (Article 6 (3)), there is a commitment not to allow any "plan or project", unless it can be shown not to cause an adverse effect on any SAC or SPA (unless it is found to be of overriding public interest, etc.). However, where there is no planning or review process (as in the case of many agricultural NH_3 sources), and the activity does not actually take place on the SAC/SPA itself, then there is apparently no mechanism in European legislation to restrict such pollutant activities. Thus, there is a European commitment to protect the Natura 2000 network as the flagship of European biodiversity, but no regulatory mechanism to avoid sources such as cattle housing, manure spreading, or even urea application, right up to the edge of a SAC boundary.

Benefits and challenges of regulatory approaches

Overall, the positive side of regulatory approaches is that they can, in principle, ensure that certain environmental objectives are met, which may otherwise not easily happen due to economic constraints. They also provide a mechanism to define clearly and reach specified measurable environmental targets (e.g. 50 mg/l for NO_3; a defined level of critical load exceedance for N deposition, etc.). For example, both the Netherlands and Denmark have achieved ~30% reduction in NH_3 emissions over the last decade, largely due to regulatory approaches. The lack of attractiveness of regulations can have the benefit of starting a longer-term dialogue with industry, showing that governments are serious about the need to reduce adverse environmental effects. By contrast, regulations can encourage a confrontational approach between government and industry, requiring government agencies to act in a "policing" role, which hinders the potential for constructive partnerships between government and industry. Furthermore, regulatory approaches may affect competitiveness compared with other industries or areas of the world where no regulations exist.

In assessing the existing regulations, the first limitation is the apparent shortage of integrated approaches to N management. This is partly a technical issue, but it also raises the question for policy makers about how to prioritize different forms of N pollution. The priority is obviously for measures which increase N use efficiency or reduce Nr inputs overall, such as balanced N fertilization. However, given the leakiness of the N cycle, many other measures lead to "pollution swapping", whereby abating one form of Nr emissions leads to increases in another pollutant form. Examples of this are the increase in springtime NH_3 emissions associated with closed seasons for manure spreading in the Nitrates Directive, and conversely the increase in NO_3 leaching associated with low-NH_3-emission manure spreading methods. A key challenge for society and governments is to establish priorities between these different pollutants and environmental effects, particularly as the priorities may vary locally and regionally.

An example of how pollutant priorities may vary spatially was illustrated by Angus *et al.* (2003) who considered the polluting effects from Nr emissions of a poultry farm located in eastern England. They conducted a Delphi questionnaire analysis, asking respondents to prioritize different pollutant concerns at different scales. Table 1 shows that the respondents rated NH_3 pollution as the priority concern for local effects (when adjacent to a nature area), but set N_2O as the priority on a global scale. Thus, depending on the location of such a farm source, a different Nr abatement strategy might be identified. It is obviously a major challenge to develop regulations that are sufficiently sophisticated to handle such differences.

Table 1. Priority environmental concerns related to N emissions from a case study of an intensive poultry farm operating in eastern England, as derived from a Delphi analysis of a wide range of expert respondents (Angus *et al.* 2003). 1, highest priority; 2, medium priority; 3, lower priority; numbers are distinguished where they were statistically different, P = 0.05; - indicates not listed as a priority by the respondents. The key message from the analysis is that the priority N problem/pollutant depends on the geographic scale of concern. Pollutant priorities for N abatement may thus vary spatially based on local and regional differences.

	General	Global	Tranboundary	National	Local
Acidification from NH_3	1	—	1	2	1
Eutrophication from NH_3	1	—	2	1	1
NH_4 aerosol as a global coolant	—	1	—	—	—
Effect of NH_3 on atmos. transport of SO_x and NO_y	—	2	2	3	—
Global warming from N_2O	1	1	—	—	—
NO_3 leaching	—	—	—	—	2

The second major concern noted with regulatory approaches is that they can cause antagonism between government and industry, which hinders the development of more creative solutions. The IPPC Directive provides a relevant example. Government pollution agencies have the power to close farms regulated under IPPC if they do not comply with the agreed national implementation of BAT, or if they lead to adverse effects on SACs/SPAs. Under this directive, a farmer has the possibility to utilize alternative techniques to those listed under the BAT reference documentation (European Commission, 2003), but only if they have the means to demonstrate that the proposed measures are at least as effective in mitigating emissions.

The choice of policy instrument, regulation or stimulation, depends on many factors, including the economic and environmental efficiencies and the legitimacy of the policy instrument. The economic and environmental efficiencies are determined by the trade-off between "environmental precision" and the transaction costs of implementing the policy measure in practice. For example, when NO_3 leaching on sandy soils is the environmental problem, the policy measure is precise when it restricts leaching losses on sites with too high NO_3 concentrations in the groundwater. However, the costs of enforcing measures only at these sites are high. Alternatively, taxing N fertilizer has low transaction cost, but has low precision too, as taxing N fertilizer will also affect sites without problems of NO_3 in the groundwater. Measures with low precision also raise the issue of legitimacy when they restrict non-polluting usage. This may be considered unfair or even illegitimate (e.g. Romstad *et al.*, 1997). The imposition of regulatory controls has, in part, challenged the view of farmers as "guardians of nature" and instead stigmatized them as "environmental criminals", especially in countries with high livestock densities (Lowe and Ward, 1997 in Romstad *et al.*, 1997).

Regulatory measures can be detailed and prescriptive, as in the case of the Nitrates Directive. The prescriptive nature of the measures increases the cost of farming and the administrative cost of control and verification, which thereby often lowers the support for the measures. Evidently, the challenge is to develop more target-oriented measures that give farmers the freedom to select those measures that are most effective and efficient from the perspectives of both farming and of environmental protection. Setting targets for N use efficiency at farm level would be such a target-oriented and integrated measure.

Voluntary approaches and the potential for their further development

A number of voluntary approaches have provided contributions to the better management of agricultural N in Europe, with a great variation between countries. These can be largely divided into government-led and industry-led initiatives.

The main government-led voluntary approach in many European countries has been the establishment of various codes of good agricultural practice (COGAPs) for the reduction of emissions to air and/or water. In relation to Nr, such codes were first developed to encourage a flexible approach to the reduction of NO_3 leaching. More recently, as noted above, national signatories of the Gothenburg Protocol have been required to establish COGAPs for reduction of NH_3 emissions. Such approaches have the clear benefit of being supportive of the industry in looking for creative solutions. On the other hand, there are doubts about how successful such voluntary codes are. Hence, some improvements in reducing emissions may be achieved, but it often remains: (a) difficult to quantify the overall benefits and (b) difficult to relate the changes to specific environmental targets. For these reasons, governments have in some cases turned voluntary COGAPs into mandatory measures in certain areas (e.g. in nitrate vulnerable zones, NVZs) designated under the Nitrates Directive.

The other group of voluntary measures is those initiated by the agricultural and related industries. These include a range of product stewardship schemes that include the development of FBMPs. The wide range of such approaches is described in detail in other chapters of these proceedings. Such approaches have substantial benefits in encouraging the development of innovative solutions in a flexible way that can be tuned to local conditions. This can lead to a much more constructive partnership approach between the agri-food supply chain and governments.

At present, much more effort is needed to encourage these approaches. In particular, there is the potential for much closer integration of concerns related to excess N in product stewardship and labelling schemes. Currently, such schemes are primarily driven by animal health and human health issues (e.g. free range farming or avoiding consumption of artificial chemicals through organic farming). By comparison, much more attention needs to be given to developing market products in relation to their environmental benefits, especially in reducing the adverse effects of N. An example of such an environmental emphasis is the LEAF (Linking Environment And Farming) initiative of the UK, which includes a traceable product labelling scheme (Drummond, 2007). In addition, some schemes may target both environmental and animal welfare benefits. A relevant example here is the recent marketing in the UK of "woodland chicken". The birds are kept free-range as part of agro-forestry systems, which encourage greater foraging of the birds. At the same time, it is expected that this system will significantly reduce NH_3 emissions, both because the birds spend more time outdoors and because a larger fraction of emitted NH_3 is recaptured in the plant-soil system of the overlaying woodland (Theobald *et al.,* 2004).

The need for greater use of economic incentives in nitrogen management

In addition to the use of industry-related approaches, more attention needs to be given to the development of economic incentive-based approaches. Something of a contradiction may be perceived in different sectors of European agriculture in relation to environmental stewardship. In the context of the reform of the Common Agricultural Policy (CAP), farmers are paid for good environmental stewardship, with the issue of "good environmental condition" focusing strongly on wildlife issues, but with typically little attention to nutrient management. These linkages are potentially strengthened through the so-called "cross-compliance" measure whereby farmers should receive their Single Farm Payments only when they also comply with all other directives and regulations. By contrast, for pig and poultry farms included under the IPPC directive, losses of N and other pollutants to the environment are considered to occur under the "polluter pays principle" used in other industries. In this approach, the farmer is responsible for all costs of reducing emissions, as well as paying for the required regulatory cost of the IPPC permit to operate.

Overall, there is a need for industry and governments to develop ways to minimize such contradictions. A key area which needs to be considered is the greater use of European agri-environment financing to support both countryside management and nutrient management issues. The new rural development programmes (RDPs) under the CAP reform provide a potential mechanism for building such approaches. In the RDPs, it is up to each Member State to identify its own priorities for which payments may be received. As an example, Austria has taken a lead in establishing certain measures to reduce NH_3 emission from agriculture as qualifying for RDP payments (Oenema and Velthof, 2007). Such approaches provide a much more positive approach to working with the agricultural industry to reduce N losses, and should be further investigated in other countries. At the same time, the CAP reform and the cross-compliance regulations should ensure greater respect of the environmental directives.

Defining strategies with an appropriate mix of instruments

From the above discussion it is clear that there are several benefits and limitations to the different regulatory, voluntary and economic approaches. In Europe, there has been a strong emphasis on regulatory approaches, but these have the disadvantage of developing confrontation between government and the agri-food chain. By contrast, there is a need for much stronger development of industry-led voluntary approaches that establish partnerships with government. Constructive approaches include market-linked agreements that address consumer concerns, as well as directing agri-environment financing schemes (such as the Rural Development Programmes) towards reduction of N emissions in agriculture.

Part of the challenge in making these changes requires the development of communication and educational tools, both for farmers and for the public. Farmers need the relevant tools to make changes appropriate to their circumstances (Figure 5), otherwise policies may not have the benefits expected. At the same time, the global N problem remains a difficult one for the public to understand. This relates to the complexity of different N forms and the many interacting environmental effects. Therefore, a substantial effort is needed to better communicate the global N problem in a way that people and the media can understand. In this way, the environmental problems of excess N, that are well known to governments and the industry, become translated into a market force for environmental food products, which can then begin to support changes in the agri-food chain.

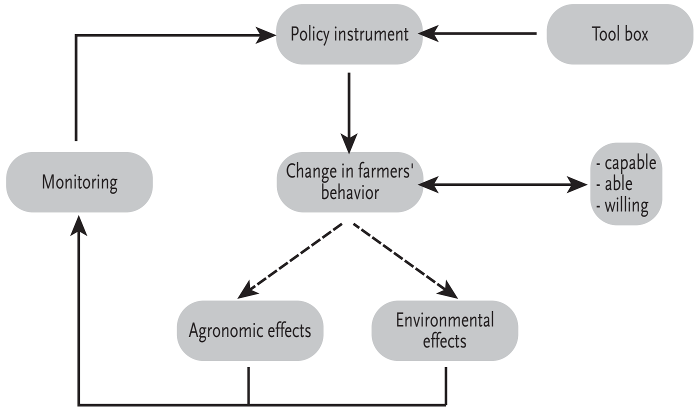

Figure 5. Interaction of government policies in relation to agronomic and environmental effects. The extent of environmental benefits will in many cases be constrained by the ability and response of farmers to the proposed policy instrument.

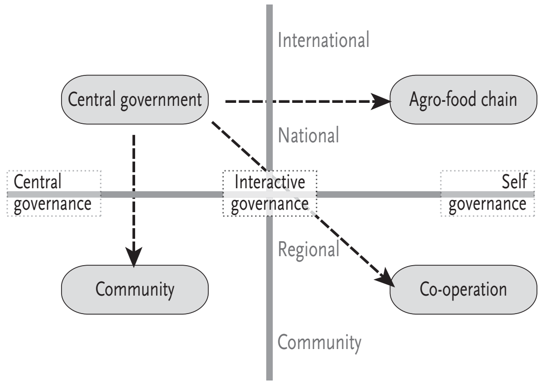

Figure 6. The development of policy strategy from central national approaches to community and self-governance approaches, encouraging greater involvement of the agro-food chain in measures to better manage the environmental consequences of agricultural N (After Van den Broek, 2005).

Figure 6 provides a conceptualization of the challenge for a more interactive approach to governance in relation to N emissions and the agri-food chain. At present, the European emphasis has been on central governance, in more of a "command and control" approach. Approaches need to be explored for a much more constructive cooperation, with government encouraging industry to take the initiative in minimizing the environmental effects of N, which has the potential to reduce the need for additional regulatory measures.

As part of this ambition for increased partnership, two key questions remain which need to be addressed by governments, the agri-food chain and other groups in society.

The first question is: what are the specific targets we agree on to reduce N emissions and impacts? It is quite feasible for voluntary measures by the agro-food chain to show improvements in, for example, N use efficiency. But are these changes enough in relation to the different environmental challenges faced? Substantial effort is needed to develop consensus, including weighting of different environmental problems related to excess N (Table 1). For measures with synergistic benefits for all forms of N pollution, there is no problem of antagonism (e.g. reducing N inputs to match more precisely to crop needs). By contrast, where pollutant swapping interactions occur, the question is: should NO_3, NH_3 or N_2O mitigation take priority, and how should this vary regionally? For each of the problems, such as eutrophication and biodiversity loss from NH_3, particulate concentrations in the atmosphere, water quality, or the contribution of N_2O to global warming, consensus is needed on the environmental targets that should be achieved. For some Nr forms, existing policies still focus on emission limits (e.g. national emissions ceilings), while there needs to be increased focus on the actual condition of the environment for the monitoring of targets (e.g. as under the Nitrates Directive and the Water Framework Directive).

The reason that such targets are essential is that they show whether the ambition level of voluntary approaches in any way matches the environmental objectives. For example, with the massive degree of exceedance of N critical loads in Europe, Nr is having significant adverse effects on biodiversity. Hence, both voluntary and regulatory NH_3 reduction measures are insufficient to meet the existing EU commitments to protect the Natura 2000 network.

The second key question to be answered is: can we adequately measure the achievement of the measures proposed? This question may seem obvious, but it provides a central limitation to the adoption of more flexible voluntary approaches. In principle, national governments will sign appropriate international commitments only if they can be assured that it will be possible to meet their obligations. This means that they must be able to measure the achievement of the objectives in relation to the parameters specified in the relevant conventions. Emissions to air provide a relevant example, where the CLRTAP agreements have been based on national emissions ceilings. Some countries such as Switzerland have encouraged "soft approaches" to reduce NH_3 emissions, based on good agricultural practices. By contrast, other countries, such as the UK, have been more reticent to adopt these measures because it is *difficult to measure the reductions in national emissions that are achieved*, even though some reductions are expected. Hence, the form in which a regulation or international target is set affects the flexibility to achieve the wider environmental intention of the agreement.

These concerns require more discussion on the indicators to monitor different regulatory, voluntary and economic measures. In particular, they point to a preference for setting the targets in a form that relates as closely as possible to the ultimate environmental effects being considered. For air, this highlights the limitation of national emission ceilings, where these are not supported by targets more closely linked to environmental conditions. In the case of water, the move to achieving "good ecological condition" under the Water Framework Directive is, in principle a step forward. Nevertheless, the debate will continue, particularly where several threats (including excess N) contribute to adverse effects, and where pollutants (such as N_2O) are highly dispersed in the atmosphere. While such issues can make it challenging to set targets in relation to environmental conditions, there remains a logical order of priority for basing committed targets: (1) environmental condition, (2) environmental state (e.g. chemical concentrations) and (3) national emissions.

Conclusion

Currently in Europe, the emphasis on reducing different effects of Nr from agriculture has been on government-led regulatory approaches. The immediate challenge with such approaches is to take a more integrated approach related to the overall cascade of Nr in the environment. In this respect, much more effort is needed in making the linkages between abatement of NH_3 and N_2O to the atmosphere, together with NO_3 leaching to freshwaters, as well as interactions with particulate matter in the atmosphere and effects on global radiative forcing through N_2O and particles (including carbon interactions). This quantification of the N cascade in itself is a major challenge. Furthermore, the simplification and better dissemination of the N issues and understanding of the cascade is a necessity. In the first instance, measures that reduce Nr inputs and optimize timing (e.g. balanced N fertilization) are of course attractive. However, because of the leaky nature of the N cycle, the achievement of major reductions in specific N pollutants will involve "pollutant swapping" between different forms of N. Thus, it is essential to seek consensus on the prioritization between different adverse effects and pollutant forms by local context.

While major progress has been made in Europe using this primarily regulatory approach, there are also clear limitations. In particular, it can create a confrontational relationship with the agri-food chain that hinders the identification of creative options, which would benefit both industry and the environment. Hence, there is a need for governments to encourage industry to take the initiative in voluntary approaches, particularly those that involve public and farmer participation (such as training activities and food stewardship/labelling schemes). In this respect, it is essential that the fertilizer industry consider not just the initial consequences of N inputs, but their whole life cycle, including their ultimate implications for emissions following use of animal feeds via manures. In addition, much more attention needs to be given to Nr management in economic approaches, such as agri-environment financing and subsidy schemes. Here, the rural development programmes of the European Union hold the potential for much stronger inclusion of measures to provide environmental benefit through reduction in Nr emissions.

In comparing the benefits of regulatory, voluntary and economic approaches, two key challenges remain. The first is to seek consensus on the environmental targets. What are the agreed levels of emission, concentrations and environmental impact to which society corporately commits? If the specific targets identified by governments are very ambitious, it is important for the industry to know if voluntary and economic approaches identified will be insufficient. The second challenge is to find more creative ways to measure the benefits of the measures to reduce N emissions. For example, FBMP guidelines may be excellent and also demonstrate improvements in N use efficiency, but governments will want to measure what can be achieved in relation to the committed environmental targets (e.g. quantified reductions in emissions, concentrations and adverse impacts). In particular, in order to count the benefits of creative "soft approaches", the dialogue with governments needs to focus on encouraging international agreements and other regulatory approaches to apply targets that are measured as close as possible in relation to the ultimate environmental issues.

Acknowledgements

The authors gratefully acknowledge financial support from the European Commission for both the NitroEurope Integrated Project (Component 10, Dissemination) and the Service contract: "Integrated measures in agriculture to reduce ammonia emissions" (070501/2005/422822/MAR/C1), together with financing from the European Science Foundation of the research network Nitrogen in Europe (NinE).

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